

Mistakes Were Made

What CYC has done wrong

Doug Lenat

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October 22, 2009



ONTOLOGY FOR THE INTELLIGENCE COMMUNITY

OIC 2009

Setting the Stage for
High-level Knowledge Fusion



5th generation
Media
MC
Seman
Web
mania

- What AI did wrong before Cyc
- What CYC has done wrong
- What AI will do wrong next

CYC introduced the process of large-scale ontological engineering in 1984.

We learned a large number of useful lessons during those 25 years

(1000 person-years = 2 million person-hours building the ontology)

Errors in representation, in methodology, in inference, in scale.

Traps we fell into, decisions we had to back out of, half-finished off-ramps to nowhere.

What CYC has done wrong

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Cyc's "upper model" contains:

18,000 Predicates

500,000 Concepts

5,500,000 Assertions

Represented in:

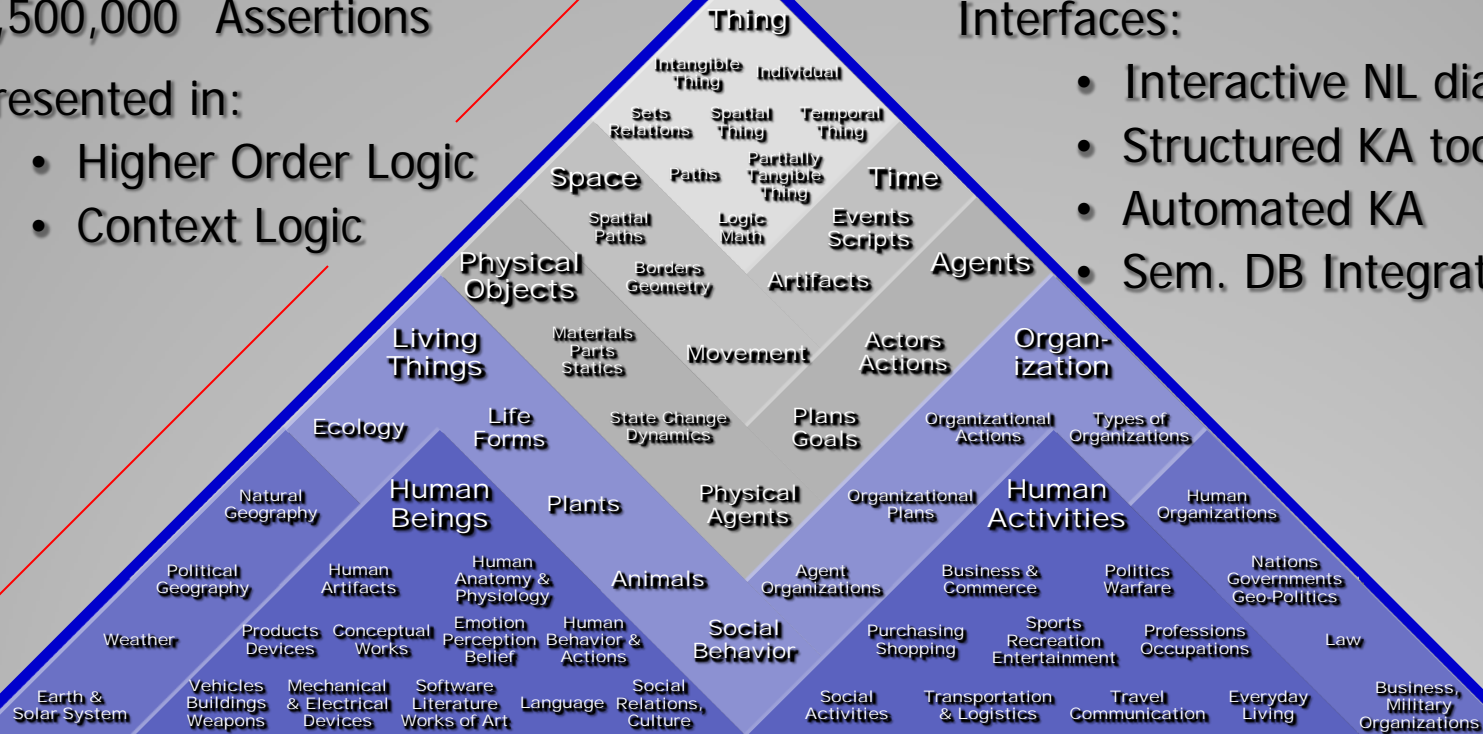
- Higher Order Logic
- Context Logic

Inference engine:

- General theorem prover
- 1050 special reasoners

Interfaces:

- Interactive NL dialogue
- Structured KA tools
- Automated KA
- Sem. DB Integration



General Knowledge about Various Domains

Specific data, facts, terms, and observations

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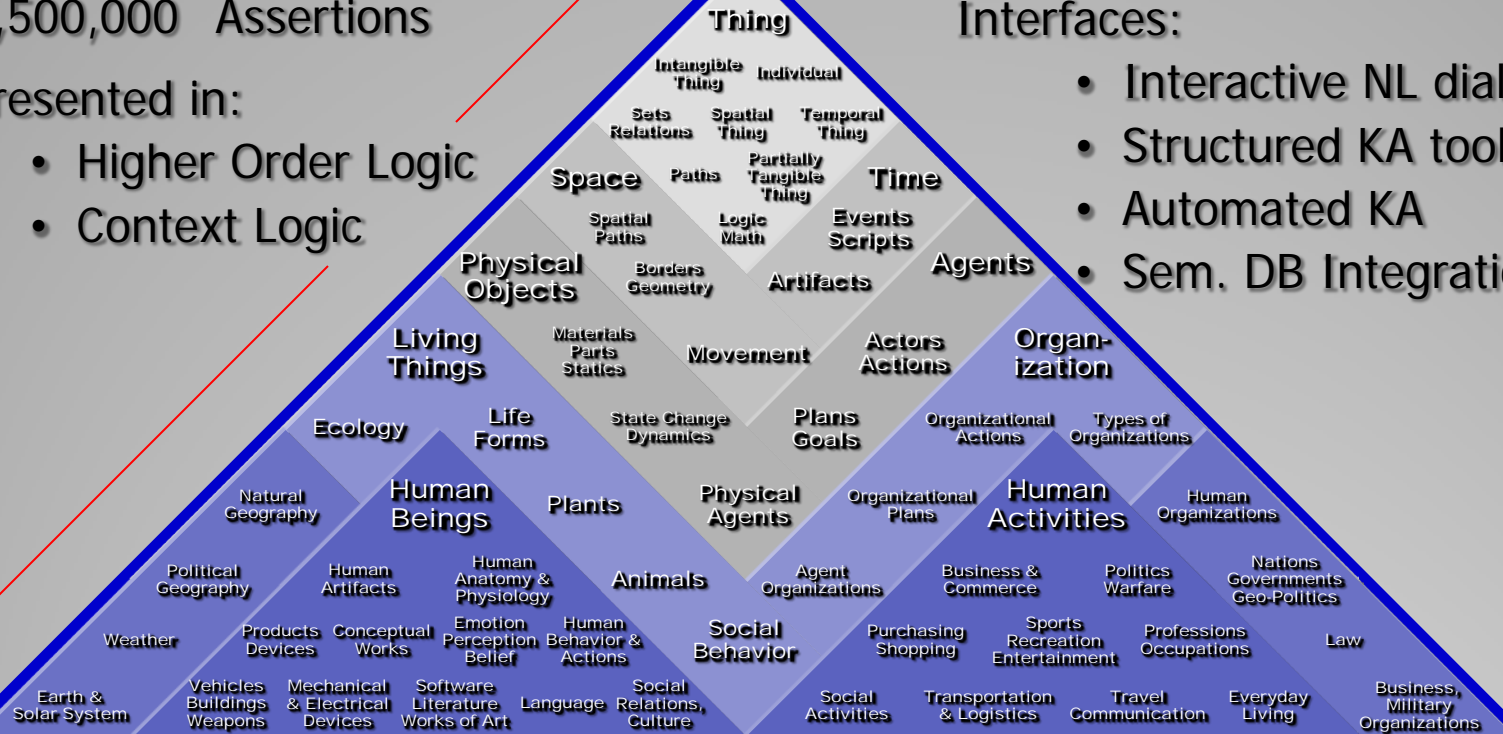
- Higher Order Logic
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- General theorem prover
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- Interactive NL dialogue
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- Sem. DB Integration



General Knowledge about Terrorism

Specific data, facts, terms, and observations about terrorist groups, individuals, and events

The Analyst's Knowledge Base

CT Analyst

"Were there any attacks on targets of symbolic value to Muslims since 1987 on a Christian holy day?"

"What sequences of events could lead to the destruction of the Hoover Dam?"



Domain Experts



Query Formulator

Explanation Generator

Scenario Generator

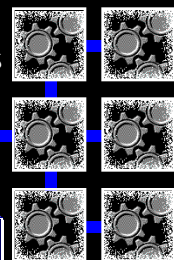
Cycorp Tools For:
-Ontology-Building,
-Browsing, -Editing,
& Fact/Rule Entry

Cyc

Reasoning Modules

General Knowledge

Terrorism Knowledge



Others'/GOTS
Analysis and
Collaboration
Components

AKB

Interface to Data Repositories

OWL &
Relational DB
"projection"
of the AKB

HUMINT
Messages

SIGINT
Message
Content

Geopolitical
Data

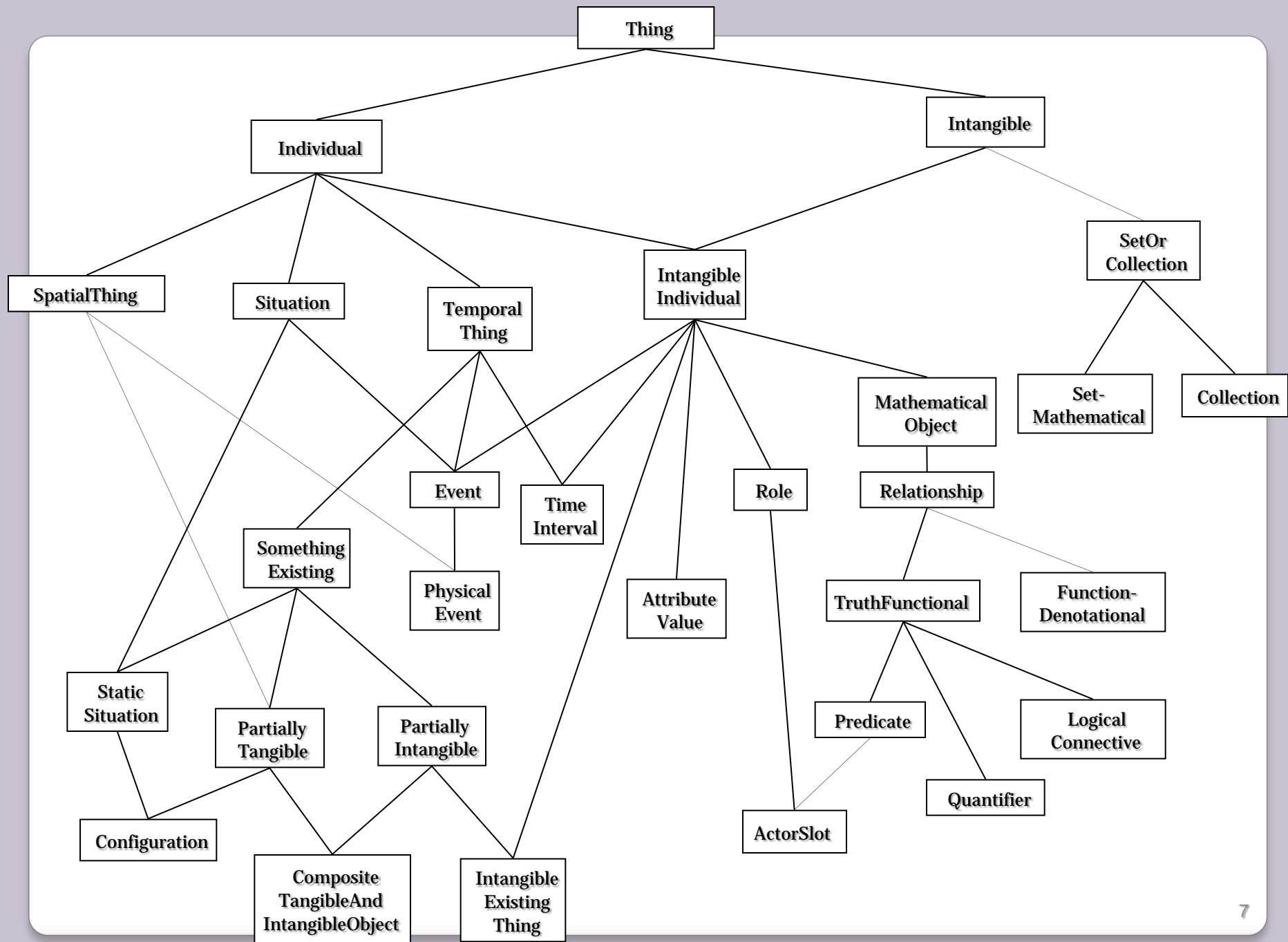
Global
Terrain
Data

Weather
Data

Satellite
Intel

Military
Intel

output of
COTS Text
Extraction
Systems



~~LO~~ mostly just impacts efficiency

**Grue: something that's green
during the day and blue at night**

- effic. of the vocab
 - Ex: big v. small trees
 - Ex: GovernmentOfFranceIn2009
 - Ex: (

“Grass is grue by day and bleen at night”

- effic. of the axioms: fewer, terser, less ambiguous assertions
 - Ex: things grue by day are usually bleen at night
 - Ex: when smurfing a car, first smurf the key
 - Ex: $\text{in}(x,y)$

**Bleen: something that's blue
during the day and green at night**

- Hence:
 - effic. of the knowledge acquisition process
 - effic. of the inference engine
 - effic. of the cross-ontology mapping axioms

~~UO~~ mostly just impacts efficiency

- effic. of the vocabulary (lower ontology): fewer/simpler terms
 - Ex: big v. small trees
 - Ex: GovernmentOfFranceIn2009
 - Ex: grue and bleen
- effic. of the axioms: fewer, terser, less ambiguous assertions
 - Ex: things grue by day are usually bleen at night
 - Ex: when smurfing a car, first smurf the key
 - Ex: **in**(x,y)
- Hence:
 - effic. of the knowledge acquisition process
 - effic. of the inference engine
 - effic. of the cross-ontology mapping axioms

Five friends get together to play 5 doubles matches, with a different group of 4 players each time. The sums of the ages of the players for the different matches are 124, 128, 130, 136 and 142 years.
What is the age of the youngest player ?

$$v+w+x+y = 124$$

$$v+w+x+z = 128$$

$$v+w+y+z = 130$$

$$v+x+y+z = 136$$

$$w+x+y+z = 142$$

- “The sun is yellow”
 - (isa TheSun **YellowObject**)
 - (hasAttribute TheSun **Yellowness**)
 - (colorOfObject TheSun **YellowColor**)
 - (**yellowColored** TheSun)
 - (frequencyOfRadiation TheSun (nanometer 570))
 - (wavelengthOfRadiation TheSun (hertz (exp 5.2 10 14)))

- “People are able to talk and are mammals”
 - (skillCapable **TypicalPerson** Speaking)
 - (genls **Person** Mammal)
 - (isa **TypicalPerson** TangibleObject)
 - (isa **Person** IntangibleObject)
 - (archetype **Person** **TypicalPerson**)
 - ($\forall x,y,z$) (archetype x y) \wedge (genls x z) \Rightarrow (isa y z)

Many ways to say the same thing

- "The sun is yellow"
 - (isa TheSun Yell...
 - (hasAttribute T...
 - (colorOfObject ...)
 - (**yellowColored** ...)
 - (frequencyOfRadi...
 - (wavelengthOfRac...

99% solution:

Just combine the two hierarchies, esp. if the same predicates don't apply (with different truth values) to corresponding members.

- "People are able to talk and are mammals"
 - (skillCapable Typ...
 - (genls **Person** ...)
 - (isa **TypicalPer** ...)
 - (isa **Person** In ...)
 - (archetype **Per** ...)
 - ($\forall x,y,z$) (archetype ...)

Recoup the lost expressivity:

Introduce predicates to tease out that aspect of the combined thing in cases where you want to talk about it and not the overall thing.

Large-scale forced duplication

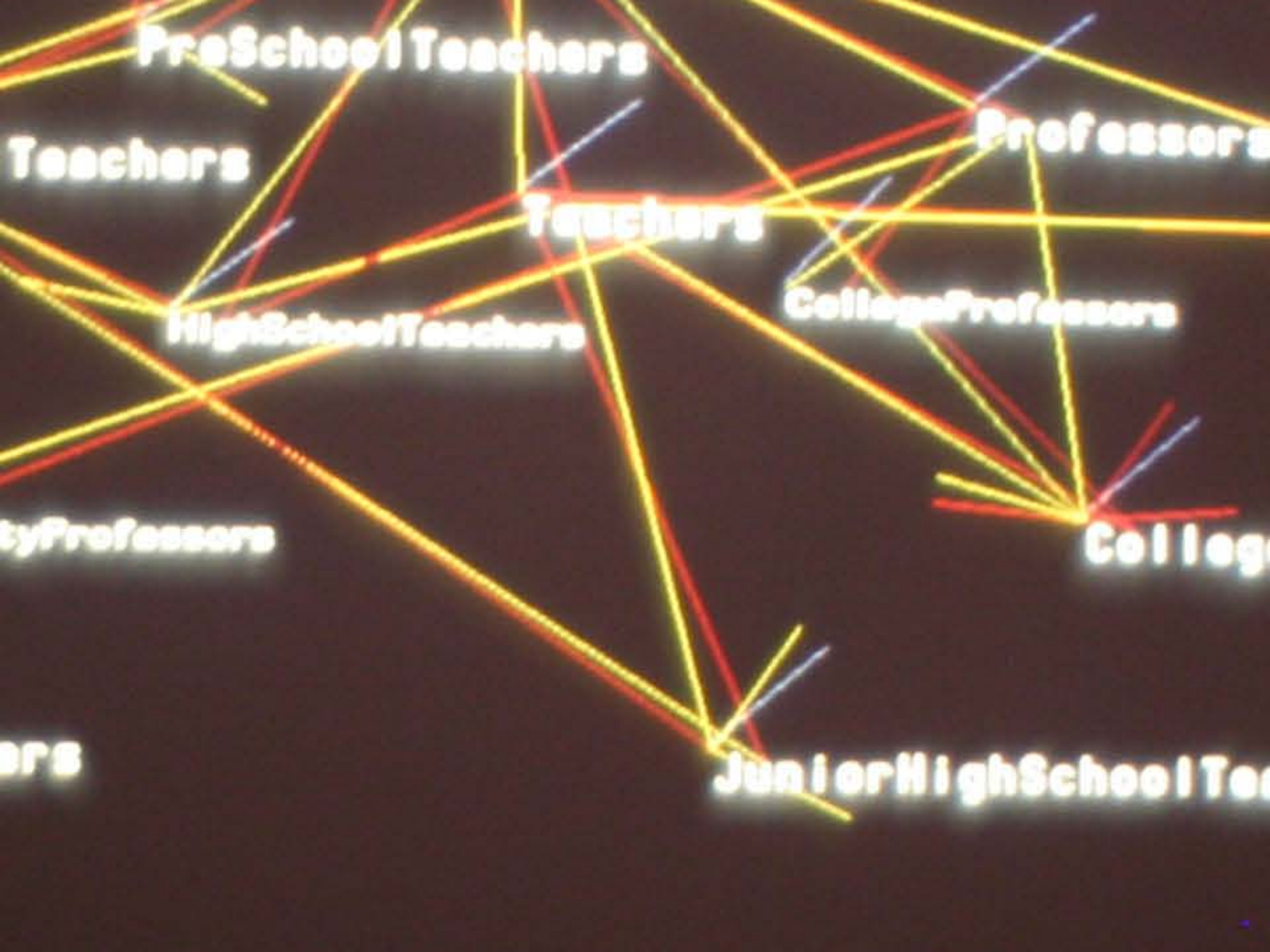
- People are composite mental and physical
(age (MindFn Frankenstein) (Years 10))
(age (BodyFn Frankenstein) (Years 34))
- Iran is similarly a composite entity: physical
(territory, buildings, roads) and mental
(social, economic, legal, military, diplomatic)

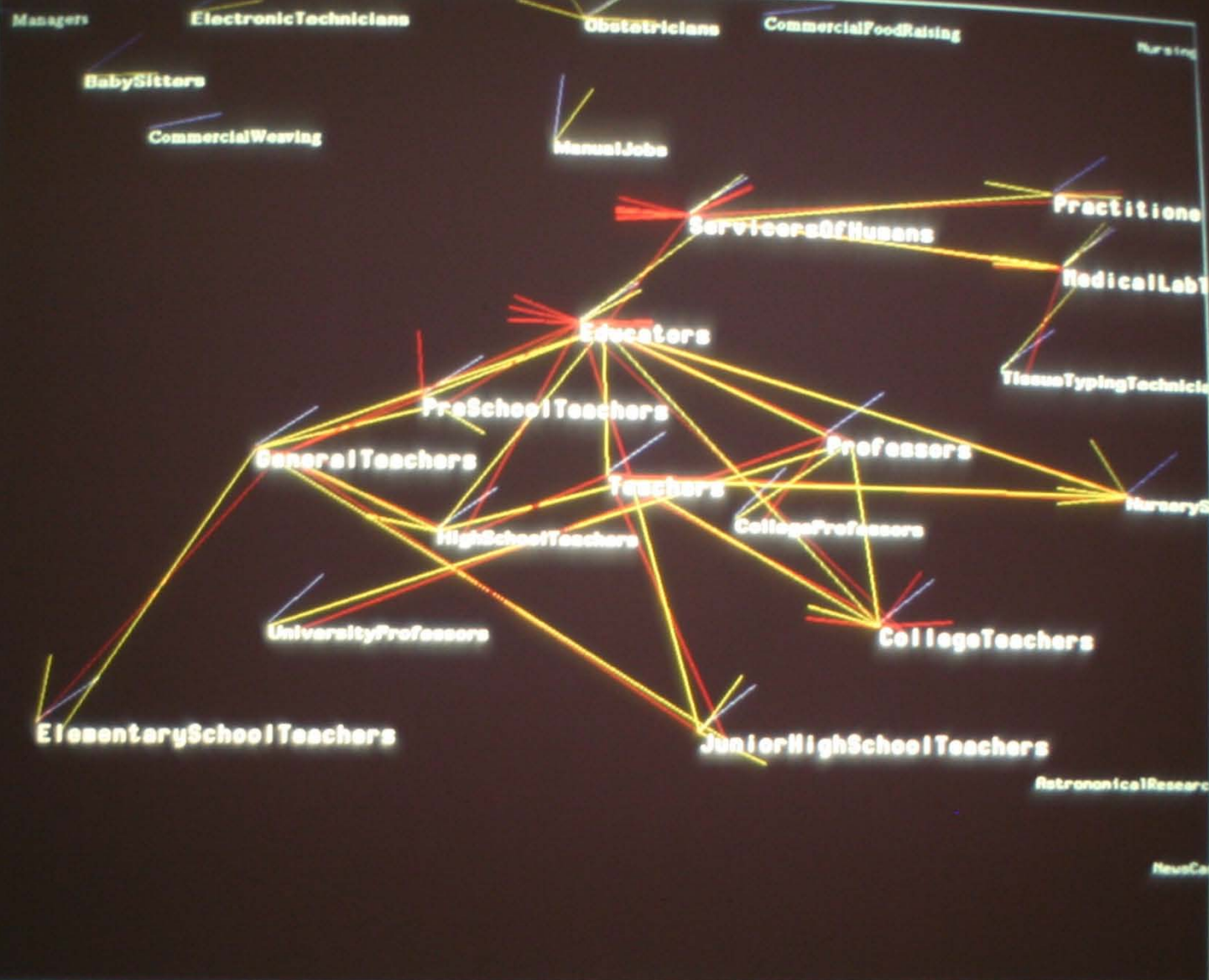
Recoup the lost expressivity:
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that aspect of the combined thing
in cases where you want to talk
about it and not the overall thing.

Large-scale forced duplication

**1984: We had to design and
build *some* interface for
ontologists building CYC**

Helicoptering
through node&link-space



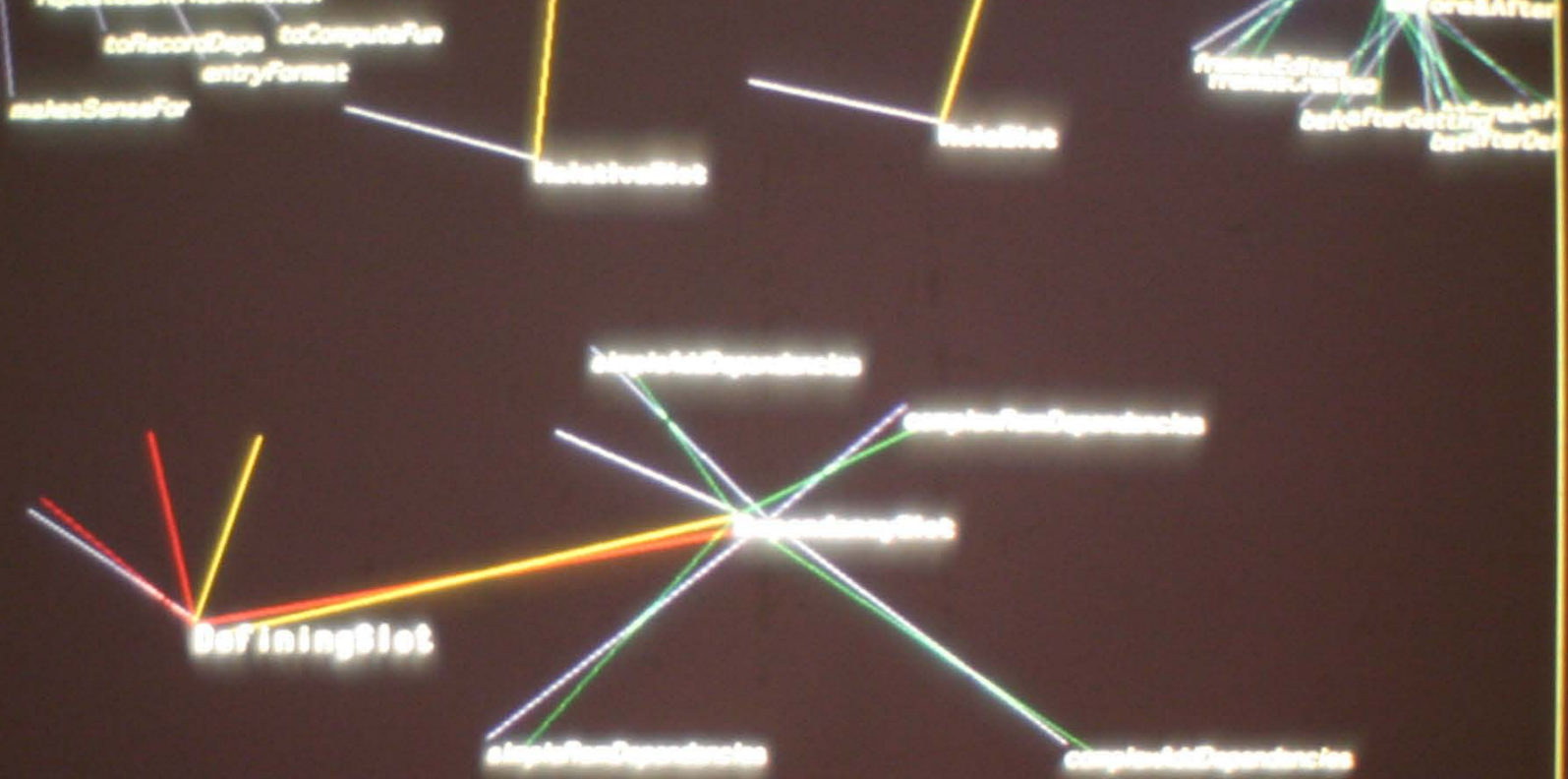


subsets
 supersets
 basicElements
 □
 unitType
 other

JustSubsets
 Subs&Supers
 JustSupers
 aSlot
 anElement
 known
 peek-at-other-end
 tr9b
 tr10
 tr112
 tr10b
 tr110
 tr110b
 tr107
 tr108
 medfnt
 cptfontb
 tr12b
 tr18
 tr121







simpleAddDependencies

complexFlowDependencies

Dependencies

simpleFlowDependencies

complexAddDependencies



**1986: Experienced users
want more text, less
“blank space”**



UE: Frame editor
MUE: Museum room editor

MCC Technical Report No. ACA/AI-357-87-Q
Updated Version: Tutorial for the
CYC Unit Editor

Mary Shepherd,
R.V. Guha, Adolfo Guzman, H. J. Hewitt, John Huffman,
Doug Lenat, Chris Maeda, Claudia Porter, David Wallace

November 1987

This document is a tutorial designed to prepare people to use CYC, by introducing them to two unit browsing and editing tools, UE and MUE. ACA/AI-357-87-Q is the current version of ACA/AI-333-87-Q.

probably easiest; type (in-package 'cyc).

ite-to-server interface function; it passes its input, an
ation, and waits for an answer. If the
it is waiting, it will signal an error. Any response from
to the actual request generated (using
O-SERVER signals an error. Otherwise, the [relevant]

ME)

This function creates a new unit -- on the CYC host --
and lets us call it NAME. The unit's
the entry #%HypotheticalStatus. It is a means of
d units can then, gradually, point to each other and to
ations represent a large larger concepts representing
c.

sinking007"). On the satellite, this is implemented as:
etical-unit ,PROTOTYPE-UNIT nil ,NAME)))

specified SLOT in UNIT (replacing any other
CYC server. Example:

nk ' (#\$USSNimitz))

S:

T (LIST ,@VALUE-LIST))

On the satellite, this function is implemented as:

```
(nabu-send-server '(outv ,UNIT ,SLOT ,VALUE))
```

```
NABU-INV (UNIT SLOT VALUE)
```

This function adds the VALUE to the list of those already in the sp
invoking INV on the remote CYC server. Example:

```
(NABU-INV #Sinking007 #ObjectSunk #USSNimitz)
```

On the satellite, this function is implemented as:

```
(nabu-send-server '(inv ,UNIT ,SLOT ,VALUE))
```

```
NCP (&rest ARGS), OR  
NABU-COMP-PLAUS (&rest ARGS)
```

This is the heart of the whole enterprise! NABU-COMP-PLAUS as
plausibility of a concept. (For more information about Compute Pla
24.0.) The argument structure is as defined by the CYC [server] fun
simple example would be:

```
(NCP #Sinking #ObjectSunk :VALUE '(LIST #UnitedStates
```

This asks CYC to judge the plausibility of the unit #Sinking having
with, among other possibilities, the value (#UnitedStatesOfAmeric

The value returned is a LIST of 5-tuples (each an interpretation): <unit slot va
The 1st element, unit, MAY NOT BE IDENTICAL to the original input UNIT!
interpretation.

The 2nd element, slot, will presumably be the same as the input SLOT (but I
haven't [yet] seen any exceptions)

The 3rd element, value, presumably MAY NOT BE IDENTICAL to the original
The 4th element, score, is a plausibility score.

```

NecessaryDefiningSlot
elementOf (#2SlotCategory #2Collection ...)
unitType (#2SlotCategory)
supersets (#2DefiningSlot)
basicElements (#2orderMatters? #2canHaveSlots ...)
myCreator (#2Huffman)
myCreationTime (#"4//24//86 09:21:14")
allSupersets (#2NecessaryDefiningSlot #2DefiningSlot ...)
allSubsets (#2NecessaryDefiningSlot)
elements (#2orderMatters? #2canHaveSlots ...)

```

NecessaryDefiningSlot

```

Unit
elementOf (#2Collection #2Unit)
unitType (#2Collection)
defn (CYC:UNIT?)
canHaveSlots (#2offset #2bbx ...)
mustInitializeSlots (#2myCreator #2myCreationTime)
subsets (#2SlotCombiner #2ExecutableFunction ...)
myCreator (#2Huffman)
myCreationTime (#"4//24//86 09:21:12")
allSupersets (#2Unit)
allSubsets (#2Unit #2SlotCombiner ...)
elements (#2ComputeByComposing #2ComputeByStarring ...)

```

Unit

```

Format
elementOf (#2Collection #2Unit)
unitType (#2Collection)
basicElements (#2SingleEntry #20set ...)
supersets (#2Unit)
canHaveSlots (#2addable? #2orderMatters? ...)
myCreator (#2Huffman)
myCreationTime (#"4//24//86 09:21:12")
allSupersets (#2Format #2Unit)
allSubsets (#2Format)
elements (#2SingleEntry #20set ...)

```

Format

ZMACS (LISP) Unit (RO)

```

ExecutableFunction
elementOf (#%Collection #%Unit)
unitType (#%Collection)
defn ..... (CYC:EXECUTABLE-FNP)
supersets (#%Unit)
subsets (#%ExecutablePredicate)
myCreator (#%Huffman)
myCreationTime (#"4//24//86 09:21:12")
allSupersets (#%ExecutableFunction #%Unit)
allSubsets (#%ExecutableFunction #%ExecutablePredicate)

```

ExecutableFunction

```

subsets
elementOf (#2NecessaryDefiningSlot #2DefiningSlot ...)
lispFnDefn (CYC:SUBSETS)
entryFormat (#2Set)
unitType (#2NecessaryDefiningSlot)
putLevel (4)
getLevel (1)
entryType (#2Collection)
makesSenseFor (#2Collection)
inverse (#2supersets)
gen1Slots (#2allSubsets #2specs)
myCreator (#2Huffman)
myCreationTime (#"4//24//86 09:21:12")

```

subsets

```

Set
elementOf (#%Format #%Unit)
differencingFn (CL:SET-DIFFERENCE)
unitType (#%Format)
addable? (T)
toCheckFormat (CYC:SET?)
myCreator (#%Huffman)
myCreationTime (#"4//24//86 09:21:17")

```

Set

unit Capacity	
Top of unit	
english	("Capacity is the amount of anything a c
instanceOf	(#2ComplexMeasurableQuantity)
allInstanceOf	(#2ComplexMeasurableQuantity #2Measurabl
genls	(#2PerceivableStuff)
plural	("Capacity")
singular	("Capacity")
measuredIn	(#2Liter)
nyLastEditor	(#2Guha)
typeOfUnitsMeasuringThisQuantity	(#2UnitOfCapacity)
More below	

fast-access slot allInstanceOf	
More above	
inverse	(#2allInstances)
entryIsA	(#2Collection)
entryFormat	(#2Set)
getLevel	(5)
putLevel	(4)
computable?	(T)
lispFnDefn	(ALLINSTANCEOF)
computeWhenInitializing?	(T)
copy?	(:NONE)
dontCache?	(T)
More below	

Bookkeeping Slot	
Top	
myLastEditTime	
perspective	
sponsor	
sponsorOf	
Bottom	

unit ComputeByComposing	
Top of unit	
english	("A SlotCombiner. λ (s2 s1): computes
instanceOf	(#2ComputeByFunction #2SlotCombiner)
allInstanceOf	(#2ComputeByFunction #2Function #2Single
allGenlReIn	(#2ComputeByComposing)
allSpecReIn	(#2ComputeByComposing)
nyLastEditor	(#2Guha)
nyCreationTime	("4-30-86 14:14:58")
nyCreator	(#2Lenat)
toComputeFun	(COMPUTE-BY-COMPOSING)
toUnrecordDeps	(UN-RECORD-COMPOSING-DEPS)
More below	

unit Lenat	
More above	
allHasAgents	(#2Lenat)
colorOfObject	(#2FleshWhiteColor)
memberOfSpecies	(#2HomoSapiensSpecies)
uePaneSelect?	(:BORDER)
acquaintedWith	(#%Guha #%Huffman #%Shepherd #%Guzm
age	(36)
inheritingSlots	(#2slotsWithInheritedConstraints #2comput
programsIn	(#2Lisp)
computersFamiliarWith	(#2DECMachine #2IBMPersonalComputer
nyLastEditor	(#2Shepherd)
More below	

Computable Slot	
Top	
allCanHaveSlots	
allGenls	
allInstanceOf	
allInstances	
allLegalSlots	
allPartTypeOf	
More below	

Show Unit	Rename Unit	Copy Unit	Instantiate Prototype
Merge Units	Subsume Unit	Continue Copy Unit	Find Similar Unit
Add New Slot	Undo Facility	Add to Paste Board	Yank to Paste Board
Yank Next to Pa			

Legal Slots	
Top	
above	
actualInstances	
alternateNames	
assimilateIn	
basicMolecularU	
basicUnit	
basicUnitOf	
below	

unit ComputeByCo
 ("A SlotCombiner
 E.g.,
 #2Uncles could be

Control-G
 Show Unit: Capac
 Control-C Co
 Enter a name to

Copying Capacity to ElectricalResistance. Do you want to change these also?					
	1st	2nd	Edit	Skip	Remove
english					<input type="checkbox"/>
Capacity is the amount of anything a container can hold. +					<input type="checkbox"/>
ElectricalResistance is the amount of anything a container can hold.	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
instanceOf					<input type="checkbox"/>
ComplexMeasurableQuantity	<input checked="" type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
typeOfUnitsMeasuringThisQuantity					<input type="checkbox"/>
UnitOfCapacity + (UnitOfElectricalResistance)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
measuredIn					<input type="checkbox"/>
Liter	<input type="checkbox"/>		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
genls					<input type="checkbox"/>
PerceivableStuff	<input checked="" type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
singular					<input type="checkbox"/>
Capacity + ElectricalResistance	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
plural					<input type="checkbox"/>
Capacity + ElectricalResistance	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Do It Abort

Legal Slots	
Top	
above	
actualInstances	
alternateNames	
assimilateIn	
basicMolecularU	
basicUnit	
basicUnitOf	
below	

Unit Editor

NIL

Legal Slots	
Top	
above	
actualInstances	
alternateNames	
assimilateIn	
basicMolecularU	
basicUnit	
basicUnitOf	
below	

unit Capacity

Top of unit

english ("Capacity is the amount of anything a c
instanceOf (#2ComplexMeasurableQuantity)
allInstanceOf (#2ComplexMeasurableQuantity #2Measurabl
genls (#2PerceivableStuff)
plural ("Capacity")
singular ("Capacity")
measuredIn (#2Liter)
myLastEditor (#2Guha)
typeOfUnitsMeasuringThisQuantity (#2UnitOfCapacity)
myCreationTime ("8-04-86 11:08:58")

More below

unit UnitOfElectricalResistance

More above

instanceOf (#2Collection)
allInstanceOf (#2Collection #2Intangible #2Everything)
genls (#2UnitOfMeasure)
plural ("UnitsOfElectricalResistance")
singular ("UnitOfElectricalResistance")
nyCreationTime ("10/17/87 14:25:38")
nyCreator (#2Shepherd)
copiedFrom (#2UnitOfCapacity)
measuredQuantity (#2ElectricalResistance)

More below

Bookkeeping Slot

Top

perspective
sponsor
sponsorOf

Bottom

Computable Slot

Top

allCanHaveSlots
allGenls
allInstanceOf
allInstanceOfP
allInstanceOfPar

unit ElectricalResistance

Top of unit

english ("The amount of resistance anything")
instanceOf (#2ComplexMeasurableQuantity)
allInstanceOf (#2Copying Liter to Ohm. Do you want to change these also?
genls (#2english
plural ("E This is the basic unit of capacity in the metric system and the basic Unit0 +
singular ("E This is the basic unit of electricalResistance in the metric system and the
measuredIn (#2instanceOf
typeOfUnitsMeasuring UnitOfCapacity + UnitOfElectricalResistance
nyCreationTime ("1 BasicUnitOfMeasure
nyCreator (#2measureOf
Capacity + ElectricalResistance

More below

unit Lenat

More above

allHasAgents (#2Lenat)
colorOfObject (#2FlashWhiteColor)

1st 2nd Edit Skip Remove

Copy	1st	2nd	Edit	Skip	Remove
<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Abort

ce
ne
s

Show Unit Merge Units Add New Slot Yank Next to Paste Board

Subsume Unit Undo Facility Layout Unit

Continue Copy Unit Add to Paste Board

Find Similar Unit Yank to Paste Board

connected to Me
copiedUnitLegal
couldBeAnEntry
cycActionToBe
cyclistNotes
defn
discoveredBy
discoveredWhen
entryOn
entryTypeOf

More below

unit ComputeByComposing.english:
("R SlotCombiner. λ (s2 s1): computes the s2 of the s1 values of a unit.
E.g.,
#2uncles could be defined as (#2ComputeByComposing #2brothers #2parents)")

Top of object

Bottom of object

Viewed Units

Top

allInstanceOf
ComputeByCo
Intangible
Radish
Shepherd
Collection

More below

Enter a string to copy Liter to: Ohm
For UnitOfElectricalResistance.english
Enter a string to copy Units of capacity measure the amount of a thing a container can hold. This is a strange typ
e of unit of measure since it can be measured in cubic yards, liters, bushels, quarts - in other words in cubic, li
quid or dry units. The basic UnitOfCapacity in CYC is the Liter to: This unit of measure if for electricity and is
measured in ohns

B 048

Unit Editor

NIL

1986: Experienced users want more text, less “blank space”

- UE: Frame editor
- **MUE: Museum room editor**

Inspired by two Macintosh games: “The Manhole” and “Cosmic Osmo”

Person

HumanScaleObject
 myCreationTime: (*1
 myCreator: (Lenat)
 english: (*Tangible

TangibleObject

Ship Canal Dam BodyPart

Person Automobi MilitaryH

LegalPerson
 myCreationTime: (*7
 myCreator: (Shepher
 english: (*A better

IntelligentAgent

Person

Corporation

myCreator: (Lenat)
 myCreationTime: (*1/30/87 15:46:36")
 english: (*A warm-blooded animal that
 seeUnitsModifyingMe: (colorOfObject+Person
 colorOfObject: (FleshWhiteColor)
 memberOfSpecies: (HomoSapiensSpecies)
 inheritingSlots: (colorOfObject slotsWithInher
 perspective: (allInstances)
 sponsorOf: (Person)
 sponsor: (Person)
 plural: ("People")
 singular: ("Person")
 canHaveSlots: (probableExpertiseInClericalIW
 instanceOf: (OrganismType)
 entryTypeOf: (discoveredBy typicalReader t Huffman

FredTheConductor
 Ballou
 Huhns
 Lester
 Ringuette
 CPorter
 Murray
 Travers
 Johns
 Kulpers
 McDermott
 Gumbo
 Russell

Marques
 Pittman
 Souther
 Mendall
 Guzman
 Guha
 Hewitt
 Kleiman
 TryCyclist1
 Mitchell
 BPorter
 Shepher
 Lenat

SentientAnimal
 myCreationTime: (*6
 myCreator: (Lenat)
 english: (*Animals

IndividualAgent

Animal

Person

Mammal
 myCreator: (Travers
 myCreationTime: (*1
 english: (*A

Vertebrate

Person

Musician

Person

MusicalConductor

Discoverer

Person

Author

Person

SamuelClemen
 JamesJoyce

FictitiousPerson

Person

StephenDedal
 HuckleberryFin

Explorer
 myCreationTi
 myCreator: (HudsonStuck
 english: (*A

Person

Indianapolitan
 myCreationTime: (*7-22-86
 myCreator: (Shepherd)
 english: (*A better name:

Person

Worker
 myCreationTime: (*1/30/87
 myCreator: (Shepherd)
 english: (*A warm-blooded

Person

DeskWork HealthTec Player HealthWer BlueCollar
 Technician PublicSec PrivateSe Nonprofit Student

EuropeanPerson
 myCreationTime: (*7-25-86
 myCreator: (Shepherd)
 english: (*A better name:

Person

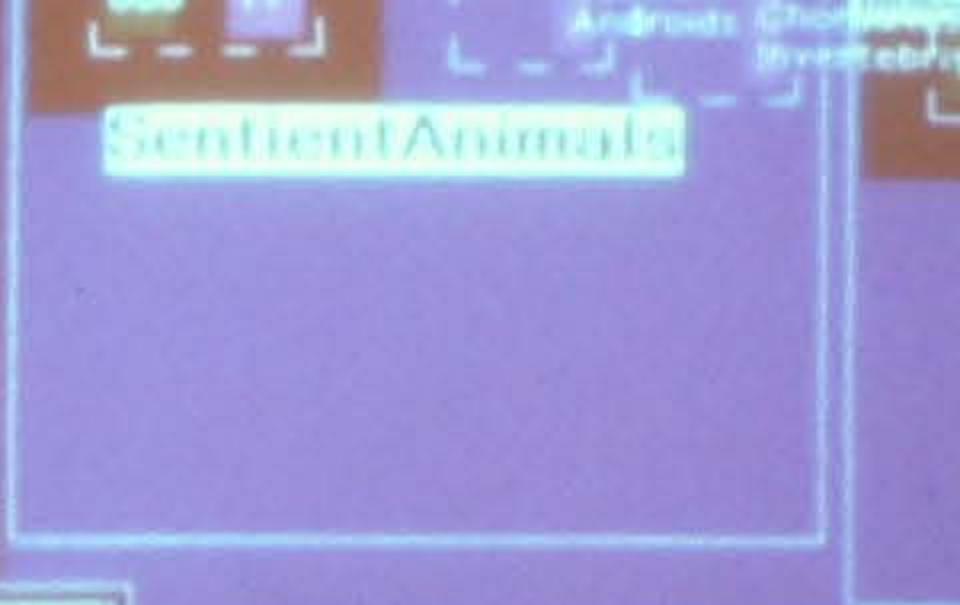
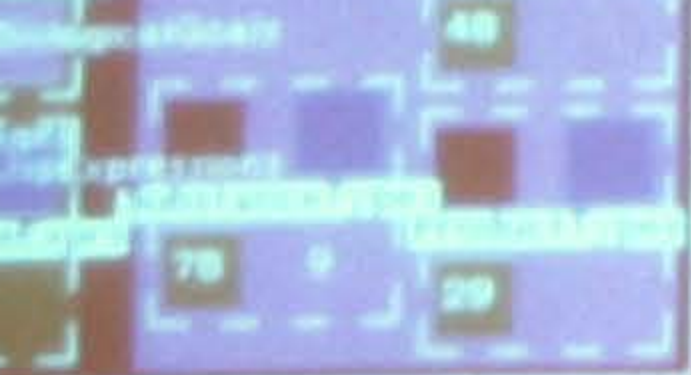
BritishPerson NorwegianPerson

AmericanPerson
 myCreationTime: (*7-29-86
 myCreator: (Shepherd)
 english: (*A better name:

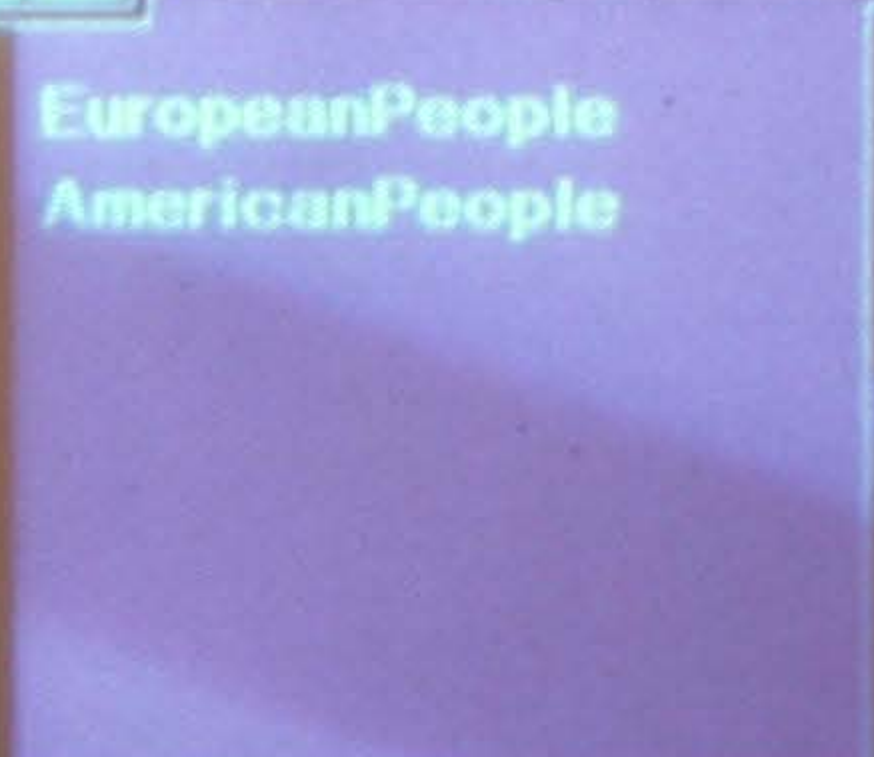
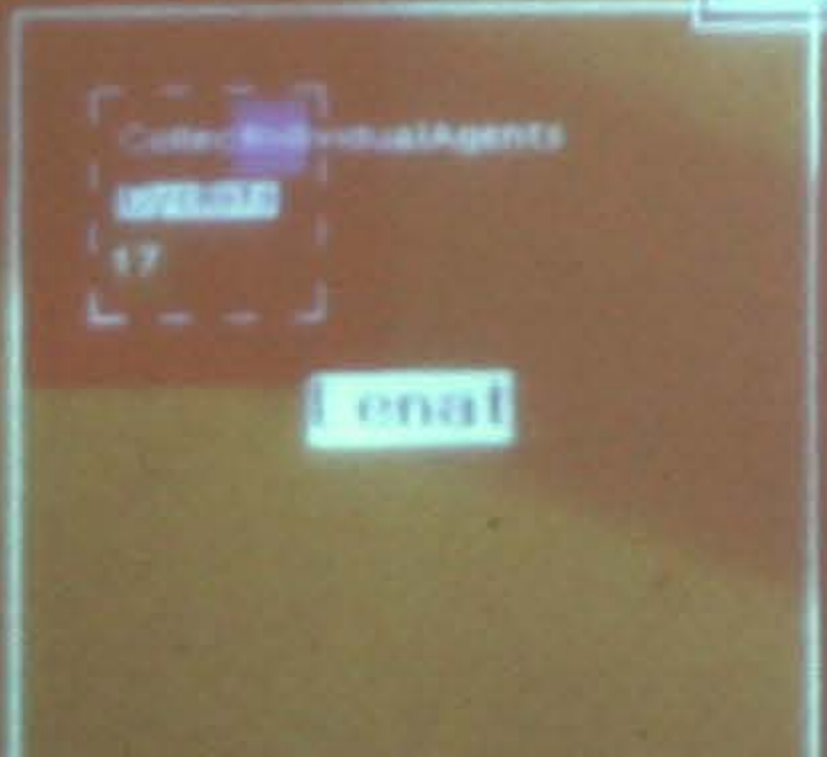
Person

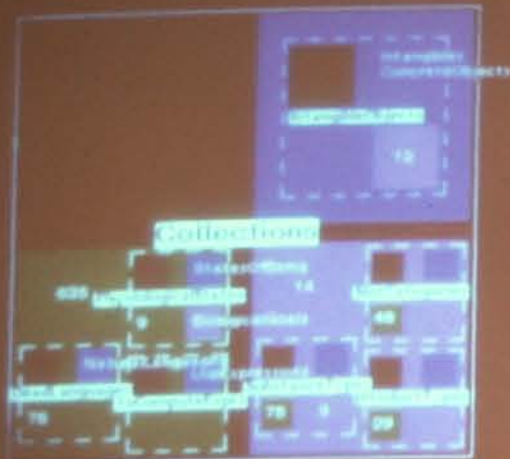
UnitedStatesPerson EnglishCanadianPerson

L: Layout Shepherd, M: Menu :R english for Shepherd

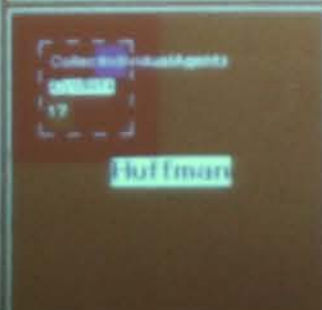
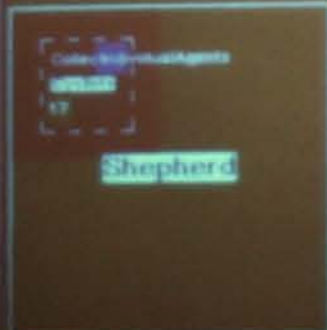
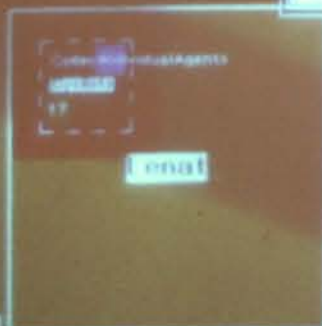


People



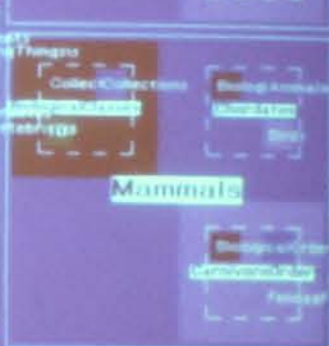
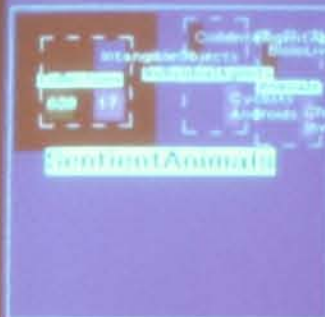
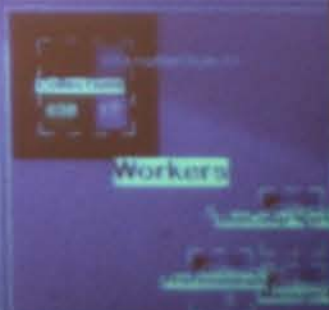


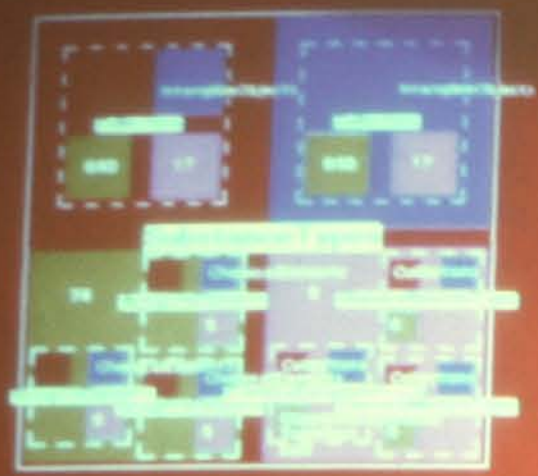
Murray Blumenthal Harold Travers
Kilmer John TryCyclot Hubert
Michael McDermott Porter Quincy
Rosen



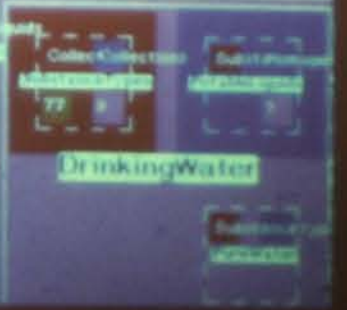
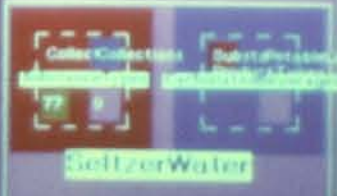
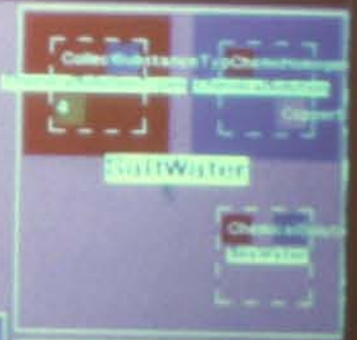
Animals

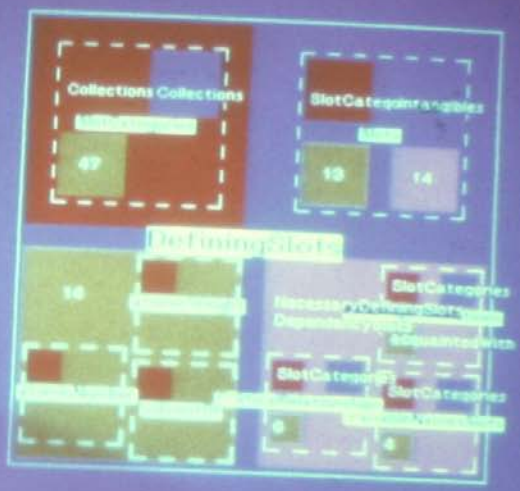
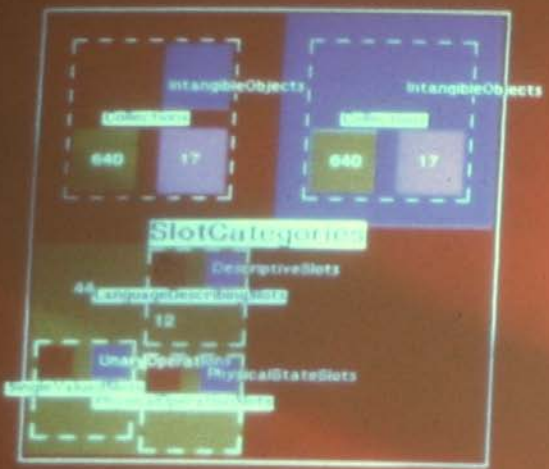
EuropeanPeople
AmericanPeople





Water Management





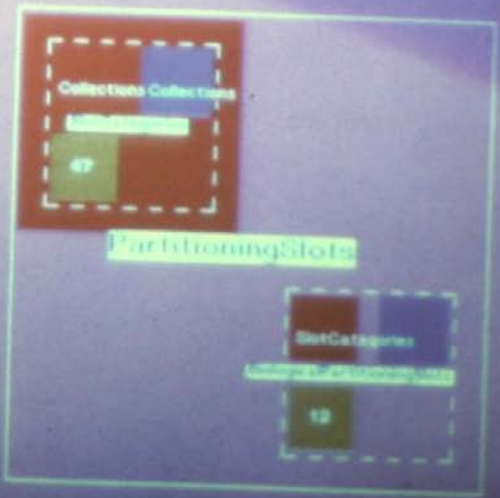
Sufficient Defining Slots

fastProcedureToFollow defn elements
 materializeSlots depends inverse
 initialize allElements toCompute
 toComputeFast sigPhiDefn

howToComputeFast

inverseProcess

criticalActions

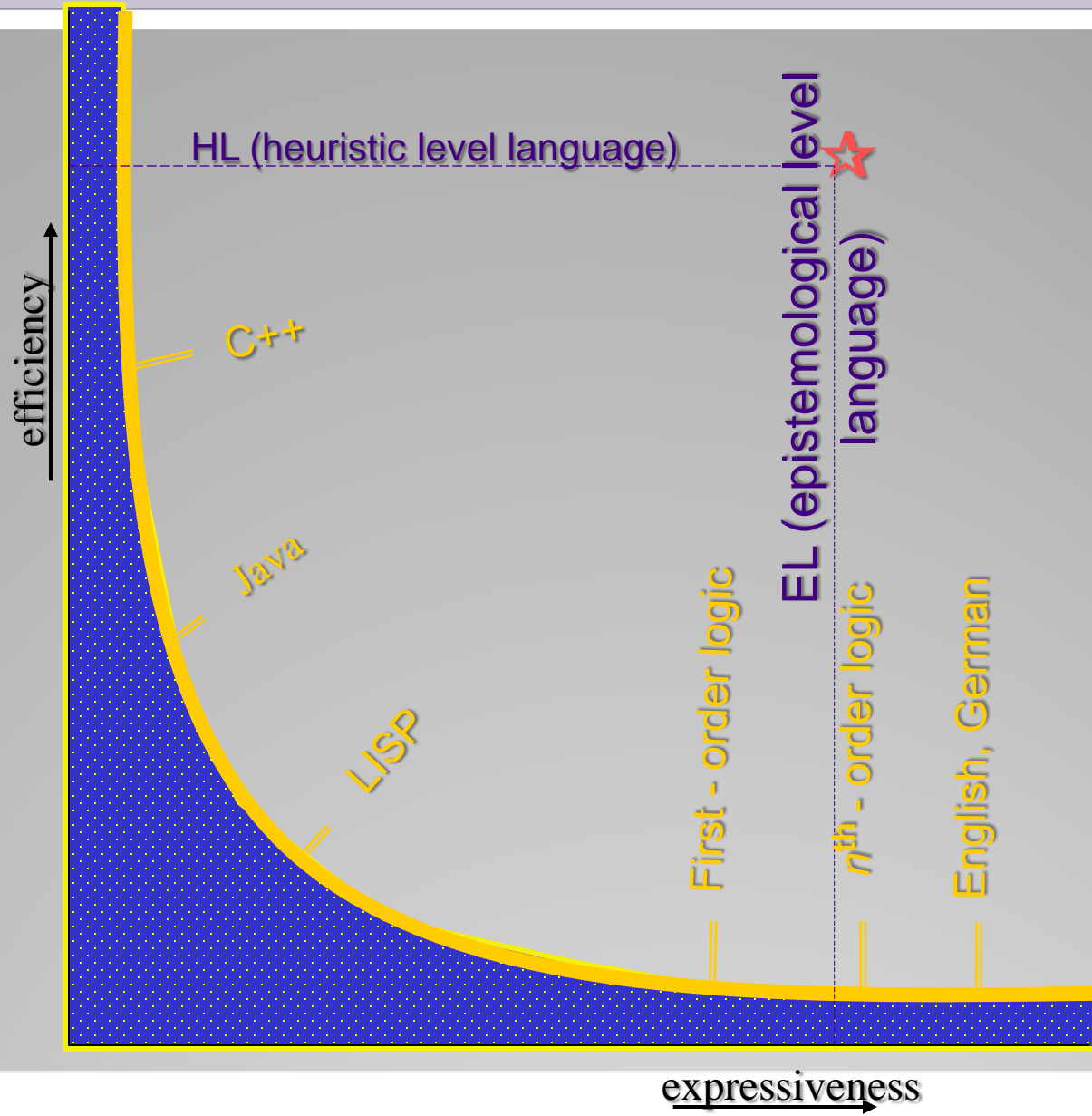


1988-89: Forced to more and more expressive representation languages:

Frames → Description Logic → FOPC → HOL (Cycl)

But with great power comes great ~~responsibility~~ **SLOWNESS**
Solution: Separate the Epistemological Problem from the Heuristic Problem.

2 representation languages → 2 editors



So: we had to learn the hard way to separate the EL from the HL

The next hard lesson: There is no one correct or best HL. Instead, there is a suite of HL modules – specialized reasoners, with (in some cases) special purpose data structures maintained so those methods can be (effic.) applied. By 1989: 20 HL modules. Today: 1k.

Always reason at the simplest language level you can, due to the tradeoff curve.

But, conversely, don't shirk from having a suitably expressive representation lang.

Representations of Knowledge

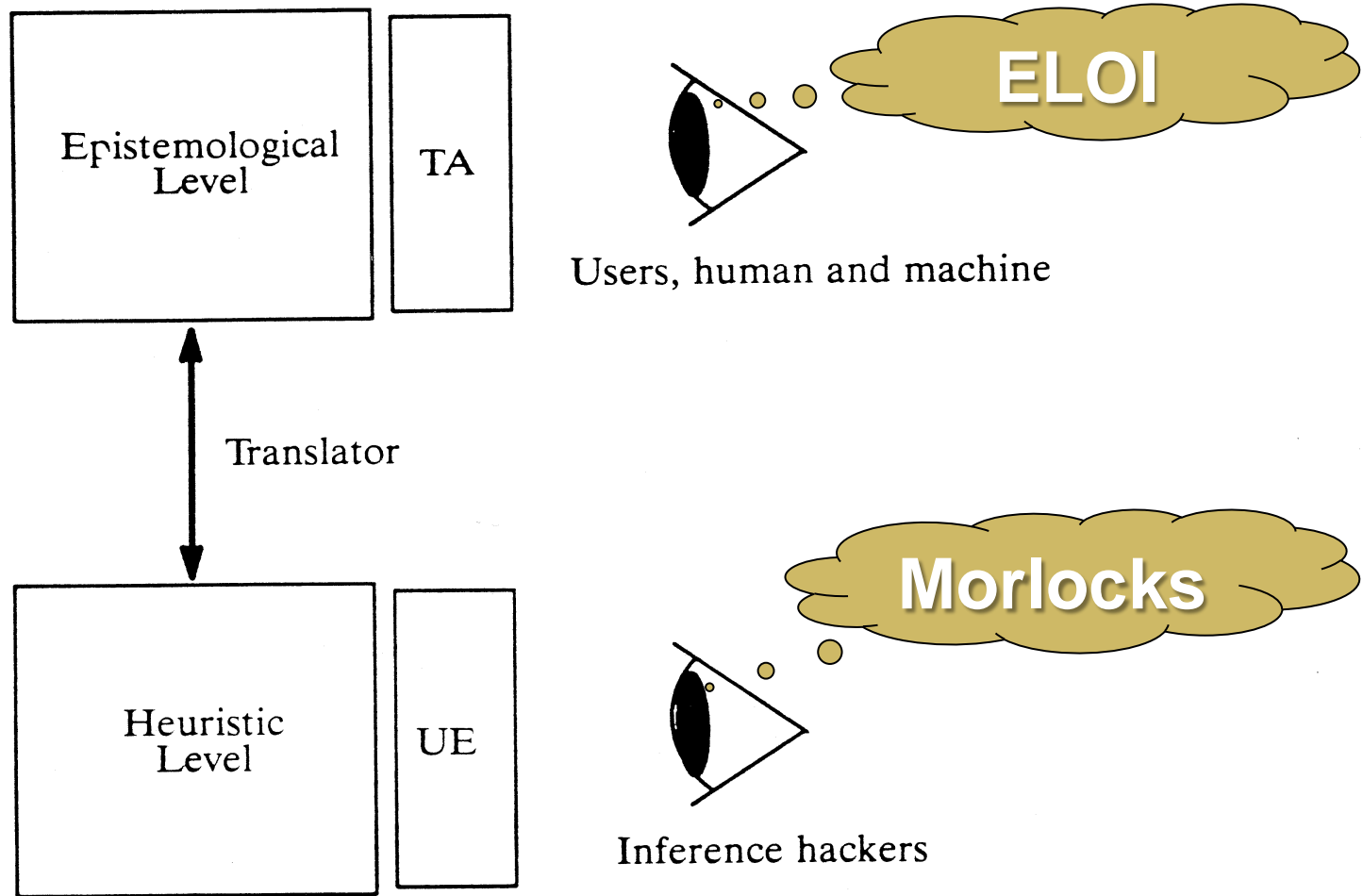


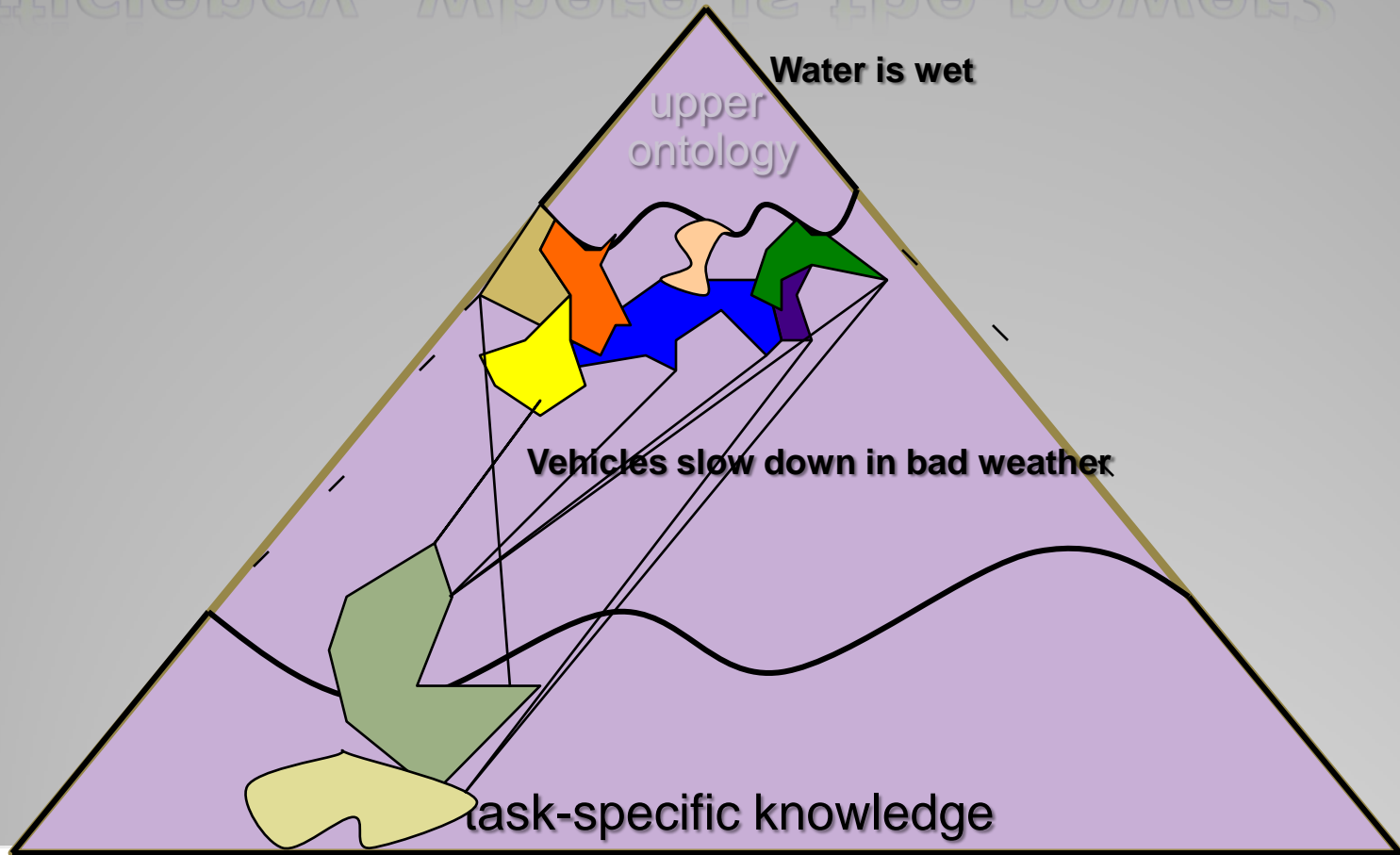
Figure 1: Schematic representation of the relationship between the Epistemological Level and the Heuristic Level. All run-time reasoning takes place at the HL, but the EH translator can make this transparent, enabling the user to interact with CYC at either level. Currently human users primarily enter knowledge with the Unit Editor (UE) at the Heuristic Level, because the organization of knowledge into frames makes browsing easier. For other programs, and for humans entering complex constraints, the Tell/Ask (TA) interface, at the Epistemological Level, is more appropriate.

1990-2009: The chasm persists

Eloi: NL dialogue-based interfaces:
the WebGame, the CAE

Morlocks: Ever more baroque versions
of the same UE machinery

So if the UO mostly impacts efficiency, where is the power?



HUMMV's lose 18% traction in 4-inch-deep mud

So if the UO mostly impacts efficiency, where is the power?

- The Upper Level need only be adequate
- The Intermediate Level is locus of power
- The Lower Levels supply the minutiae

So Upper + Intermed. is what we need to share with each other

Answering even an innocuous-sounding question:

“Can vehicle X get from Y to Z by time t ?”

may require intermediate-level knowledge about
localized spatial things, pathways,
earth sciences, weather, topography,
oceanography (depth, temperature, biota),
terrain, transportation, industry, vehicles,
geopolitics (“international waters”),
communications, the driver, holidays, ...

**So Upper + Intermed. is what we
need to share with each other**

What Needs to be Shared?

- bits/bytes/streams/network...
- alphabet, special characters,...
- words, morphological variants,...
- syntactic meta-level markups (HTML)
- semantic meta-level markups (XML, OWL)
- content (logical representation of doc/DB)
- context (models of the user's prior/tacit knowledge (incl. common sense, recent history), wants/needs, budget,...and ***n*** dimensions of metadata: time, space, level of granularity, the source's purpose/ideology...)



You
are
here

To do the logical/arithmetic combination across information sources, we need ***tens of thousands*** of relations, not ***tens***

DAML+OIL, OWL add a few more distinctions:

inverses, unambiguous properties, unique properties, lists, restrictions, cardinalities, pairwise disjoint lists, datatypes, ...

- content (logical representation of doc/DB)
- context (models of the user's prior/tacit

Tiny vocabulary (# distinctions) of standard relations:
rdf:type, subclass, label, domain, range, comment, ...

Beyond which diversity is tolerated

Which means divergence is inevitable

“What do you mean we have no standard, we have ***lots*** of standards!”

To do the logical/arithmetic combination across information sources, we need ***tens of thousands*** of relations, not ***tens***

- bits/bytes/streams
- alphabet, special characters
- words, morphological
- syntactic meta-level markups
- semantic meta-level markups
- content (logical representation of a document)
- context (models of the user's prior/tactical knowledge (incl. common sense, recent history, wants/needs, budget,...and ***n*** dimensions of metadata: time, space, level of granularity, the source's purpose/ideology...))

Analogy: # words in the English language

There is no “correct” Ontology

- Are apes monkeys?
- Are poinsettias red flowers?
- Do we need to distinguish instance & subtype?
- Are these two terms the same thing:
 - Black US Presidents in the 20th Century
 - Female US Presidents in the 20th Century
- Davidsonian reification of events or not?

No need for separate ontologies

- Are apes monkeys?
- Are poinsettias red flowers?

(ist <context> <assertion>)

➤ **An assertion may be true in some contexts and false in others**

- Explicitly *contextualize* each assertion

"If it's raining, carry an umbrella"

- ◇ the performer is a human being,
- ◇ the performer is sane,
- ◇ the performer can carry an umbrella; thus:
 - the performer is not a baby, not unconscious, not dead,
- ◇ the performer is going to go outdoors now/soon,
- ◇ their actions permit them a free hand (e.g., not wheelbarrowing)
- ◇ their actions wouldn't be unduly hampered by it (e.g., marathon-running)
- ◇ the wind outside is not too fierce (e.g., hurricane strength)
- ◇ the time period of the action is after the invention of the umbrella
- ◇ the culture is one that uses umbrellas for rain- (not just sun-) protection
- ◇ the performer has easy access to an umbrella; thus:
 - not too destitute, not someone who lives where it practically never rains,
 - not at the office/theater/... caught without an umbrella
- ◇ the performer is going to be unsheltered for some period of time
 - the more waterproof their clothing, the gentler the rain, and
 - the warmer the air, the longer that time period
- ◇ the performer will not be wet anyway (e.g., swimming)
- ◇ the rain is annoying -- but merely annoying. Thus:
 - not ammonia rain on Venus, radioactive post-apocalyptic rain,
 - biblical (Noah's-ark-sized, or frogs/blood as rained on Pharaoh)
 - the performer is not a hydrophobic person, gingerbread man, etc.,
 - and not a hydrophilic person, someone dying of thirst, etc.

No need for separate ontologies

- Are apes monkeys?
- Are poinsettias red flowers?

(*ist* <context> <assertion>)

- **An assertion may be true in some contexts and false in others**
 - **Contexts (microtheories) are themselves terms in the ontology.**
(*genIMt* HockeyMt SportsMt)
 - **12 facets or dimensions that (largely) characterize a Mt.**
- Explicitly ***contextualize*** each assertion

12 Dimensions of Ontol. Contexts

- **Anthropacity / Let's**
- **Time**
- **GeoLocation**
- **TypeOfPlace**
- **TypeOfTime**
- **Culture**
- **Sophistication/Security**
- **Topic**
- **Granularity**
- **Modality/Disposition/Epistemology**
- **Argument-Preference**
- **Justification**

How we evaluate proposed dimensions

Criteria:

- Do they separate out mutually-irrelevant (and esp. mutually-incompatible) portions of the KB?
- Is it easy for Cyc to mechanically compute the overlap or disjointness of regions of n-dim. context-space?
- Cognitive assonance: Do they (esp. their extrema) correspond to familiar real-world notions?
- Using them, is it empirically faster to enter assertions?
- Using them, is it empirically faster to do inference?

Mathematical Factoring of Contexts

UnitedStatesIn1985Context:

There are at least 900,000 doctors.

PennsylvaniaIn1985Context:

Dick Thornburgh is governor

LehighCountyInFebruary1985Context:

~~Dick Thornburgh is governor and there are at least 900,000 doctors.~~

This inference depends on the time, space, and respective granularities of the contexts.

"Calculi" for each dimension (and set)

Suppose we know that P holds in context C1

and $P \Rightarrow Q$ holds in context C2

Then in what context C3 can we expect Q to hold?

Often this can be answered *dimension-by-dimension*

- E.g., if we know the time period and granularity of C1 and C2, we can infer (constrain) the time period and granularity of C3.
- E.g., if C1 is what men 18-40 think, and C2 is what Texans over 21 think, then C3 is what Texan males 21-40 think.
- E.g., if C1 or C2 makes a simplifying assumption such as ignoring air resistance, then that generally inherits to C3.

4 ways to cut ontological corners and end up with something that might demo well but not scale up

- Ignorance-based: Depend on the theory (#terms, #instances, #rules) being tiny
- Ignore elaboration tolerance (a static KB which is massively tuned, optimized, cached, etc. ahead of time, and whenever a new assertion gets added to it.)
- Restricted expressivity of the representation language (e.g., SAT constraints; propositional calculus; Horn; description logic; first order logic;...)
- One global context (no contradictions, limited domain, simplified world)

As with pharmaceuticals, what is toxic in one dosage is sometimes quite efficacious in a lesser dosage

- Ignorance-based: Depend on the theory (#terms, #instances, #rules) being tiny
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- Restricted expressivity of the representation language (e.g., SAT constraints; propositional calculus; Horn; description logic; first order logic;...)
- One global context (no contradictions, limited domain, simplified world)
 - often a context *is* internally consistent (analog: the Earth is locally flat)
 - even a larger “problem solving context” that spans persistent contexts
 - often some (sub)problems *can* be represented and solved in a simpler repr.
 - effectively limit the size of the subtheory “explored” during inference
 - using relevance heuristics, spreading activation, contexts, etc.
 - this speeds up inference and also speeds up knowledge entry

Another Pitfall: Naming/commenting a term independently of the axioms

- Danger: bugs creep in: mismatches between what the English (name + comment) and the formal axioms say about the term.
- One solution have the system automatically generate the NL comment (and even the name) from the formal assertions
 - Additional pro's: Faster; catches missing axioms
 - Con's: stilted comment; neologism searches will "miss"
 - Mitigation: placeholder NL assertions (IOU's)

Imbuing constant names with power

- 99.9...% of the meaning is in the assertions about the terms, not in the names
 - E.g., **Garbage-disposals** and **Microwave-ovens** are known only to be **Kitchen-Appliances**
- So: one trap is to **take term names too seriously** (i.e., in situations where the associated set of assertions doesn't explicitly contain all that extra information)
- A related trap is to **take NL names too seriously**, and be led into ambiguity.
 - Sometimes they are related: **Coral-Color Coral-Reef Coral-Polyp**
 - Sometimes not: **Horse** as animal, apparatus, heroin,...
- The way out of this trap:
 - Constant term names should be unambiguous
 - Explicit lexicon(s) mapping constant terms to NL(s)

Imbuing constant names with power

MicrowaveOven is a type of Kitchen-Appliance

Dishwasher is a type of Kitchen-Appliance

The basic idea:
Get the computer to *understand*, not just store, information. Then it can *reason* to answer your queries.

Imbuing constant names with power

Rthagide-disjaks is a type of Kitchen-Appliance

Gracinimumples is a type of Kitchen-Appliance

The basic idea:

Get the computer to *understand*, not just store, information. Then it can *reason* to answer your queries.

Imbuing constant names with power

You can't use X if it **alorxes** Y but lacks any Y
Rthagide-disjaks is a type of Kitchen-Appliance

Gracinimumples is a type of Kitchen-Appliance

Rthagide-disjaks alorxes Vorawnistz.

Gracinimumples alorxes Vorawnistz and Buzqa.

Buzqa is a Thwarn and supplied through Epluns.

The basic idea:

Get the computer to *understand*, not just store, information. Then it can *reason* to answer your queries.

Imbuing constant names with power

etc. ← all the other stuff that everybody knows.

Eventually, after writing millions of these rules, the system knows as much about pipes, liquids, water, electricity, microwave ovens, dishwashers, cars, colors, movies, heights, etc. as you and I do.

Eventually, there is just one interpretation of that model, and it corresponds to the real world.

The basic idea:
Get the computer to *understand*, not just store, information. Then it can *reason* to answer your queries.

But long before that, the axioms model the world well enough that – as with human beings – it is cost-effective to act on conclusions derived from them.

Increased knowledge → incr. understanding → incr. confidence/trustworthiness.

- 99.9...% of the meaning is in the assertions about the terms, not in the names
 - E.g., if **Garbage-disposals** and **Microwave-ovens** are known only to be **Kitchen-Appliances**
- So: one trap is to take term names too seriously (i.e., in situations where the associated set of assertions doesn't explicitly contain all that extra information)
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Imbuing constant names with power

Lexical Entry Example: Coke

Constant : Coke-TheWord

isa : EnglishWord

Mt : EnglishMt

singular : "coke"

massNumber : "coke"

pnSingular : "Coke"

pnMassNumber : "Coke"

(denotation Coke-TheWord ProperCountNoun 0 (ServingFn CocaCola))

(denotation Coke-TheWord ProperMassNoun 0 CocaCola)

(denotation Coke-TheWord MassNoun 0 Cocaine-Powder)

(denotation Coke-TheWord MassNoun 2 ColaSoftDrink)

(denotation Coke-TheWord SimpleNoun 0 (ServingFn ColaSoftDrink))

<various other denotations of the English word "coke">

SLANG

SLANG

SLANG

Lexical Entry Example: Eat

Constant: Eat-TheWord

isa: EnglishWord

Mt: EnglishMt

infinitive: "eat"

pastTense: "ate"

perfect: "eaten"

agentive-Sg: "eater"

(subcatFrame Eat-TheWord Verb 0 TransitiveNPCompFrame)

(verbSemTrans Eat-TheWord 0 TransitiveNPCompFrame

(and (isa :ACTION EatingEvent)

(performedBy :ACTION :SUBJECT)

(inputsDestroyed :ACTION :OBJECT)))

- 99.9...% of the meaning is in the assertions about the terms, not in the names
 - E.g., if **Garbage-disposals** and **Microwave-ovens** are known only to be **Kitchen-Appliances**
- So: one trap is to take term names too seriously (i.e., in situations where the associated set of assertions doesn't explicitly contain all that extra information)
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 - Sometimes not: **Horse** as animal, apparatus, heroin,...
- The way out of this trap:
 - Constant term names should be unambiguous
 - Explicit lexicon(s) mapping constant terms to NL(s)

Imbuing variable names with power

```
((ForAll ?mother)
  ((ForAll ?child)
    (older ?mother ?child)))
```

Imbuing variable names with power

Over-generalization

Over-generalization

Is this a good default-true rule:

“Every organism has a head”

Replace it by a few rules for vertebrates, insects,...

Over-generalization

Over-specialization

Over-specialization

- “Every person was born later than his mother”
animal & ancestor; created thing & creator; cause/effect
- “Sailboat masts are (more or less) rigid”

```
(implies
  (and
    (isa ?MST Mast-Device)
    (physicalParts ?BOT ?MST)
    (isa ?BOT Sailboat)
    (rigidityOfObject ?MST Rigid))
```

(relationAllInstance rigidityOfObject Mast-Device Rigid)

Over-specialization

“Sailboats have masts and hulls.”

“Sailboats have masts.”

“Sailboats have hulls.”

```
(implies (isa ?BOT Sailboat)
  (thereExists ?MST
    (thereExists ?HUL
      (and (isa ?MST Mast-Device)
        (isa ?HUL Hull-BoatPart)
        (physicalParts ?BOT ?MST)
        (physicalParts ?BOT ?HUL))))))
(implies (isa ?BOT Sailboat)
  (thereExists ?MST
    (and (isa ?MST Mast-Device)
      (physicalParts ?BOT ?MST))))
(implies (isa ?BOT Sailboat)
  (thereExists ?H
    (and (isa ?MST Hull-Boat)
      (physicalParts ?BOT ?H))))
```

Independent Assertions Glommed Together

“Sailboats have masts.”

```
(relationAllExists physicalParts Sailboat Mast-Device)
```

“Sailboats have hulls.”

```
(relationAllExists physicalParts Boat Hull-Boat)
```

```
(implies (isa ?BOT Sailboat)
```

```
(thereExists ?MST
```

```
(and (isa ?MST Mast-Device)
```

```
(physicalParts ?BOT ?MST))))
```

```
(implies (isa ?BOT Sailboat Boat)
```

```
(thereExists ?H
```

```
(and (isa ?MST Hull-Boat)
```

```
(physicalParts ?BOT ?H))))
```

Why separate them?

1. They generalize to diff. levels
2. Separated, they can then be naturally expressed as efficient (terse, fast) GAF's

Independent mistakes Glommed Together

~~TheGovernmentOfFrance, TheGovernmentOfFranceIn1997,
TheGovernmentOfSpain, TheGovernmentOfSpainIn1997,...~~

Nonatomic terms created by functions being applied to arguments:

(GovernmentFn Iraq)

(DuringMt 1997 (GovernmentFn Iraq))

~~Kilometer, Kilogram, Kilocalorie...~~

(unitMultiplicationFactor (Kilo ?UNIT) ?UNIT 1000)

(resultIsa (Kilo Meter) Distance)

((Kilo Meter) 8.3)

Pre- vs. Post-coordination

Faceting

Factoring

Over-reification
OVER-REIFICATION

(marriedIn <groom> <bride> <wedding> <date>)

Events are *rich* (no limit to the number of args)

(groom Wedding0947 JoeSmith)

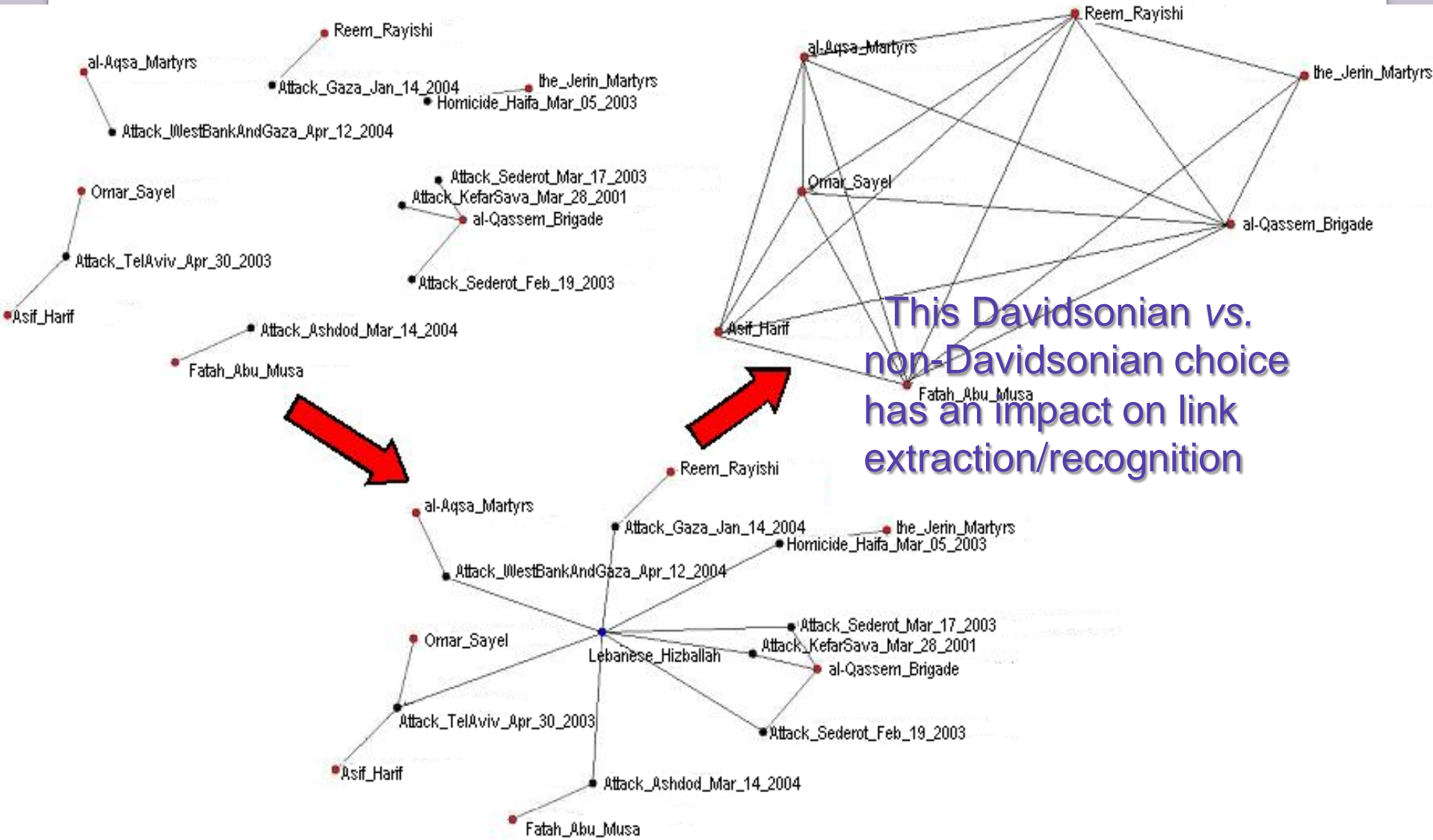
(bride Wedding0947 JaneDoe)

(dateOfEvent Wedding0947

(DayFn 13 (MonthFn May (YearFn 1999))))

- Not all situations are *rich*: (successor 812 813)
- This Davidsonian vs. non-Davidsonian choice has an impact on link extraction/recognition

Pitfall: Choosing Predicates that lump independent properties together



(teamLineup DallasCowboys-1998 TroyAikman EmmittSmith MichaelErvin ...)

2 ways out of this trap:

- Make closure-like assertions about argument order
- Reify the separate assertions about each player's position

(positionOfPersonInOrganization TroyAikman DallasCowboys-1998 Quarterback)
(positionOfPersonInOrganization EmmittSmith DallasCowboys-1998 RunningBack)

• • •

- Every football team has at least one QB
- For any play, the offense has 1 QB on the field
- The QB's role in a play is ...

Predicates that hide concepts (and assertions) in *argument order*

Cyc's "upper model" contains:

18,000 Predicates

500,000 Concepts

5,500,000 Assertions

Represented in:

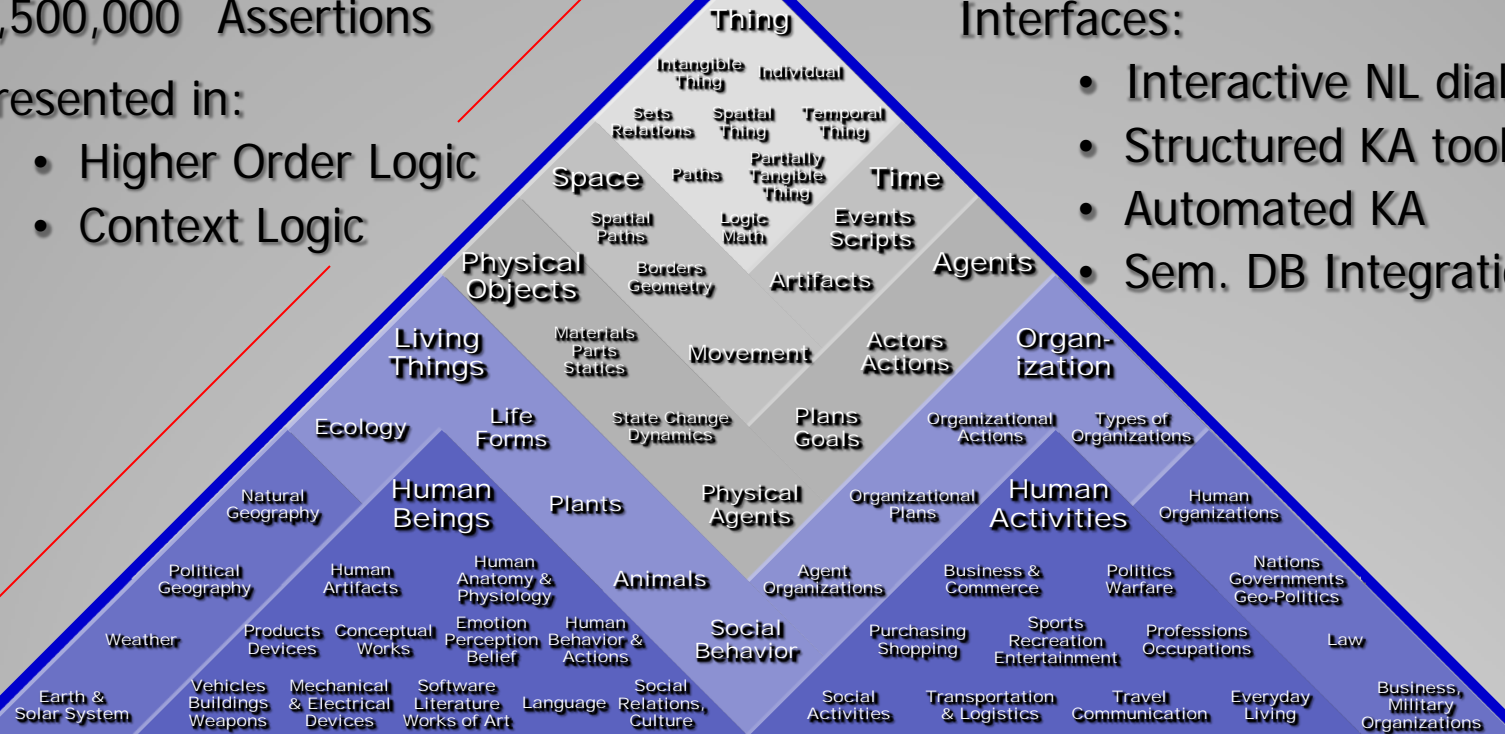
- Higher Order Logic
- Context Logic

Inference engine:

- General theorem prover
- 1050 special reasoners

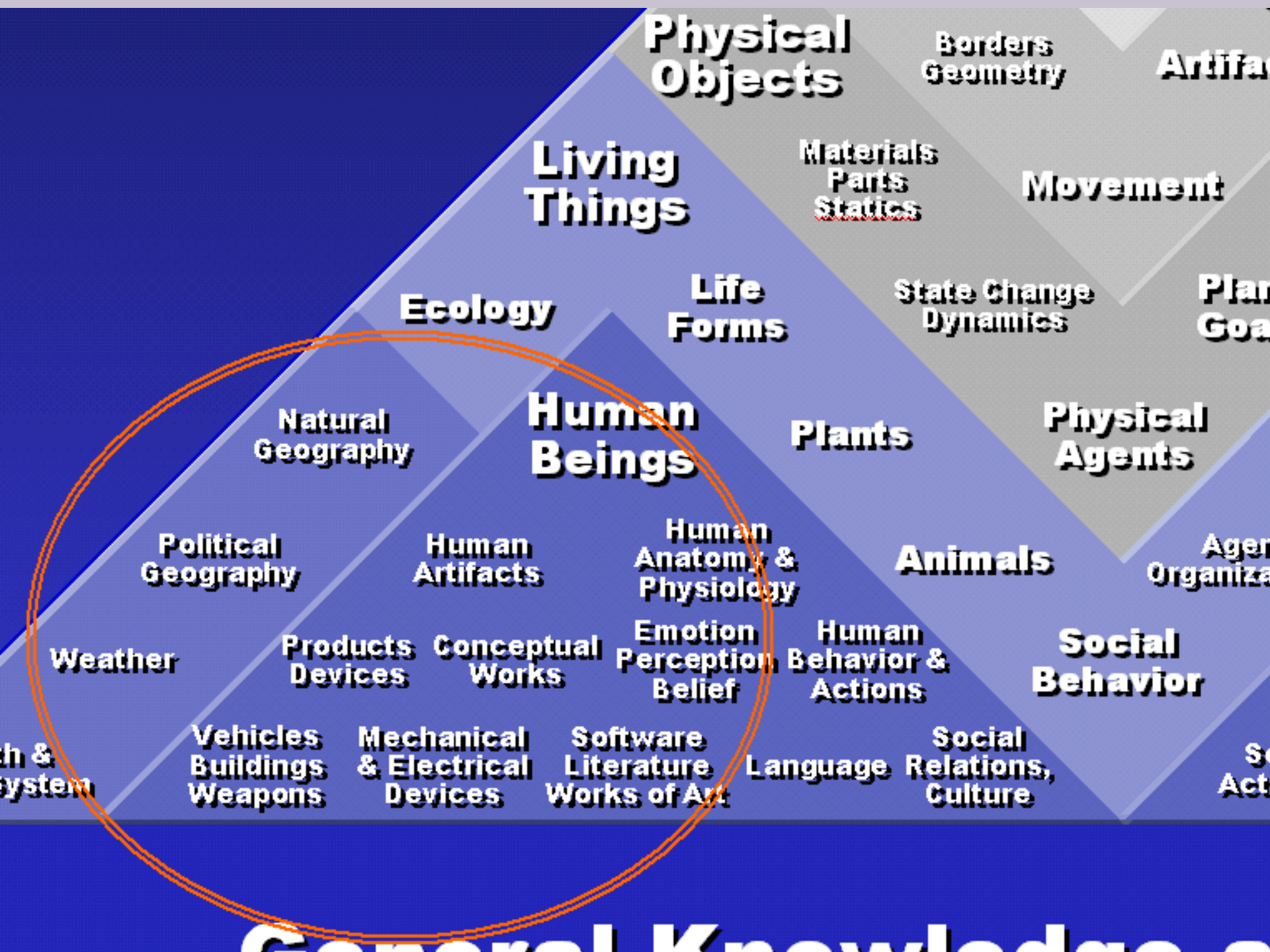
Interfaces:

- Interactive NL dialogue
- Structured KA tools
- Automated KA
- Sem. DB Integration



General Knowledge about Various Domains

Specific data, facts, terms, and observations



(isa ?ARG1 WeaponType)

1071 answers for ?ARG1 :

[105MMRifledBoreCannon](#) [125MMSmoothBoreCannon](#) [2s12-Mortar](#) [76MMRifledBoreCannon](#)
[85MMSmoothBoreCannon](#) [A-5C-Fighter](#) [AGS-17](#) [AH-1J-Helicopter](#) [AIM-7M-AirToAirMissile](#)
[AIM-9J-AirToAirMissile](#) [AIM-9M-AirToAirMissile](#) [AIM-9P4-AirToAirMissile](#) [ANFOBomb](#)
[ASWMortarLauncher](#) [AT-5](#) [ATGMLauncher-9P111](#) [ATGMLauncher-9P135M2](#)
[ATGMLauncher-AT13](#) [ATGMLauncher-AT7](#) [ATGMLauncher-D10T2S](#) [ATGMLauncher-Eryx](#)
[ATGMLauncher-Milan](#) [AcousticWeapon](#) [AdvancedAmphibiousAssaultVehicle](#)
[AdvancedArmoredPersonnelCarrier](#) [AerialBomb](#) [AerialBomb-MK53](#) [AerialBomb-MK82](#)
[AerialBomb-MK83](#) [AerialBomb-MK84](#) [AgentOrange](#) [AirDefenseGun](#) [AirDefenseSystem](#)
[AirDefenseWeapon](#) [AirToAirMissile](#) [AirToSurfaceMissile](#) [AirToSurfaceMissile-AGM-114](#)
[AmphibiousAssaultShip](#) [AnthraxSporeBasedWeapon](#) [AnthraxSprayer-PortableWeapon](#)
[AntiAircraftArtillery](#) [AntiAircraftArtilleryGun](#) [AntiAircraftGun](#) [AntiAircraftGun-SelfPropelled](#)
[AntiAircraftGunSP-Leopard2](#) [AntiAircraftGunSP-Urutu](#) [AntiAircraftGunSP-ZSU23-4](#)
[AntiAircraftWeapon](#) [AntiArmorHandGrenade](#) [AntiArmorMine](#) [AntiArmorWeapon](#) [AntiPersonnelMine](#)
[AntiPersonnelWeapon](#) [AntiRadarMissile](#) [AntiShipCruiseMissile](#) [AntiShipMissile](#) [AntiSubmarineRocket](#)
[AntiTankGuidedWeapon](#) [AntiTankGuidedWeapon-AT3Sagger](#) [AntiTankHandGrenade](#)
[AntiTankWeapon](#) [AntiTankWeapon-M47Dragon](#) [AntiTankWeapon-Rocket](#)
[ArleighBurkeClassDestroyer](#) [ArmorPiercingDiscardingSabot](#) [ArmorPiercingDiscardingSabot-FinStabilized](#)
[ArmoredFightingVehicle](#) [ArmoredInfantryFightingVehicle](#) [ArmoredMortarVehicle](#) [ArmoredTOWVehicle](#)
[Arrow](#) [Artillery-SelfPropelled](#) [Artillery-Towed](#) [ArtilleryShell](#) [ArtilleryShellRemoteDetonatedBomb](#)
[AssaultRifle](#) [AssaultRifle-AK47](#) [AssaultRifle-G36](#) [AssaultRifle-G36C](#) [AssaultRifle-G36K](#)
[AssaultRifle-M14](#) [AssaultRifle-M16A1](#) [AssaultRifleAgran](#) [AtomicBomb](#) [AttackAircraftCarrier](#)
[AttackHelicopter](#) [AttackSubmarine](#) [AutomaticFirearm](#) [AutomaticFirearm-BeltFed](#)
[AutomaticFirearm-BlowbackOperated](#) [AutomaticFirearm-ClipFed](#) [AutomaticFirearm-GasOperated](#)
[AutomaticFirearm-HopperFed](#) [AutomaticFirearm-RecoilOperated](#) [AutomaticFirearm-StripFed](#)

([genu Assaultrifle-AK47 ?ARG2](#))

97 answers for ?ARG2 :

[Agent-Underspecified](#) [Artifact](#) [Artifact-Generic](#) [Artifact-HumanCreated](#) [Artifact-NonAgentive](#)
[Assaultrifle](#) [Assaultrifle-AK47](#) [AutomaticFirearm](#) [AutomaticFirearm-GasOperated](#) [BilateralObject](#)
[Boundary-Underspecified](#) [BusinessRelatedThing](#) [Collectible](#) [Container-Underspecified](#)
[ContainerIndependentShapedThing](#) [ConventionalWeapon](#) [CulturalThing](#) [DangerousTangibleThing](#)
[DangerousThing](#) [Device-SingleUser](#) [DirectFireWeapon](#) [DurableGood](#) [EnduringThing-Localized](#)
[FiniteSpatialThing](#) [FrontAndBackSidedObject](#) [Gun](#) [Gun-BreechLoading](#) [Gun-Portable](#)
[HexalateralObject](#) [HumanScaleObject](#) [InanimateObject](#) [InanimateObject-NonNatural](#) [Individual](#)
[Landmark-Underspecified](#) [LeftAndRightSidedObject](#) [Location-Underspecified](#) [ManMadeThing](#)
[ManufacturedGoods](#) [MechanicalDevice](#) [MilitaryEquipment](#) [MilitaryHardware](#)
[MilitaryThing-SpatiallyLocalized](#) [MilitaryWeapon](#) [NonFluidlikeTangibleThing](#) [NonNaturalThing](#)
[NotVeryRoundObject](#) [ObjectWithUse](#) [PartiallyTangible](#) [PartiallyTangibleProduct](#) [PhysicalDevice](#)
[PolyDimensionalThing](#) [PortableObject](#) [PositiveDimensionalThing](#) [PoweredDevice](#) [Product](#)
[ProjectileLauncher](#) [ProjectileLauncher-Direct](#) [ProjectileWeaponOrLauncher](#) [Region-Underspecified](#) [Rifle](#)
[RigidPortableObject](#) [SelectiveFireFirearm](#) [ShapedObject](#) [SmallArm-Weapon](#) [SolidTangibleArtifact](#)
[SolidTangibleThing](#) [SomethingExisting](#) [SpatialThing](#) [SpatialThing-Localized](#) [SpatialThing-NonSituational](#)
[SpatiallyContinuousThing](#) [SurfaceRegion-Underspecified](#) [Technology-Artifact](#) [TemporalThing](#)
[TemporallyExistingThing](#) [Thing](#) [ThreeDimensionalThing](#) [TopAndBottomSidedObject](#)
[Trajector-Underspecified](#) [TriggerableDevice](#) [UserTriggeredWeapon](#) [Weapon](#)
([CollectionDifferenceFn](#) [SomethingExisting](#) [Organization](#)) ([CollectionDifferenceFn](#) [SpatialThing](#) [Situation](#))
([CollectionDifferenceFn](#) [TemporalThing](#) [BiologicalLivingObject](#))
([CollectionUnionFn](#) ([TheSet](#) [Action](#) [Artifact-Generic](#) [PropositionalConceptualWork](#)))
([CollectionUnionFn](#) ([TheSet](#) [AxisymmetricObject](#) [BilateralObject](#)))
([CollectionUnionFn](#) ([TheSet](#) [DurableGood](#) [ServiceEvent](#) [Product](#)))
([CollectionUnionFn](#) ([TheSet](#) [Event](#) [Artifact](#))) ([CollectionUnionFn](#) ([TheSet](#) [Gun-Portable](#) [Bomb](#)))
([CollectionUnionFn](#) ([TheSet](#) [MilitaryEquipment](#) ([GroupFn](#) [CommunicationDevice](#))))
([CollectionUnionFn](#) ([TheSet](#) [SolidTangibleThing](#) [LiquidTangibleThing](#)))
([CollectionUnionFn](#) ([TheSet](#) [SpatialThing](#) [VectorInterval](#)))
([CollectionUnionFn](#) ([TheSet](#) [TemporalThing](#) [Collection](#)))
([CollectionUnionFn](#) ([TheSet](#) [WeaponSystem](#) [MilitaryWeapon](#)))
([MeaningInSystemFn](#) [SENSUS-Information1997](#) "DECOMPOSABLE-OBJECT")
([MeaningInSystemFn](#) [SENSUS-Information1997](#) "SEPARABLE-ENTITY")

37 Relations Between Temporal Things

- temporalBoundsIntersect
 - temporallyIntersects
 - startsAfterStartingOf
 - endsAfterEndingOf
 - startingDate
 - temporallyContains
- temporallyCooriginating
- temporalBoundsContain
- temporalBoundsIdentical
 - startsDuring
 - overlapsStart
 - startingPoint
- simultaneousWith
 - after

Temporal Relations

Temporal Granularity: one of many types of metadata

“Ariel Sharon was in Jerusalem throughout 2005
(except for isolated trips each < 1 week long)”



“Condoleezza Rice made a ten-day trip to
Jerusalem in February of 2005”



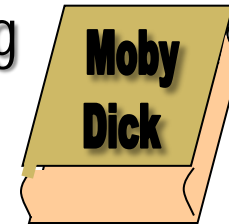
**Both of them were in Jerusalem during February 2005
(at least for a few contiguous days during that month)**

Information-Bearing Things

Books, web-page copies,
radio broadcasts,
utterances, intell cables,
TV series,...

What is “Moby Dick” ?

InformationBearingThing
(IBT)



**Problem: People refer to all
of these as "Moby Dick"**

AbstractInformationStructure
(AIS)

“ ' T i s M o b y
D i c k ! ”

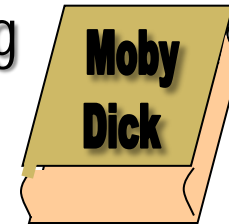
PropositionalInformationThing
(PIT)

(#\$thereExists ?SEE
(#\$and
(#\$isa ?SEE Seeing)
(#\$objectPerceived ?SEE #MobyDick)
(#\$perceiver ?SEE #CaptainAhab)))

What is “Moby Dick” ?

ConceptualWork
(CW)

InformationBearingThing
(IBT)



MobyDickTheBook-CW

AbstractInformationStructure
(AIS)

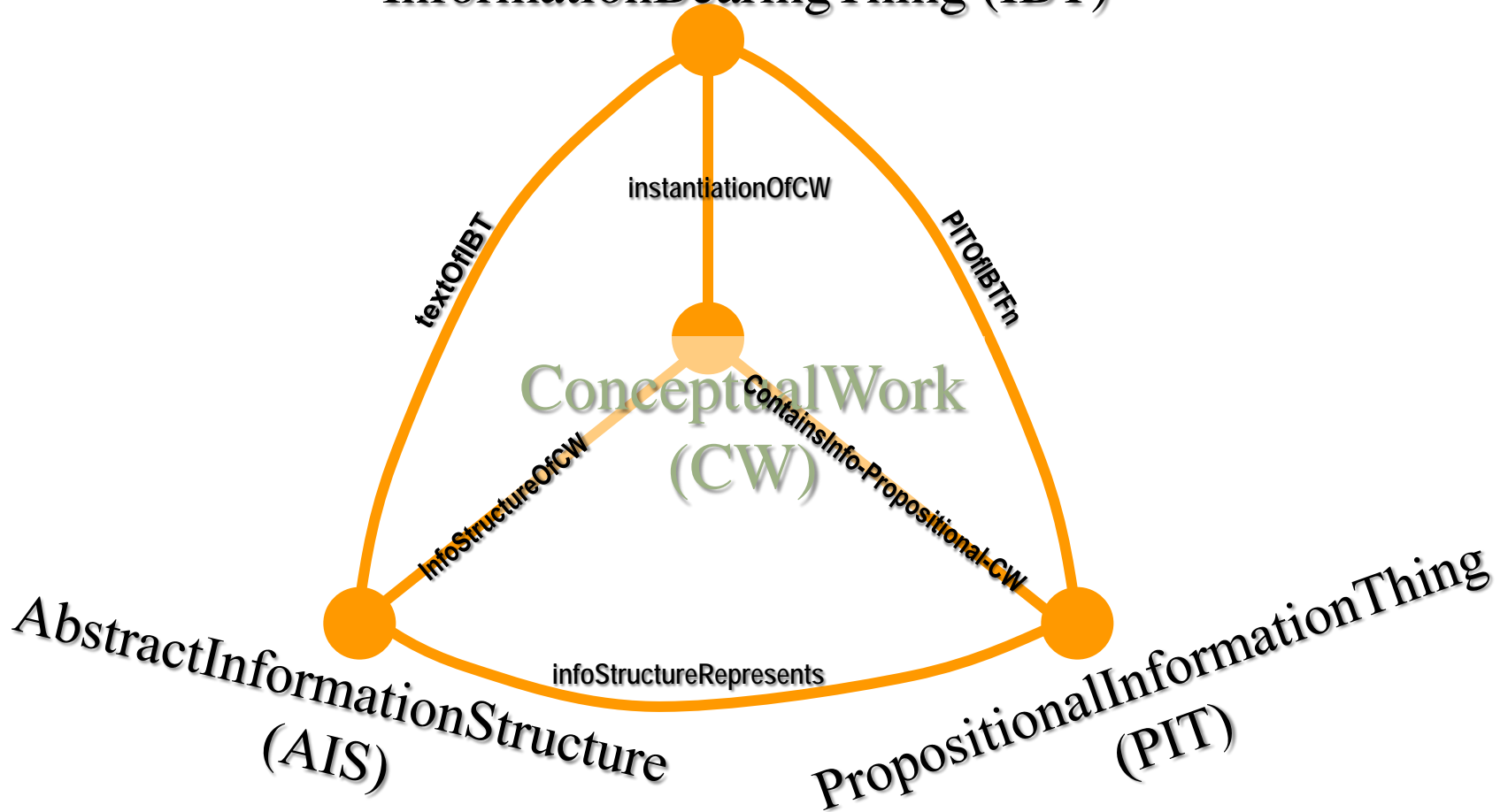
“ ’ T i s M o b y
D i c k ! ”

PropositionalInformationThing
(PIT)

(#\$thereExists ?SEE
(#\$and
(#\$isa ?SEE Seeing)
(#\$objectPerceived ?SEE #MobyDick)
(#\$perceiver ?SEE #CaptainAhab)))

What is “Moby Dick” ?

InformationBearingThing (IBT)



Relations Between an Event and its Participants

- performedBy
- causes-EventEvent
 - objectPlaced
- objectOfStateChange
 - outputsCreated
 - inputsDestroyed
 - assistingAgent
 - beneficiary
- fromLocation
 - toLocation
 - deviceUsed
 - driverActor
 - damages
 - vehicle
- providerOfMotiveForce
 - transportees

Over 400 more.

In In Our Geospatial Ontology

- We started in 1984 with just one binary predicate, “in”.
- $\text{in}(X,Y)$ means the inner object X is spatially located in the region defined by the outer object Y .
- If I just tell you $\text{in}(X,Y)$, and you aren't told what X and Y are, then you (and Cyc) can't answer questions like these:
 - From the outside of Y , can I see any part of X ?
 - If I turn Y over and shake it, will X fall out?
 - Is there room to put more things in Y ?
 - Is X actually a part of Y ?
- Such failures led to our introducing new, more precise, more specialized versions of “in”. By now there are over 75 such predicates, organized in a graphical taxonomy.

In In Our Geospatial Ontology

- Is the inner thing part of the outer object?
 - Yes → Then use **physicalDecompositions**
 - Not at all → Then use **objectFoundInLocation**
- Can a cutting plane cut the inner object and not the non-cospatial outer object?
 - No → Then use **spatiallyContains**
 - Yes → Then use **sticksInto**
 - Can the inner object be seen sticking out on both sides of the outer object?
 - Yes → Then use **surroundsRinglike**

In In Our Geospatial Ontology

- Can the inner object leave by passing by (passing through gaps among) members of the outer group?
 - Yes → Then use **in-Among**
 - Is the inner object also one of those outer group members?
 - Yes → Then use **groupMemberOf**
- Is the inner object a building built on the outer object, which is a plot of land?
 - Yes → Then use **groundsOfBuilding**

In In Our Geospatial Ontology

- If the outer object moves, does the inner object move along with it ?
 - Yes → Then use **physicallyContains**
 - Is the inner object a hole or cavity in the outer object?
 - Yes → Then use **containsCavity**
 - Is some part of the inner object in every part of the outer object?
 - Yes → Then use **constituents**
 - Was it used in constructing the outer object?
 - Yes → Then use **builtUsingParts** (if it still has essentially the same shape and properties) or **ingredients** (if it doesn't)

In In Our Geospatial Ontology

- Can the physically-contained “inner” object be removed if sufficient force is supplied in some direction, without damaging either object?
 - Yes → Then use **nailedOrPinnedIn** if the direction required is outward; use **screwedIn** if the required direction to apply the force is rotational
- Various specialized forms of **in-Container**
 - wearsClothing -- by object type
 - protectiveContains -- by purpose
 - coversBaglike -- by object feature
 - occupantsAre -- by object type

In In Our Geospatial Ontology

- Various specialized forms of **physicallyContains**
 - anatomicalParts, electricalParts, hasDevices, hasFloors, hasRooms, hasMarkings, mainProduct, movingParts, mealComponent, outfitParts, portalHasCovering, packaging, celestialSubRegion, geographicSubRegion...
- These semantic disentanglings lead to the question:
Is Virginia an intelligent agent or just a region?
 - In one context (Geography), it is just a region.
 - In others (GeopoliticalDualistTheoryOfTheWorld), both

Propositional Attitudes

Relations Between Agents and Propositions

- goals
- intends
- desires
- hopes
- expects
- believes
- opinesThat
- knowsThat
- remembersThat
- perceivesThat
- seesThat
- fearsThat

These are **modal***; assertions using them go beyond 1st-order logic.

* I.e., modus ponens, substitution of equals for equals, etc. often doesn't hold.

deliberateActors

assistingAgent

- ◆ controllingLaunchAuthority-USAF <-
- ◆ dutyOfficerOfTask <-
- ◆ launchAerospaceControlOfficer <-
- ◆ launchMissionDirector <-
- ◆ launchOperationsDirector <-
- ◆ launchRangeControlOfficer <-
- ◆ launchRangeOperationsCommander <-
- ◆ launch AFLD-AFSD <-
- ◆ missionFlightControlOfficer ...

computerInteractionUser

- ◆ mySentientSessionUser <-

crewMember

- ◆ driverActor ...

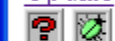
deliberateSocialParticipants

- ◆ (PresentTenseVersionFn deliberateSocialParticipants)
- ◆ adversaryInConflict ...
- ◆ agreementSponsors <-
- ◆ arbitrageur ...
- ◆ authorizingAgents <-
- ◆ buyingPerformer ...

- ◆ communicationParticipants ...
- ◆ competingAgents ...
- ◆ contractee <-
- ◆ contractor <-
- ◆ cooperatingParticipants ...
- ◆ cultureCoreParticipants <-
- ◆ guestAtSocialGathering <-
- ◆ guestInHosting ...
- ◆ host ...
- ◆ hostOfEvent <-
- ◆ initiator ...
- ◆ interviewee ...
- ◆ interviewer <-
- ◆ keyParticipants ...
- ◆ mediators ...
- ◆ meetingParticipants ...
- ◆ negotiators <-
- ◆ noVoter <-
- ◆ officiator ...
- ◆ pickupCourier <-
- ◆ presenter <-
- ◆ projectLeader <-
- ◆ projectParticipants ...
- ◆ providerOfService ...
- ◆ sellingPerformer ...

Update

Search

Tools: [Asrt](#) [Comp](#) [Crt](#) [Doc](#) [Hist](#) [KCTR](#) [Run](#) [Nav](#) [Ovlp](#) [Prefs](#) [Query](#)Login: [ChrisD](#)No gloss [v](#) Ignore Case Lucky

Clear

[SKSMan](#) [SubL](#) [View](#) [WFF](#)

Server: capella

... [SingleDoerAction](#)◆ [BodyMovementEvent](#)... [Situation](#)◆ [PurposefulPhysicalAction](#)**[VoluntaryBodyMovement](#)**◆ [Applauding-Clapping](#) <-◆ [AquaticBodyMovement](#)◆ [SkinnyDipping](#) <-◆ [Splashing](#) <-◆ [Swimming-Generic](#) ...◆ [TreadingWater](#) <-◆ [BaseballSwing](#) <-◆ [Biting](#)◆ [\(BitingByFn Mammal\)](#) <-◆ [BitingAnAgent](#) <-◆ [BitingFingernails](#) <-◆ [BlockingAPunch](#) <-◆ [BlowingAir](#)◆ [InsufflatingSomething](#) <-◆ [Puffing](#) <-◆ [ChangingPosture](#)◆ [Kneeling](#) <-◆ [Lying-Physical](#) <-◆ [RollingOver-Animal](#) <-◆ [SittingDown](#) <-◆ [Chewing](#)◆ [\(SubcollectionOfWithRelationToTypeFn Chewing objectActedOn Chewing](#)◆ [CoordinatedBodyMovement](#)◆ [BalancingSomething](#) ...◆ [CatchingWithHands](#) <-◆ [Cheerleading](#) <-◆ [Dancing](#) ...◆ [Diving](#) ...◆ [DodgingSomething](#) ...◆ [Juggling](#) <-◆ [ManipulatingWithFingers](#) ...◆ [Pedaling](#) <-◆ [PedalingABicycle](#) <-◆ [Rowing](#) <-◆ [Tackling](#) <-◆ [CrossingLegs](#) <-◆ [FingerMovement](#)◆ [PushingAButton](#) ...◆ [GrabbingOntoWithHand](#) <-◆ [HandAndWristMovement](#)◆ [TurningSomethingWithHand](#) <-

ResearchCyc Browser (ariadne) (Untitled)

CanCan No dloss GREP

HL Support Detail [Refresh]

Strength : Default Module : TVA

Mt : [CurrentWorldDataCollectorMt-NonHomocentric](#)

HL Formula :

[\(typeBehaviorIncapable Can Cancan-StyleOfDance performedBy\)](#) ← Can a can can-can?

Justification :

- [\(typeBehaviorIncapable InanimateObject AtLeastPartiallyMentalEvent doneBy\)](#) in [AnimalActivitiesMt](#)
- [\(transitiveViaArgInverse typeBehaviorIncapable genlPreds 3\)](#) in [UniversalVocabularyMt](#)

[:GENLPREDS \(genlPreds performedBy doneBy\)](#) in [CurrentWorldDataCollectorMt-NonHomocentric](#)

- [\(transitiveViaArgInverse typeBehaviorIncapable gens 1\)](#) in [UniversalVocabularyMt](#)

[:GENLS \(gens Can InanimateObject\)](#) in [CurrentWorldDataCollectorMt-NonHomocentric](#)

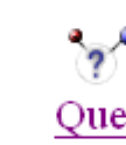
- [\(transitiveViaArgInverse typeBehaviorIncapable gens 2\)](#) in [UniversalVocabularyMt](#)


[:GENLS \(gens Cancan-StyleOfDance AtLeastPartiallyMentalEvent\)](#) in [CurrentWorldDataCollectorMt-NonHomocentric](#)

Update Comm: Storing Only Agenda: Idle KB: 7113 System: 1.10183

Confusing the user by:


- talking in logic vs. NL
- talking in too-precise NL
- including prior/tacit knowl.



 *CanCan*
 No gloss

Confusing the user by:

- ✓ talking in logic vs. NL
- talking in too-precise NL
- including prior/tacit knowl.

 **HL Support Detail** [\[Refresh\]](#) [\[C\]](#)

Strength : Default **Module :** TVA




Mt : [CurrentWorldDataCollectorMt-NonHomocentric](#)

HL Formula :

[\(typeBehaviorIncapable Can Cancan-StyleOfDance performedBy\)](#) ←

Can a can can-can?

Justification :

- [Inanimate objects](#) cannot play the role of [doer](#) in [partially mental event](#). 
- Argument 3 of [#\\$typeBehaviorIncapable](#) is transitive with respect to the inverse of [#\\$genlPreds](#).
- If some agent [deliberately performed](#) some action, then it [did](#) that action. (claimed by [GENLPREDS](#) module)
- Argument 1 of [#\\$typeBehaviorIncapable](#) is transitive with respect to the inverse of [#\\$genls](#).
- A [can](#) is a type of [inanimate object](#). (claimed by [GENLS](#) module) 
- Argument 2 of [#\\$typeBehaviorIncapable](#) is transitive with respect to the inverse of [#\\$genls](#).
- [Cancan dancing](#) is a type of [partially mental event](#). (claimed by [GENLS](#) module) 


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 [Update Comm:](#) Storing Only [Agenda:](#) Idle **KB:** 7113 [System:](#) 1.10183

 *CanCan*
 No gloss [v] [GREP] [C]

Confusing the user by:

- ✓ talking in logic vs. NL
- talking in too-precise NL
- ✓ including prior/tacit knowl.

 **HL Support Detail** [Refresh] [C]

Strength : Default **Module :** TVA

Mt : [CurrentWorldDataCollectorMt-NonHomocentric](#)

HL Formula :

[\(typeBehaviorIncapable Can Cancan-StyleOfDance performedBy\)](#)



Can a can can-can?

Justification :

● [Inanimate objects](#) cannot play the role of [doer](#) in [partially mental event](#).



A [can](#) is a type of [inanimate object](#). (claimed by [GENLS](#) module)



[Cancan dancing](#) is a type of [partially mental event](#). (claimed by [GENLS](#) module)



What AI did wrong before Cyc

AI Magazine Volume 29 Number 2 (2008) (© AAAI)

Articles

The Voice of the Turtle: Whatever Happened to AI?

Doug Lenat

**Errors in representation, in methodology, in inference, in scale.
Traps we fell into, decisions we had to back out of, half-finished off-ramps to nowhere.**

■ *On March 27, 2006, I gave a light-hearted and occasionally bittersweet presentation on “Whatever Happened to AI?” at the Stanford Spring Symposium presentation—to a lively audience of active AI researchers and formerly active ones (whose current inaction could be variously ascribed to their having aged, reformed, given up, redefined the problem, and so*

We’re now well past 2001; where is HAL? When Marvin Minsky advised Arthur C. Clarke and Stanley Kubrick, 40 years ago, it seemed that achieving a full HAL-like AI by 2001 was every bit as likely as, well, commercial Pan Am flights to the moon by 2001.¹ As Bill Rawley said, the future is just not what

back-and-forth clarification dialogues with us, their human users. But for that to be anywhere near as efficient as conversing with another human being—for the computer to not come off like an idiot savant or idiot—requires its knowing a vast panoply of facts (hot coffee is hot; jet planes fly hundreds of miles per hour),

The Analyst's Knowledge Base

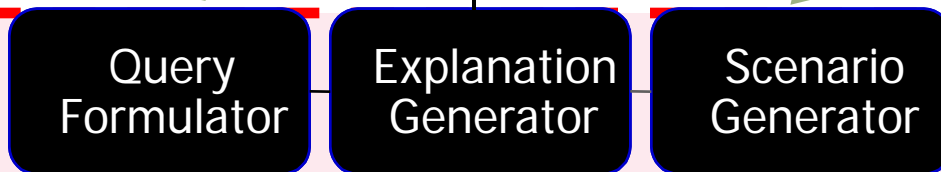
CT Analyst

"Were there any attacks on targets of symbolic value to Muslims since 1987 on a Christian holy day?"

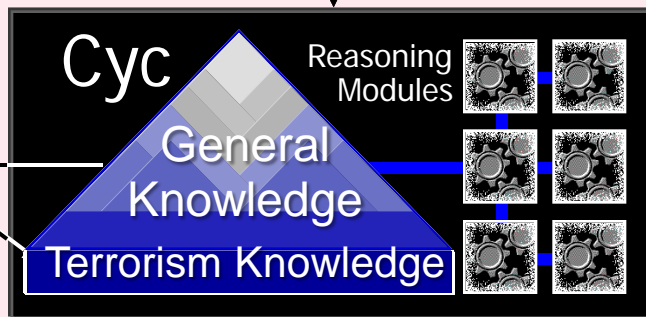
"What sequences of events could lead to the destruction of the Hoover Dam?"



Domain Experts



Cycorp Tools For:
-Ontology-Building,
-Browsing, -Editing,
& Fact/Rule Entry

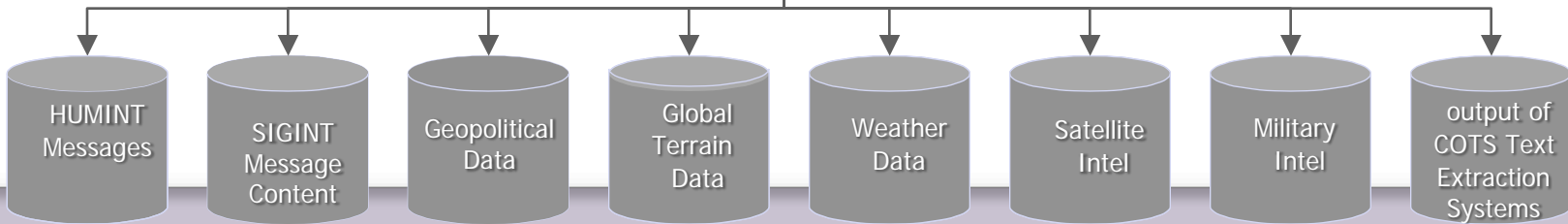


Others'/GOTS
Analysis and
Collaboration
Components

AKB

Interface to Data Repositories

OWL &
Relational DB
"projection"
of the AKB



The Analyst's Knowledge Base

CT Analyst

"Were there any attacks on targets of symbolic value to Muslims since 1987 on a Christian holy day?"

"What sequences of events could lead to the destruction of the Hoover Dam?"



Domain Experts



Query Formulator

Explanation Generator

Scenario Generator

Painful lesson about understanding the user's *ad hoc* English query:

- Understand fragments of it,
- Confirm those (optional), and then
- Semantically fit those pieces together

Cycorp T
Ontology
-Browsing
& Fact/R

COTS
and
ion
nts

OWL &
Relational DB
"projection"
of the AKB

HUMINT
Messages

SIGINT
Message
Content

Geopolitical
Data

Global
Terrain
Data

Weather
Data

Satellite
Intel

Military
Intel

output of
COTS Text
Extraction
Systems

The Analyst's Knowledge Base

Painful lesson about aligning to third-party ontologies and data bases:

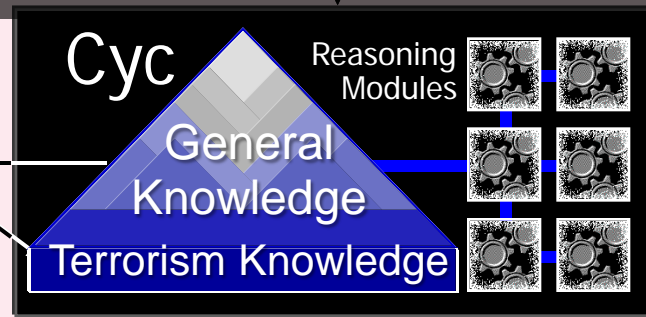
- “more-or-less-the-same-term” is not enough
- Explicit rule for each schema element, each “entry code”, and each database polymorphism
- Metarules about DBs to help plan the querying

Domain Experts



“Were
target
to M
a C

Cycorp Tools For:
-Ontology-Building,
-Browsing, -Editing,
& Fact/Rule Entry



Others'/GOTS
Analysis and
Collaboration
Components

I A K B

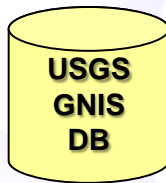
Interface to Data Repositories

OWL &
Relational DB
“projection”
of the AKB



- the **population** field of the GNIS table contains the number of inhabitants of the city that that row is “about”

(fieldDecoding (LogicalSchemaFn Usgs-Gnis) ?x
(TheFieldCalled “**population**”)
(**numberOfInhabitants**
(TheReferentOfTheRow Usgs-Gnis) ?x))



The Geographic Names Information System (GNIS)
DB maintained by the *US Geological Survey* (USGS).

- metalevel statistics on that DB to help plan queries

E.g., these were asserted into the (MappingMtFn Usgs-KS) context:

```
(resultSetCardinality Usgs-Gnis-PS
  (TheSet (PhysicalFieldFn Usgs-Gnis-PS "state"))) TheEmptySet
60.0)
```

```
(resultSetCardinality Usgs-Gnis-PS
  (TheSet
    (PhysicalFieldFn Usgs-Gnis-PS "primary_long")
    (PhysicalFieldFn Usgs-Gnis-PS "primary_lat")
    (PhysicalFieldFn Usgs-Gnis-PS "name")))
  (TheSet
    (PhysicalFieldFn Usgs-Gnis-PS "county")
    (PhysicalFieldFn Usgs-Gnis-PS "state")))
530.36)
```

The Analyst's Knowledge Base

Painful lesson about aligning to third-party ontologies and data bases:

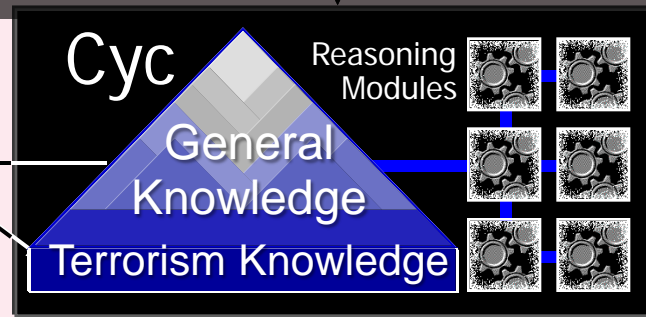
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Domain Experts



“Were
target
to M
a C

Cycorp Tools For:
Ontology-Building,
-Browsing, -Editing,
& Fact/Rule Entry



Others'/GOTS
Analysis and
Collaboration
Components

IAKB

Interface to Data Repositories

OWL &
Relational DB
“projection”
of the AKB

HUMINT
Messages

SIGINT
Message
Content

Geopolitical
Data

Global
Terrain
Data

Weather
Data

Satellite
Intel

Military
Intel

output of
COTS Text
Extraction
Systems

“What major US cities are particularly vulnerable to an anthrax attack now?”

“major US city” \Leftrightarrow U.S. City with $>1M$ population

“particularly vulnerable to an anthrax attack”

\Leftrightarrow

- the current ambient temperature at ?C is above freezing, and
- ?C has more than 100 people for each hospital bed, and
- the number of anthrax host animals near ?C $> 100k$

Cyc knows that pullets are chickens, so don't add those two numbers together!

Cyc AKB: Design

- Basic design: An extension of Cyc's ontology, KB, and HL reasoners
- Held 3 workshops to elicit terrorism experts' consensus on:
 - * Questions (templates and fragments) that often come up
 - * What an ideal relational DB schema would be (for indivs, groups, events)
- Use a logic of contexts (Cyc Microtheories) to distinguish and correctly combine information from multiple sources (written at different times, levels of granularity, cultural ideology...)
 - * E.g., the user might want the AKB to answer a query...
 - ...using only US-intell-vetted data repositories available in Aug. 2001
 - ...including all wire service sources except radical Arab news sources
 - ...using only sources which the CIA believes that HAMAS trusts

Cyc AKB: Construction

- Construct Analysts' Knowledge Base (AKB) by extending Cyc
- Extend the ontology (based on the experts' "dream DB schema")
[note that this and the other steps go on in parallel]
- Manually "prime the pump": add specific assertions in CycL
- Develop a structured interface for non-Cyclists to use, and have them (e.g., poli sci students) manually enter much more
- Find ways to (semi-)automatically slurp mass quantities more
 - by "fishing" unstructured text sources
 - by SKSI (semantic knowl. source integration) maps to DBs
- Develop a structured interface for end users

Thing

Intangible Individual
Thing

General Knowledge about Terrorism:

Terrorist groups are capable of directing assassinations:

(implies

(isa ?GROUP TerroristGroup)

(behaviorCapable ?GROUP AssassinatingSomeone directingAgent))

...

If a terrorist group considers an agent an enemy, that agent is vulnerable to an attack by that group:

(implies

(and

(isa ?GROUP TerroristGroup)

(considersAsEnemy ?GROUP ?TARGET))

(vulnerableTo ?GROUP ?TARGET TerroristAttack))

Earth &
Solar System

Buildings
Weapons

& Electrical
Devices

Literature
Works of Art

Language

Relations,
Culture

Social
Activities

Transportation
& Logistics

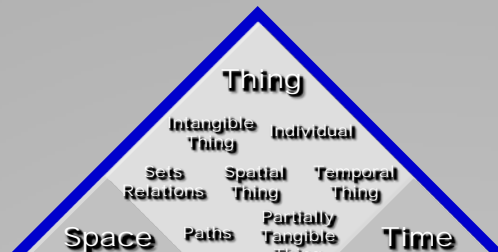
Travel
Communication

Everyday
Living

Military
Organizations

General Knowledge about Terrorism

**Specific data, facts, and observations
about terrorist groups and activities**



Specific Facts about Al Qaida:

(basedInRegion AlQaida Afghanistan) Al-Qaida is based in Afghanistan.

(hasBeliefSystems AlQaida IslamicFundamentalistBeliefs) Al-Qaida has Islamic fundamentalist beliefs.

(hasLeaders AlQaida OsamaBinLaden) Al-Qaida is led by Osama bin Laden.

...

(affiliatedWith AlQaida AlQudsMosqueOrganization) Al-Qaida is affiliated with the Al Quds Mosque.

(affiliatedWith AlQaida SudaneseIntelligenceService) Al-Qaida is affiliated with the Sudanese Intell Service

...

(sponsors AlQaida HarakatUIAnsar) Al-Qaida sponsors Harakat ul-Ansar.

(sponsors AlQaida LaskarJihad) Al-Qaida sponsors Laskar Jihad.

...

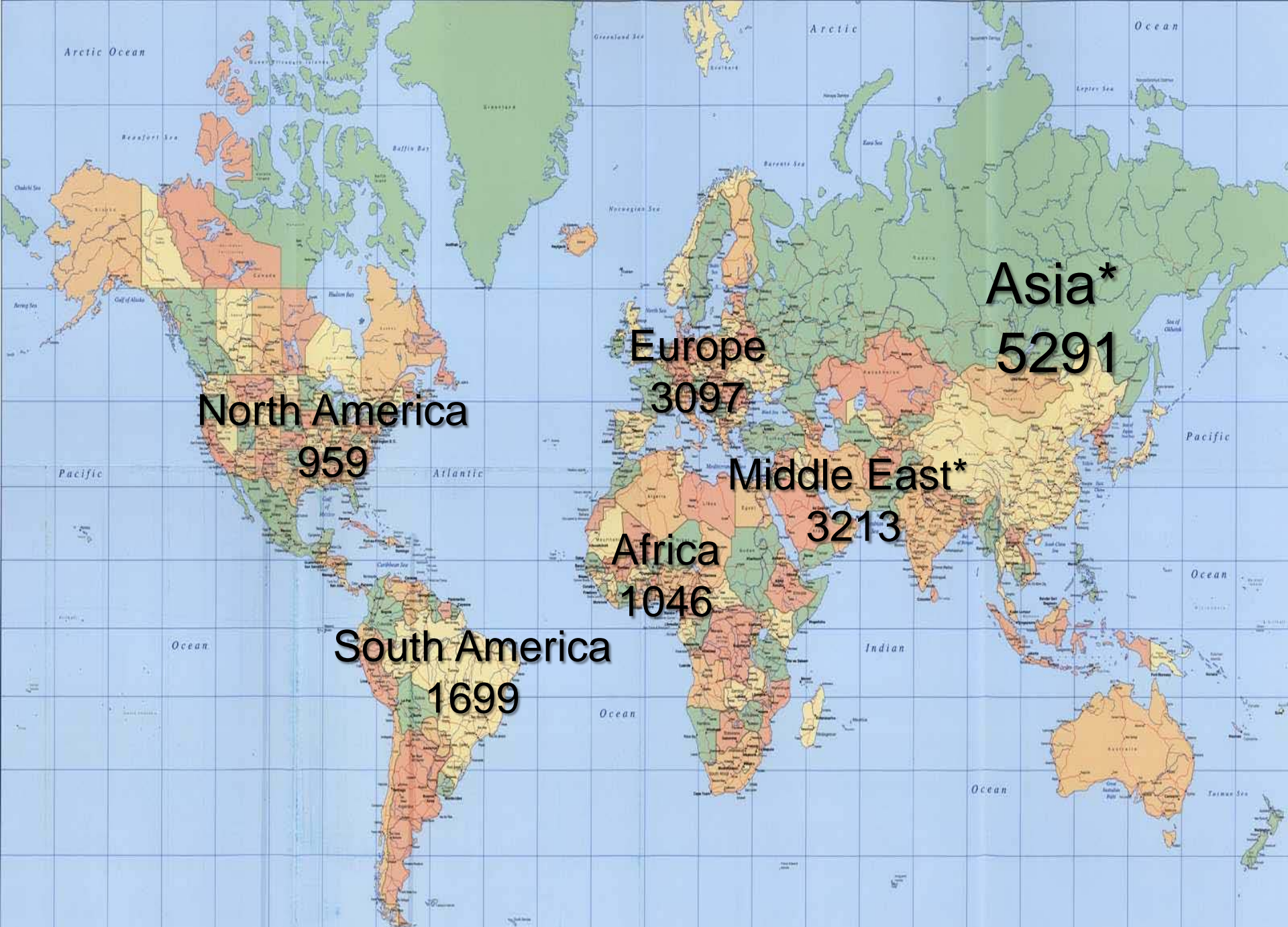
(performedBy EmbassyBombingInNairobi AlQaida) Al-Qaida bombed the Embassy in Nairobi.

(performedBy EmbassyBombingInTanzania AlQaida) Al-Qaida bombed the Embassy in Tanzania.

General Knowledge about Terrorism



Specific data, facts, and observations about terrorist groups and activities



North America
959

South America
1699

Europe
3097

Africa
1046

Middle East*
3213

Asia*
5291

* Middle East totals included in Asia totals

Attack type percent by Levant Country

Lebanon

- Armed attack: 22%
- Bombing (non-suicide): 15%
- Kidnapping: 12 %
- Assassination/Murder: 6.5%
- Suicide bombing: 3%
- Grenade attack: 2.1%

Israel

- Armed attack: 38%
- Suicide bombing: 15%
- Bombing (non-suicide): 13%
- Missile attack: 6%
- Assassination/murder: 6%
- Mortar attack: 1.8%
- Kidnapping: 1.7%

West Bank and Gaza

- Armed attack: 81%
- Bombing (non-suicide): 45%
- Suicide bombing: 15%
- Murder/Assassination: 7.5%
- Ambushes: 4.4%
- Mortar attack: 3.5%
- Missile attack: 3.0%

Syria

- Armed attack: 50%
- Mortar attack: 30%
- Missile attack: 30%
- Ambushes: 17%
- Bombing (all): 18%
- Assassination/murder: 6%

Jordan

- Armed attack: 36%
- Bombing (all): 13%
- Assassination/murder: 10%
- Ambushes: 4%
- Arson: 4%
- Kidnapping: 3%

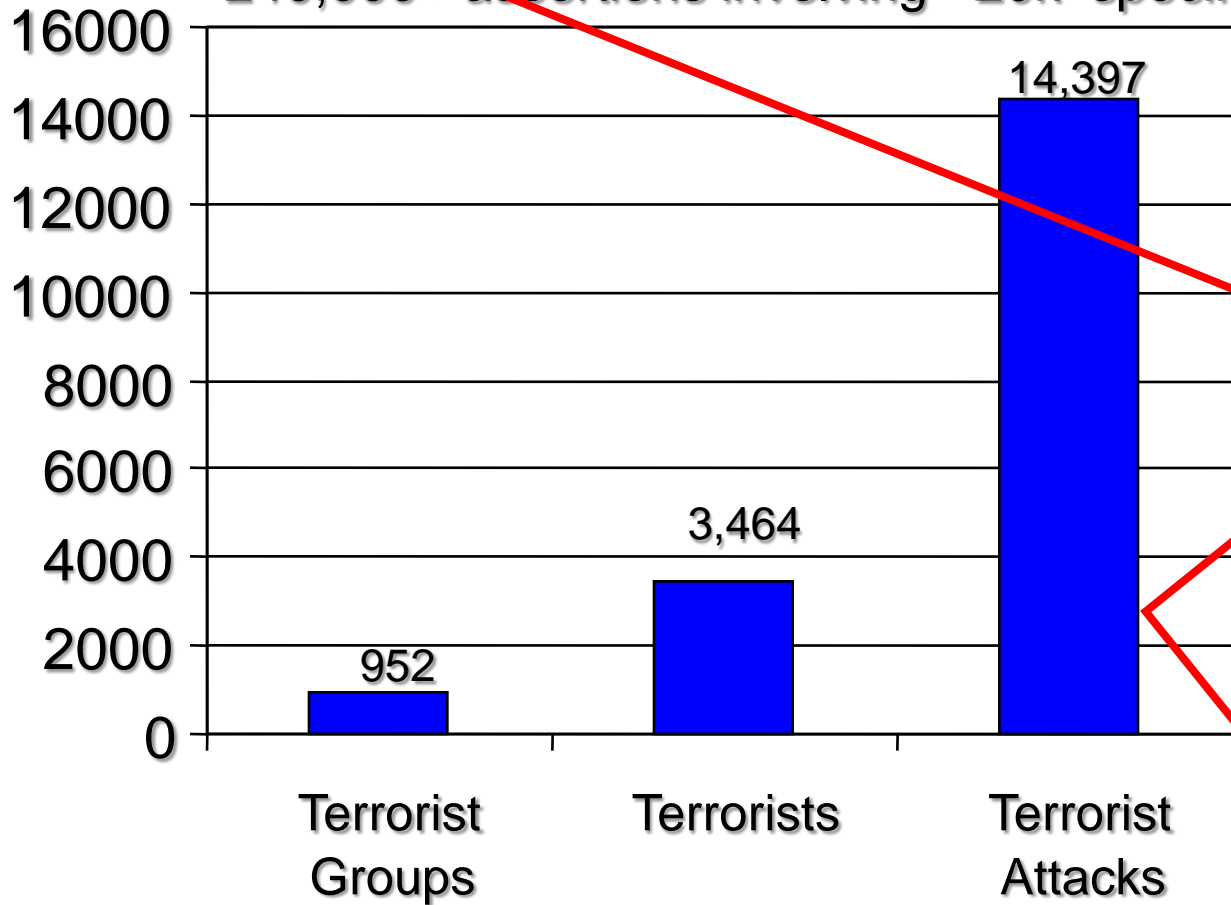


West Bank
Gaza Strip
Israel

AKB Entities

Some of the Terrorism Entities in the AKB

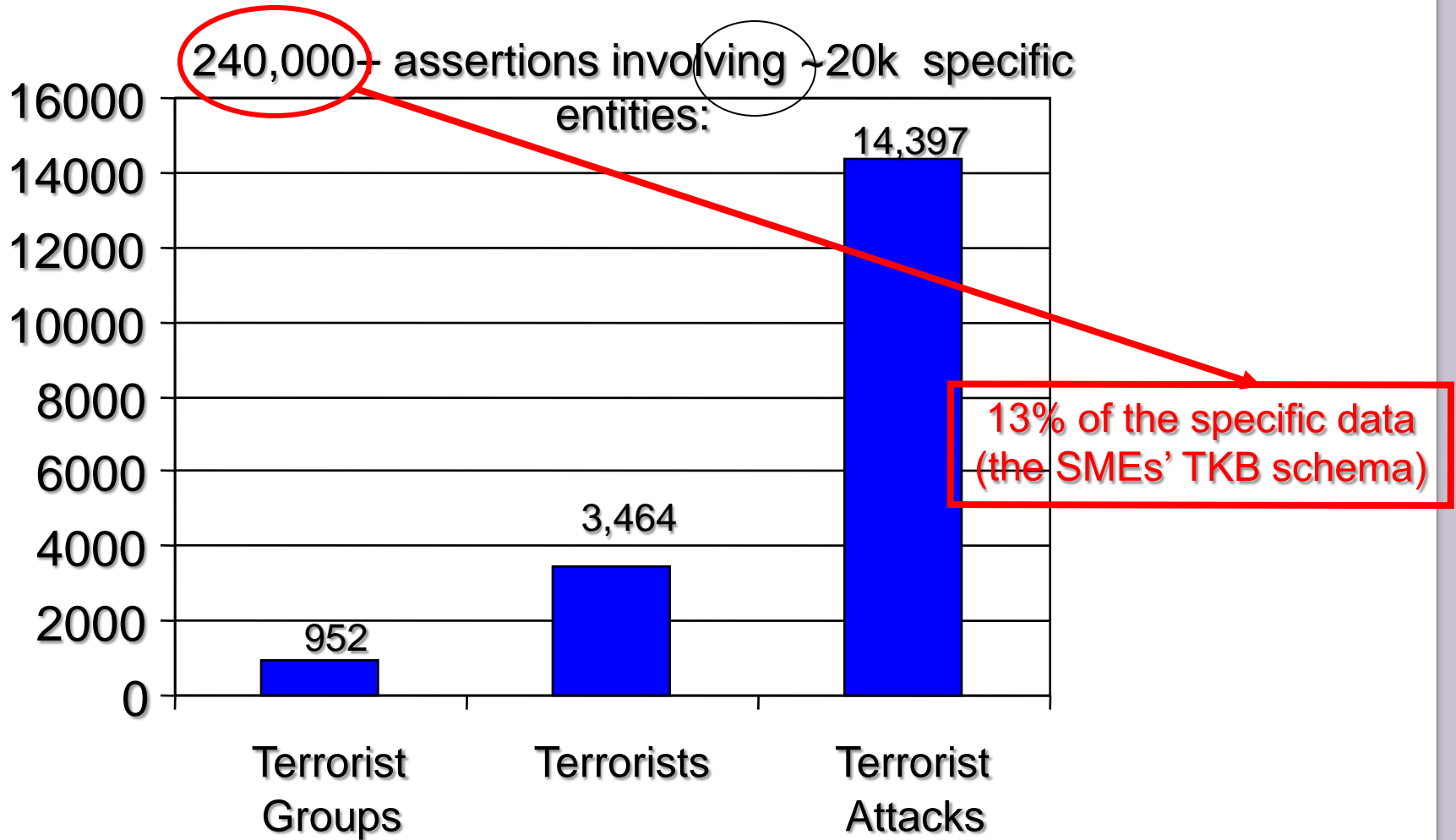
240,000+ assertions involving ~20k specific entities:



(Not counting related concepts such as:
Pipe bomb, Embassy,
Collaborator,
Types of victims/targets
Specific victims,...

AKB Entities

Some of the Terrorism Entities in the AKB



The FET (Fact Entry Tool) Enables SMEs to Represent CT Knowledge and Terrorism Facts

“According to the website ‘Inside Terrorism’, the ANVC’s headquarters has been in Garo Hills, India, since sometime in December, 1995. ”

```
(thereExists ?TIME
  (and
    (temporallySubsumes (DateFn 12/1995) ?TIME)
    (ist
      (MtSpace
        (ContextOfPCWFn WebSite-Inside-Terrorism)
        (MtTimeWithGranularityDimFn
          (TimeIntervalInclusiveFn ?TIME Today-Indexical TimePoint)))
      (residenceOfOrganization ANVC GaroHillsIndia))))))
```

“According to the website ‘Inside Terrorism’, the ANVC’s headquarters has been in Garo Hills, India, since sometime in December, 1995.”



Find Terror Organization Achik National Volunteer Council

	Description		Fact
	Organization's headquarters:		Garo Hills, India
	<i>When:</i>		from sometime in December, 1995 to today
	Performs this kind of attack:		kidnapping
	<i>Against this kind of target:</i>		
	<i>In this location:</i>		
	<i>When:</i>		
	Other criminal activity:		
	<i>In location:</i>		
	<i>When:</i>		

“According to the website ‘Inside Terrorism’, the ANVC’s headquarters has been in Garo Hills, India, since sometime in December, 1995.”



Find Terror Organization Achik National Volunteer Council

	Description		Fact
	Organization's headquarters:		Garo Hills, India
	<i>When:</i>		from sometime in December, 1995 to today
	Performs this kind of attack:		kidnapping
	<i>Against this kind of target:</i>		public official
	<i>In this location:</i>		India
	<i>When:</i>		from sometime in the late part of 1995 to today
	Other criminal activity:		money laundering
	<i>In location:</i>		India
	<i>When:</i>		late 1995 to early 2003

“According to the website ‘Inside Terrorism’, the ANVC’s headquarters has been in Garo Hills, India, since sometime in December, 1995.”



Find Terror Organization Achik National Volunteer Council

	Description		Fact
	Organization's headquarters:		Garo Hills, India
	<i>When:</i>		from sometime in December, 1995 to today
	Performs this kind of attack:		kidnapping
	<i>Against this kind of target:</i>		public official
	<i>In this location:</i>		India
	<i>When:</i>		from sometime in the late part of 1995 to today
	Other criminal activity:		money laundering
	<i>In location:</i>		India
	<i>When:</i>		late 1995 to early 2003

14,600 other target types



“According to the website ‘Inside Terrorism’, the ANVC’s headquarters has been in Garo Hills, India, since sometime in December, 1995.”



Find Terror Organization Achik National Volunteer Council

	Description		Fact
	Organization's headquarters:		Garo Hills, India
	<i>When:</i>		from sometime in December, 1995 to today
	Performs this kind of attack:		kidnapping
	<i>Against this kind of target:</i>		public official
	<i>In this location:</i>		India
	<i>When:</i>		from sometime in the late part of 1995 to ...
	Other criminal activity:		money laundering
	<i>In location:</i>		India
	<i>When:</i>		late 1995 to early 2003

7,763 other action types

“According to the website ‘Inside Terrorism’, the ANVC’s headquarters has been in Garo Hills, India, since sometime in December, 1995.”



Find Terror Organization Achik National Volunteer Council

Description	Fact
Organization's headquarters:	Garo Hills, India
<i>When:</i>	from sometime in December, 1995 to today
Performs this kind of attack:	kidnapping
<i>Against this kind of target:</i>	public official
<i>In this location:</i>	India
<i>When:</i>	from sometime in the late part of 1995 to
Other criminal activity:	money laundering
<i>In location:</i>	India
<i>When:</i>	late 1995 to early 2003

Indefinitely many precise or vague time expressions

Even simple queries require 3-4 reasoning steps

“In what countries bordering Pakistan are there members of the ANVC?”

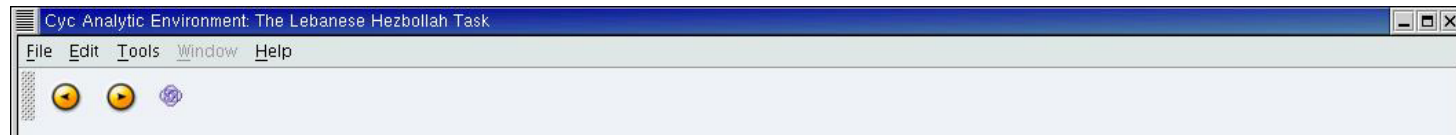
The screenshot displays the Cyc Analytic Environment interface for the task "The Lebanese Hezbollah Task". The main window shows a query: "What values of *COUNTRY* are there such that". Below the query, four logical constraints are listed:

- * *COUNTRY* is a country,
- * and some other agent *MEMBER* is a member of [Achik National Volunteer Council](#),
- * and *MEMBER* is located in *COUNTRY*,
- * and Pakistan borders on *COUNTRY*?

Below the query, there are buttons for "Ask", "Save", "Stop", and a checkbox for "Allow Speculation?". The interface also features a "Task Info" and "Concepts" tab, a "Results" pane on the left, and a "Monitoring" pane at the bottom. The status bar at the bottom indicates "Status: Idle" and "Message:".

Even simple queries require 3-4 reasoning steps

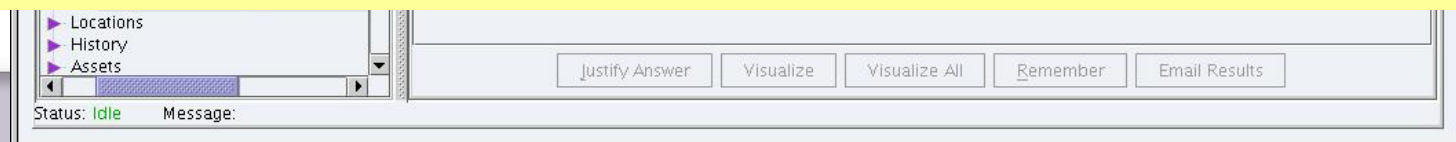
“In what countries bordering Pakistan are there members of the ANVC?”



Each answer that CAE finds for this generally involves a 1-4-step (not 0-step) argument (reasoning chain):

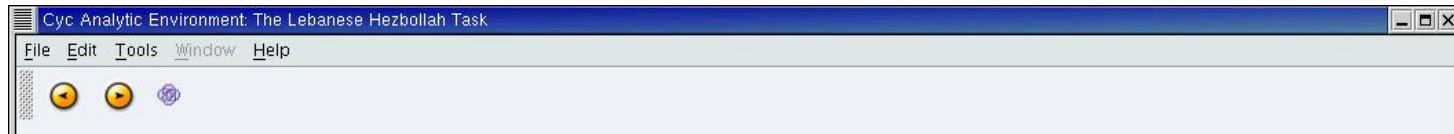
E.g., for the answer “India”, the justification is:

- According to the web site ‘Inside Terrorism’, the ANVC’s headquarters has been in Garo Hills, India from the beginning of January, 1996 through today.
- If an organization’s HQ is in place x, then there are members of that organization in place x.
- If someone is in place x, they are in every super-region of x.
- India borders Pakistan



Even simple queries require 3-4 reasoning steps

“In what countries bordering Pakistan are there members of the ANVC?”

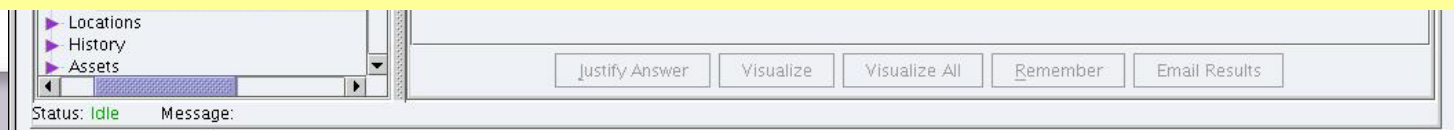


Each answer that CAE finds for this generally involves a 1-4-step (not 0-step) argument (reasoning chain):

E.g., for the answer “India”, the justification is:

- According to the web site ‘Inside Terrorism’, the ANVC’s headquarters has been in Garo Hills, India from the beginning of January, 1996 through today.
- ~~• If an organization’s HQ is in place x, then there are members of that organization in place x.~~
- ~~• If someone is in place x, they are in every super-region of x~~
- ~~• India borders Pakistan.~~

Don't include Prior & Tacit Knowledge



Even simple queries require 3-4 reasoning steps

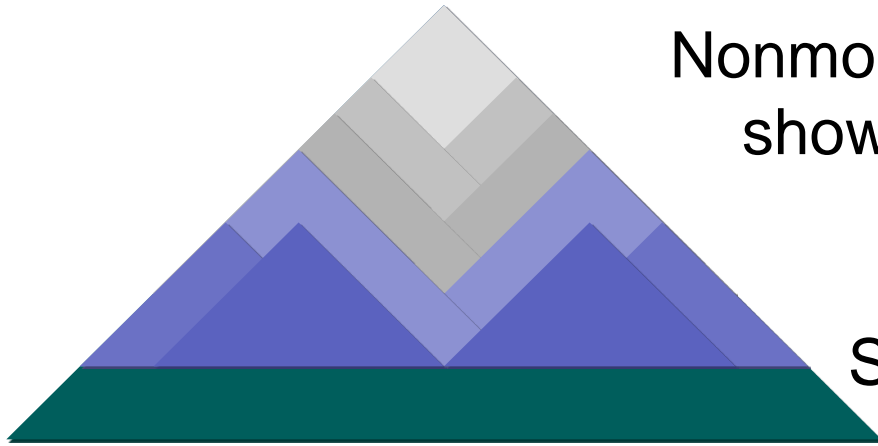
“Terrorist events with no civilian casualties?”

“Terrorist events with only American casualties?”

Source 1: Khobar Towers bombing had a total of 17 casualties.

Source 2: 17 U.S. soldiers killed in Khobar Towers bombing.

Even though they are expressed in formal logic,
most axioms state *usuals*, not absolute truths.



Nonmonotonic (later information can
show that something you earlier
believed is false after all).

So the reasoning is default.

Argumentation: Gather up all the pro- and con-
arguments, and compare them. Check: for each *con*
argument, is there a *pro* argument which is preferred?

To conclude *preferred*(A1,A2): Prefer short arguments to long ones;
recent ones to stale ones; expert ones to novice ones; constructive
ones to nonconstructive ones; formal ones to informal ones; etc.

What factors argue <for/against> the conclusion that <ETA> <performed> <the March 2004 Madrid attacks>?

For:

- ETA often executes attacks near national election
- ETA has performed multi-target coordinated attacks
- Over the past 30 years, ETA performed 75% of all terrorist attacks in Spain
- Over the past 30 years, 98% of all terrorist attacks in Spain were performed by Spain-based groups, and ETA is a Spain-based group.

Against:

- ETA warns (a few minutes ahead of time) of attacks that would result in a high number civilian casualties, to prevent them. There was no such warning prior to this attack.
- ETA generally takes responsibility for its attacks, and it did not do so this time.
- ETA has never been known to falsely deny responsibility for an attack, and it did deny responsibility for this attack.

- Collaboration with the Cleveland Clinic; initial domains are cardiothoracic surgery, echocardiography, cath, infectious disease,...
- Task: Originally: identify potential trial participants for cohort studies by querying patient info. Once it worked: Generate external outcomes reports; interlingua enabling less repetitive interdepartmental patient data entry system
- Main motivation: Query formation/asking cycle is 1 month
- Challenges:
 - Data from disparate sources must be combined
 - Doctors unfamiliar with underlying data schemata and with forming logic-based queries
 - Their typical query is 50-250 words long

CAE App: Medical Cohort Planning

Identify a patient population (a cohort) for a clinical trial

- FIND all native aortic valve replacements performed at CCF between January 1, 2000 and December 31, 2004 with a pre-operative diagnosis, as determined by echocardiogram, of moderately severe or severe aortic stenosis and moderate to severe left ventricular impairment.
- INCLUDE operations in which concomitant primary CABG or concomitant mitral or tricuspid valve repair was performed.
- EXCLUDE all patients with any prior valve repair or replacement; or with concomitant pulmonary valve repair; or with concomitant mitral, tricuspid, or pulmonary valve replacement; or with aortic regurgitation greater than moderate degree.

Typical Query for outcomes study

56,000 more examples: www.clinicaltrials.gov



Typed-in Query

Partially parse

Understood Fragments

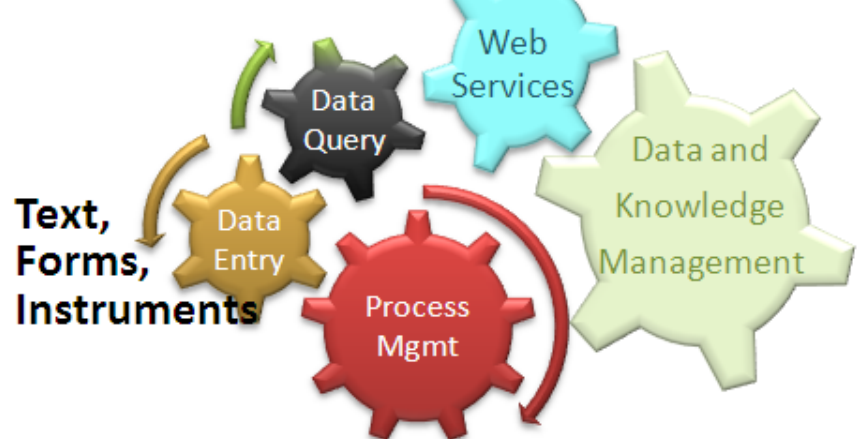
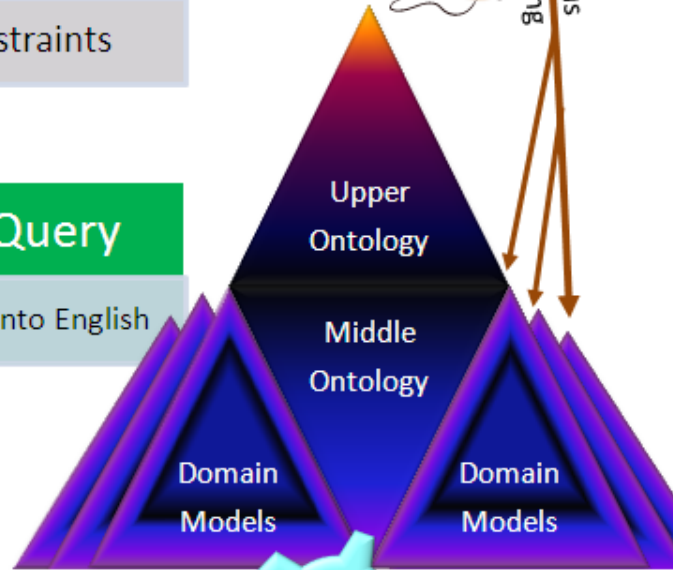
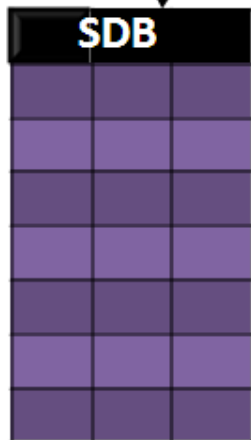
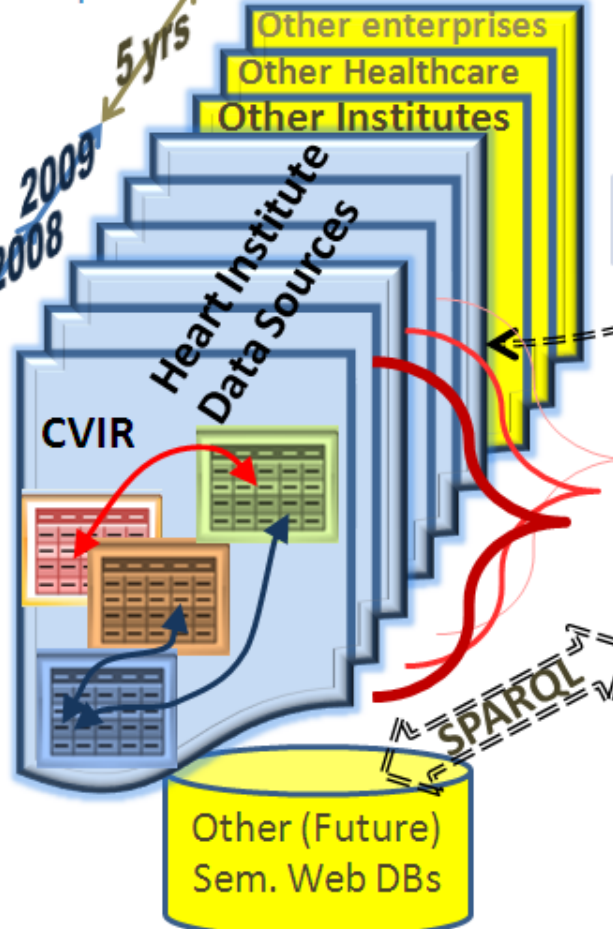
Apply domain & commonsense constraints

Combined into a Logical Query

Diagram temporal relns. Paraphrase into English



- Augment
- Manage
- Replace



SQL

SPARQL

SPARQL

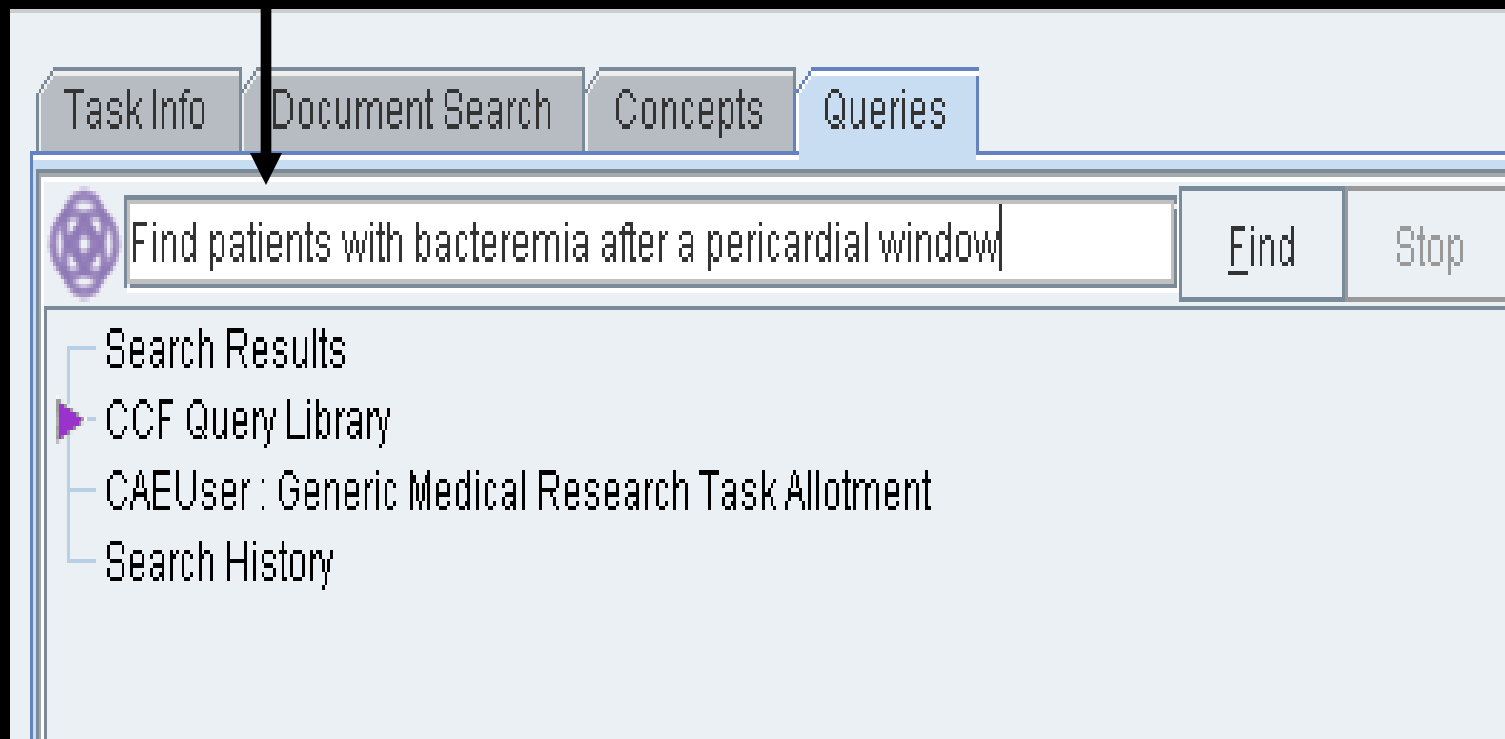
patients who had bacteremia after a pericardial window

- ▼ Search Results
 - ▼ patients who had bacteremia after a pericardial window
 - ▼ Simple Fragments
 - _____ is a case of bacteremia.
 - _____ is a pericardial window.
 - The patient ID for _____ is _____.
 - _____ contains information pertaining to _____.
 - _____ is a surgical procedure performed during _____.
 - _____ is before _____.
 - ▶ Temporal Questions
 - ▶ Keyword Search
 - ▼ CCF Query Library
 - ▼ CCF Query Fragments
 - ▶ helper fragments
 - ▼ Patient
 - The patient ID for ?PATIENT is ?ID.
 - ?PATIENT is the patient involved in ?MEDICALLY-RELATED-EVENT.
 - ▶ Encounter
 - ▶ Evaluation
 - ▶ Management
 - ▶ Morbidity
 - ▶ Dismissal List properties
 - ▶ CAEUser : Generic Medical Research Task Allotment
 - Search History

- Users will want to type unrestricted English queries.
 - Let them, but then partially parse the queries into fragments
 - The users say yes/no for the fragments (lesson: minimize the number of fragments presented, BUT it's worth guessing at "combines")
 - Use domain knowledge, general common sense knowledge, and models of the user and the user's context (and discourse pragmatics) to semantically combine those fragments into a meaningful utterance
- Users often err when writing spatiotemporal constraints
 - Palette of objects/events they can drag around and graphically arrange into a configuration; i.e., 2D space (vs. 1D text) repr. 3D space + time

Lessons from that application

Simple English sentences are typed into the query search box



Simple English sentences are typed into the query search box

The screenshot shows a software interface with tabs for 'Task Info', 'Document Search', 'Concepts', and 'Queries'. The 'Queries' tab is active, and a search box contains the text 'Find patients with bacteremia after a pericardial window'. To the right of the search box are 'Find' and 'Stop' buttons. Below the search box, a tree view shows the search results. The tree is expanded to show 'Simple Questions' under the main query. A list of seven simple questions is displayed, each with a vertical line to its left. A black arrow points from the bottom of the tree to the first question. The questions are:

- The patient ID for PATIENT is _____.
- PATIENT is the patient involved in _____ and PATIENT is the patient involved in _____.
- PATIENT is the patient involved in _____ and _____ is a pericardial window.
- _____ is a case of bacteremia.
- _____ involves the infection : bacteremia.
- _____ is after _____.
- PATIENT is the patient involved in _____ and _____ is a surgical procedure performed during _____.
- _____ contains information pertaining to _____.

Other items in the tree view include 'Keyword Search', 'CCF Query Library', 'CAEUser : Generic Medical Research Task Allotment', and 'Search History'.

The system extracts entities, concepts, and relations from the text and instantiates them according to rules and constraints (argument types, disjointness, containment, inter-arg constraints, etc.) placed on the concepts and relations

Examples of Cyc knowledge used

Ex. 1.: Whenever the doctor mentions a surgical procedure, suggest that they may want a fragment about the patient and the patient's ID (this is often a "column" in the final table of answers they are seeking.)

Ex. 2.: Whenever the doctor mentions an infectious organism, suggest that they may want a fragment about cases where patients have contracted that type of infection.

In CCFOntologyMt:

```
(generateFormulasForElements-Termlsa  
  CCFInfectionPathogenType  
  (TheSet infectionCausedByOrganismType))
```

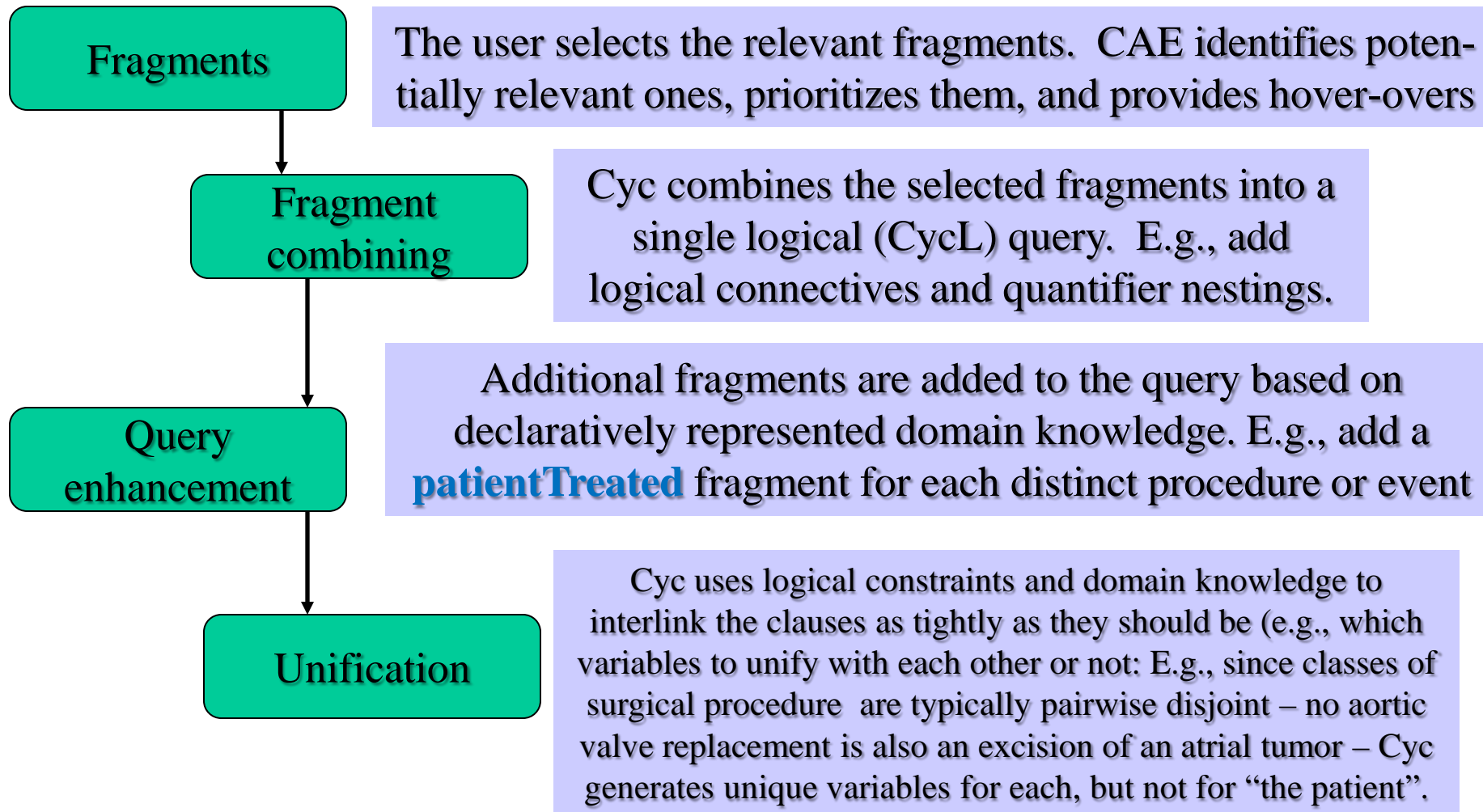
Cyc believes it to be appropriate to generate a formula for **infectionCausedByOrganismType** whenever an instance of **CCFInfectionPathogenType** is a member of the valid term set.

The user selects the relevant query fragments

The screenshot shows a software interface with tabs for 'Task Info', 'Document Search', 'Concepts', and 'Queries'. The 'Queries' tab is active, displaying a search query: 'Find patients with bacteremia after a pericardial window'. Below the query is a 'Find' button and a 'Stop' button. The search results are expanded to show 'Simple Questions' with several fragments highlighted in yellow. A context menu is open over the highlighted text, with options: 'Copy Query Text', 'Open', 'Delete', and 'Combine selected queries'. The 'Combine selected queries' option is highlighted in yellow. The interface also includes a 'Search Results' tree on the left with items like 'CCF Query Library', 'CAEUser: Generic Medical Research', and 'Search History'.

Cyc then automatically combines - as best it can - all the fragments into a single meaningful logical (CycL) query

Combining the selected fragments into a full query (in HOL – namely, CycL)



Examples of Cyc knowledge used

1784 pieces of pre-existing (prior to this project) Cyc KB knowledge used while handling a typical query. E.g.:

Inferred Disjointness constraints:

(disjointWith PericardialWindow-SurgicalProcedure MedicalPatient)

Justification: [we are “counting” each of these assertions, in the total:]

(gens PericardialWindow-SurgicalProcedure PericardialProcedure-Surgical) in UniversalVocabularyMt

(gens PericardialProcedure-Surgical CardiacProcedure-Surgical) in UniversalVocabularyMt

(gens CardiacProcedure-Surgical SurgicalProcedure) in UniversalVocabularyMt

(gens SurgicalProcedure MedicalCareEvent) in BaseKB

(gens MedicalCareEvent PhysicalSituation) in BaseKB

(gens PhysicalSituation Situation-Localized) in UniversalVocabularyMt

(gens Situation-Localized Situation) in UniversalVocabularyMt

(disjointWith SpatialThing-NonSituational Situation) in BaseKB

(gens EnduringThing-Localized SpatialThing-NonSituational) in UniversalVocabularyMt

(gens Agent-NonGeographical EnduringThing-Localized) in UniversalVocabularyMt

(gens EmbodiedAgent Agent-NonGeographical) in UniversalVocabularyMt

(gens PerceptualAgent-Embodied EmbodiedAgent) in UniversalVocabularyMt

(gens Animal PerceptualAgent-Embodied) in UniversalVocabularyMt

(gens MedicalPatient Animal) in UniversalVocabularyMt

The full query now appears in the query construction screen. This is the English paraphrase of the underlying CycL query that has been built up.

Task Info Document Search Concepts Queries

- Give the values of *BLOODSTREAM-INFECTION*, *ID* and *PERICARDIAL-PROCEDURE* such that:
 - All of the following are true
 - The patient ID for *PATIENT* is *ID*.
 - PERICARDIAL-PROCEDURE* is a pericardial window.
 - PATIENT* is the patient involved in *PERICARDIAL-PROCEDURE*.
 - BLOODSTREAM-INFECTION* is a case of bacteremia.
 - PATIENT* is the patient involved in *BLOODSTREAM-INFECTION*.

Save
New Tab
Stop

Palette

BLOODSTREAM-INF...
PERICARDIAL-PRO...

Context: always Edit...

Results: All Time limit: 600

More...

Answers

Bloodstream infection	Id	Pericardial procedure

Justify Fact Sheet Visualize Visualize All



Task Info Document Search Concepts Queries

- Give the values of *BLOODSTREAM-INFECTION*, *ID* and *PERICARDIAL-PROCEDURE* such that:
- All of the following are true
 - The patient ID for *PATIENT* is *ID*.
 - PERICARDIAL-PROCEDURE* is a pericardial window.
 - PATIENT* is the patient involved in *PERICARDIAL-PROCEDURE*.
 - BLOODSTREAM-INFECTION* is a case of bacteremia.
 - PATIENT* is the patient involved in *BLOODSTREAM-INFECTION*.

Ask

Save

New Tab

Stop

Palette

- BLOODSTREAM-INF...
- PERICARDIAL-PRO...

Context: always Edit...

Results: All Time limit: 600

More...

Answers

Bloodstream infection	Id	Pericardial procedure
<div> <p>Terms that can be temporally qualified are referenced here.</p> </div>		

Justify Fact Sheet Visualize Visualize All



Task Info [X] Document Search [X] Concepts [X] Queries [X]

- Give the values of *BLOODSTREAM-INFECTION*, *ID* and *PERICARDIAL-PROCEDURE* such that:
- All of the following are true
 - The patient ID for *PATIENT* is *ID*.
 - PERICARDIAL-PROCEDURE* is a pericardial window.
 - PATIENT* is the patient involved in *PERICARDIAL-PROCEDURE*.
 - BLOODSTREAM-INFECTION* is a case of bacteremia.
 - PATIENT* is the patient involved in *BLOODSTREAM-INFECTION*.

Ask

Save

New Tab

Stop

Palette

- BLOODSTREAM-INF...
- PERICARDIAL-PRO...

BLOODSTREAM-INF...

Context: always Edit...

Results: All Time limit: 600

More...

Answers

Bloodstream infection	Id	Pericardial procedure
<div><p>The user can drag and drop these to form sequences</p></div>		

Justify Fact Sheet Visualize Visualize All



Task Info Document Search Concepts Queries

- Give the values of *BLOODSTREAM-INFECTION*, *ID* and *PERICARDIAL-PROCEDURE* such that:
 - All of the following are true
 - The patient ID for *PATIENT* is *ID*.
 - PERICARDIAL-PROCEDURE* is a pericardial window.
 - PATIENT* is the patient involved in *PERICARDIAL-PROCEDURE*.
 - BLOODSTREAM-INFECTION* is a case of bacteremia.
 - PATIENT* is the patient involved in *BLOODSTREAM-INFECTION*.
 - PERICARDIAL-PROCEDURE* is before *BLOODSTREAM-INFECTION*.

Ask
Save
New Tab
Stop

Palette

- BLOODSTREAM-INF...
- PERICARDIAL-PRO...



Context: always Edit...

Results: All Time limit: 600

More...

Answers

Bloodstream infection	Id	Pericardial procedure

Here the user has specified that the pericardial procedure is before the infection



Task Info Document Search Concepts Queries

- Give the values of *BLOODSTREAM-INFECTION*, *ID* and *PERICARDIAL-PROCEDURE* such that:
 - All of the following are true
 - The patient ID for *PATIENT* is *ID*.
 - PERICARDIAL-PROCEDURE* is a pericardial window.
 - PATIENT* is the patient involved in *PERICARDIAL-PROCEDURE*.
 - BLOODSTREAM-INFECTION* is a case of bacteremia.
 - PATIENT* is the patient involved in *BLOODSTREAM-INFECTION*.
 - PERICARDIAL-PROCEDURE* is before *BLOODSTREAM-INFECTION*.

Ask

Save

New Tab

Stop

Palette

- BLOODSTREAM-INF...
- PERICARDIAL-PRO...

PERICARDIAL-PRO... BLOODSTREAM-INF...

Context: always Edit...

Results: All Time limit: 600

More...

Answers

Bloodstream infection	Id	Pericardial procedure

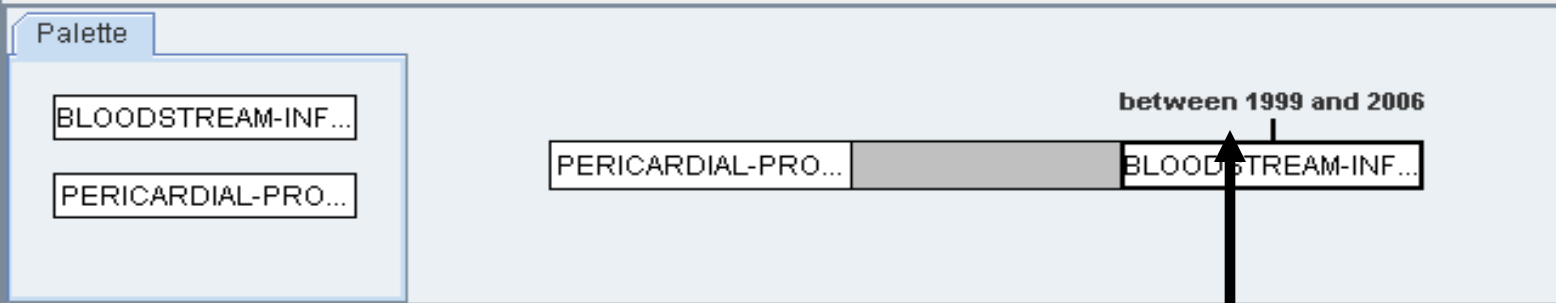
At that point, the constraint is automatically added to the query

Justify Fact Sheet Visualize Visualize All

Give the values of *BLOODSTREAM-INFECTION*, *ID* and *PERICARDIAL-PROCEDURE* such that:

- All of the following are true
 - The patient ID for *PATIENT* is *ID*.
 - PERICARDIAL-PROCEDURE* is a pericardial window.
 - PATIENT* is the patient involved in *PERICARDIAL-PROCEDURE*.
 - BLOODSTREAM-INFECTION* is a case of bacteremia.
 - PATIENT* is the patient involved in *BLOODSTREAM-INFECTION*.
 - PERICARDIAL-PROCEDURE* is before *BLOODSTREAM-INFECTION*.
 - BLOODSTREAM-INFECTION* happened between 1999 and 2006.

Ask
Save
New Tab
Stop



Context: always Edit...

Results: All Time limit: 600

More...

Answers

The user can also specify a range of times that the condition or procedure must occur within.



Task Info Document Search Concepts Queries

- Give the values of *BLOODSTREAM-INFECTION*, *ID* and *PERICARDIAL-PROCEDURE* such that:
 - All of the following are true
 - The patient ID for *PATIENT* is *ID*.
 - PERICARDIAL-PROCEDURE* is a pericardial window.
 - PATIENT* is the patient involved in *PERICARDIAL-PROCEDURE*.
 - BLOODSTREAM-INFECTION* is a case of bacteremia.
 - PATIENT* is the patient involved in *BLOODSTREAM-INFECTION*.
 - PERICARDIAL-PROCEDURE* is before *BLOODSTREAM-INFECTION*.
 - BLOODSTREAM-INFECTION* happened between 1999 and 2006.

Ask

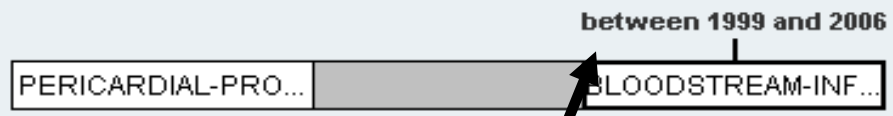
Save

New Tab

Stop

Palette

- BLOODSTREAM-INF...
- PERICARDIAL-PRO...



Context: always Edit...

Results: All Time limit: 600

More...

Answers

Bloodstream infection	Id	Pericardial procedure

Here the user has stated that the infection must have occurred between 1999 and 2006.

Answers (4)

**PATIENT
DATA
REDACTED**

Id	Infection	Pericardial Procedure
	the case of bacteremia of the patient with ID 31077290 on April 24, 2001	the pericardial window of the patient with ID 31077290 starting at 14:38:00, April 17, 2001
	the case of bacteremia of the patient with ID 62034912 on December 10, 2004	the pericardial window of the patient with ID 62034912 starting at 13:40:00, November 9, 2004
	the case of bacteremia of the patient with ID 24472418 on June 23, 1999	the pericardial window of the patient with ID 24472418 starting at 16:05:00, December 30, 1998
	the case of bacteremia of the patient with ID 27843204 on March 23, 1999	the pericardial window of the patient with ID 27843204 starting at 15:28:00, March 23, 1999

Justify

Fact Sheet

Visualize

Visualize All

The answers in each column (except for the already-very-straightforward Patient ID number column) are paraphrased at ~0 cost using information contained in the justification for the query

CycL → SPARQL/SQL

- The user has produced a coherent query, paraphrased to them in English but underlying that is a full formal logic (CycL) query
- It often leads to dozens or hundreds of SPARQL and/or SQL queries (e.g., a single logical term might be indicated in multiple ways in multiple information sources)
- Logical properties of the vocabulary enable various simplifications of the query; i.e., sometimes Cyc can prove that some branches of the query will be unproductive
- The query is ordered according to cardinality and connectedness properties; i.e., Cyc applies metarules to optimize the query (or set of queries), esp. SPARQL ones
- SKSI (Semantic Knowledge Source Integration) modules translate the CycL into strings, URIs, and RDF patterns appropriate for delivery to the SPARQL/SQL service

CycL → SPARQL transformation

Example Query

What patients had a CCF tumor excision during the years 1998 through 2005 ?

(and

(temporallyBetween-Inclusive ?PRO (YearFn 1998) (YearFn 2005))

(isa ?PRO TumorExcision)

(cCFCCFID ?PAT ?ID)

(patientTreated ?PRO ?PAT)

(cCFEventOccursAt ?PRO ClevelandClinicMainCampus))))))

CycL → SPARQL transformation

In transforming the query the system appeals to context-dependent transformation rules, such as these:

```
(implies
  (and
    (rdf-type ?PATIENT MedicalPatient)
    (rdf-type ?PRO ?TYPE)
    (gens ?TYPE CCFThingWithIndirectTemporalData)
    (cCF-contains ?PTREC ?PATIENT)
    (cCF-contains ?PTREC ?EVT)
    (cCF-contains ?EVT ?PRO))
  (patientTreated ?PRO ?PATIENT))
```

```
(implies
  (and
    (gens ?TYPE CCFThingWithIndirectTemporalData)
    (rdf-type ?PRO ?TYPE)
    (cCFEventPlace ?EVT ?LOC)
    (cCF-contains ?EVT ?PRO))
  (cCFEventOccursAt ?PRO ?LOC))
```

```
(implies
  (and
    (rdf-type ?TEMP-DATA CCFEventDate)
    (cCFDateTimeMax ?TEMP-DATA ?MAX)
    (startsAfterStartingOf ?MAX ?EARLY)
    (cCF-contains ?EVT ?TEMP-DATA)
    (cCF-contains ?EVT ?SUB-EVT)
    (rdf-type ?SUB-EVT ?TYPE)
    (gens ?TYPE CCFThingWithIndirectTemporalData)
    (endsAfterEndingOf ?LATE ?MAX))
  (temporallyBetween-Inclusive ?SUB-EVT ?EARLY ?LATE))
```

Even a tiny CCF query requires *thousands* of inferences involving extant (pre-project-start) Cyc assertions

“What patients had bacteremia after a pericardial window?”

Fragments get chosen; most of them have blanks to fill in.

Each blank is converted to a logical *variable*.

Which blanks might/must/mustn't be unified (same variable)?

s is a CCF patient

t had an infection *u* .

v was a bacteremia infection

w had a procedure *x* .

y was a pericardial window

Prior to the CCF project, Cyc's KB had 184 specializations of Medical Care Event:

Medical Care Event

Ablation

Ligation

Coronary Artery Bypass Graft

Biopsy-Surgical Procedure

Trephining Someone

Prostatectomy

Robotic Surgery

Outpatient Surgery

Inpatient Surgery

Liposuction Surgery

Removal Of Unique Body Part

Appendectomy

...

Tonsillectomy

Gum Surgery

Surgical Treatment

Transplant Surgery

Heart Transplant Surgery

General Surgery

Major Surgery

Open Heart Surgery

Root Canal Surgery

Vaccination Event

Booster Vaccination Event

Anthrax Military Vaccination Sc

ript

Medical Testing

...

Prior to the CCF project, Cyc's KB had 350+ specializations of AilmentCondition:

AttentionDeficitDisorder
Glaucoma SpinalStenosis
SleepDeprivation Ache-
AilmentCondition Migraine
Hemorrhaging-TheCondition
Jaundice ParasiticAilment
BacillaryAngiomatosis
Cryptosporidiosis Rickettsiosis
EpidemicTyphus-NAmerica
ArthropodInfestation
ExternalArthropodInfestation
InternalArthropodInfestation
Trichinosis Schistosomiasis
Ascariasis
BladderFlukeInfestation

...

Atherosclerosis
MultiplePersonalityDisorder
Adenomyosis Scabies
AmyotrophicLateralSclerosis
Scoliosis Hypoglycemia
TempromandibularJointSyndr
ome AcetylcholinePoisoning
CadmiumPoisoning
CarbonMonoxidePoisoning
FoodborneBotulism
InhalationalBotulism
WoundBotulism
InfantBotulism Endometriosis
Neuralgia Sciatica
Diverticulitis Gout
MacularDegeneration

...

Prior to the CCF project, Cyc's KB had 200+ specializations of Bacterium:

StreptococcusPneumoniae
StreptococcusPyogenes
Bacillaceae-Family
Bacillus-Genus
BacillusCereus-Species
Monotrichous
Bacterium-Monotrichous
Peritrichous
Bacterium-Peritrichous
Amphitrichous
Bacterium-Amphitrichous
Tenericutes-Division
Mollicutes-Class
Anaeroplasmataceae-Family
...

Asteroplasma-Genus
Acholeplasmatales-Order
Acholeplasmataceae-Family
Acholeplasma-Genus
Phytoplasma-Genus
Eperythrozoon-Genus
Mycoplasmatales-Order
Mycoplasmataceae-Family
Mycoplasma-Genus
MycoplasmaPneumoniae-Species
Spirillales-Order
Vibrionaceae-Family
Vibrio-Genus
VibrioCholerae-Species
...

Prior to the CCF project, Cyc's KB had hundreds of pre-existing relevant relationships

General Role Predicates:

objectActedOn
eventOccursAt
dateOfEvent
objectPlaced
objectRemoved
deviceUsed

...

Medical domain specific relations:

infectionCausedByOrganism
infectingPathogen
patientTreated
deviceTypeTreatsConditionType
causeOfDeathTypeOfType
formOfDisease
ailmentTypeAffects
ailmentEpidemicType
ailmentAcquiredBy
ailmentTypicallyAcquiredBy
indicatedDrug
mortalityRiskForCondition
survivalRate
riskOfInfectionFromTypeToType

...

“Slurp” the CCF ontology into Cyc

- Start with (pre-)existing Cyc medical ontology
- Import CCF specific medical domain ontology
 - OWL files generate new collections and predicates
 - Controlled vocabulary lists generate new (mostly) collections
 - 90% of the import was automated; now over 95%
- Merge the newly created terms onto existing terms when possible and assert mappings (ptrec:Patient maps to pre-existing MedicalPatient)
- Add required **genls**, **isa**, and other basic assertions to integrate the imported ontology into the Cyc ontology

“Slurp” the CCF ontology into Cyc

Establish bridging (translation) rules

- Define rules that allow users to associate patients, dates, locations, etc. with the various events – e.g. define **patientTreated** as a relationship between a medical event and a patient.
- Define rules that allow users to easily express complicated logical conditions – e.g. the defining rules for **PrimarySurgery**, **isolatedProcedureOfType**, **concomitantProcedures**, etc.
- Define concise vocabulary for constructions that are complicated or difficult to express – e.g. “aortic valve replacement” is represented as a single non-atomic term. This allows the user to specify this very common procedure with a single fragment instead of three distinct fragments in the CCF ontology (which in turn came about due to there not being an explicit functional term composition construct in the CCF representation).

Use of Cyc Knowledge

In answering *ad hoc medical* queries
by clinical researchers at CCF

- Converting the NL query → Understood “fragments”
- Combining the selected fragments into a full query
- Converting the query from HOL form (CycL) into one or more SPARQL and/or SQL queries and sending them to the service
-- for efficiency of running the SPARQL/SQL queries, making judicious choices of, e.g., clause ordering
- Parse more complex fragments (esp. temporal ones)
- Persistent queries (triggers/schedules and actions)
- Ontologize new domains and align to new data sources
- Extend downward (patient data entry)
- Extend outward (generate internal and 3rd party external reports)

Task Info Concepts Queries

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

Clear

Find

- patient
- heart valve repair or replacement
- 30 days
- history and physical exam
- diagnosing
- cardiac valve endocarditis

Search Results

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

Terms

Simple Fragments

- _____ is before _____.
- _____ is less than _____.
- _____ occurs at the patient's _____.
- An evaluation in _____ includes the diagnosis or finding _____.
- The diagnosis in _____ is cardiac valve endocarditis.
- The patient ID for _____ is _____.
- _____ is a history and physical exam.
- _____ is a heart valve repair or replacement.
- _____ is cardiac valve endocarditis.

Temporal Questions

- What heart valve repair or replacements occurred less than 30 days after what cardiac valve endocarditis?
- What heart valve repair or replacements occurred less than 30 days after what history and physical exams?

General Fragments

Supplemental Fragments

CCF Query Library

Chris Deaton: CCF Medical Research using the CAE

Search History

- Is it true that:
- All of the following are true

Add Group

Remove Group

Time Graph

Context Edit...

Results: All

Time limit: 10 min

Compute justifications?

More



Ask

Report

Schedule

Save

New Tab

Stop

Answers

Task Info Concepts Queries

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

Clear

Find

- patient
- heart valve repair or replacement
- 30 days
- history and physical exam
- diagnosing
- cardiac valve endocarditis

Search Results

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

Terms

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- _____ is before _____.
- _____ is less than _____.
- _____ occurs at the patient's _____.
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- The diagnosis in _____ is cardiac valve endocarditis.
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- _____ is a history and physical exam.
- _____ is a heart valve repair or replacement.
- _____ is cardiac valve endocarditis.

Temporal Questions

- What heart valve repair or replacements occurred less than 30 days after what cardiac valve endocarditis?
- What heart valve repair or replacements occurred less than 30 days after what history and physical exams?

General Fragments

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Chris Deaton: CCF Medical Resea

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Results: All

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Compute justifications?

More



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Schedule

Save

New Tab

Stop

Answers

(#\$patientTreated TREATMENT PATIENT) means that PATIENT, an instance of #Animal, is an instance of #MedicalPatient during TREATMENT (an instance of #MedicalTreatmentEvent) and is treated by that TREATMENT.

Task Info Concepts Queries

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

- patient
- heart valve repair or replacement
- 30 days
- history and physical exam
- diagnosing
- cardiac valve endocarditis

Search Results

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve

Terms

Simple Fragments

- _____ is before _____.
- _____ is less than _____.
- _____ occurs at the patient's _____.
- An evaluation in _____ includes the diagnosis or finding _____.
- The diagnosis in _____ is cardiac valve endocarditis.
- The patient ID for _____ is _____.
- _____ is a history and physical exam.
- _____ is a heart valve repair or replacement.
- _____ is cardiac valve endocarditis.

Temporal Questions

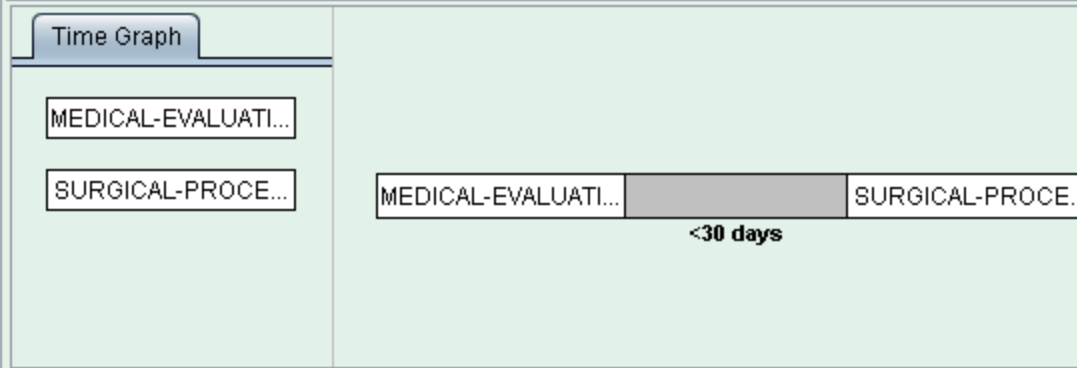
- What heart valve repair or replacements occurred less than 30 days after what cardiac valve endocarditis?
- What heart valve repair or replacements occurred less than 30 days after what history and physical exams?

- General Fragments
- Supplemental Fragments

- CCF Query Library
- Chris Deaton: CCF Medical Research using the CAE

- Give the values of *SURGICAL-PROCEDURE* and *MEDICAL-EVALUATION* such that:
- All of the following are true
 - SURGICAL-PROCEDURE* is a heart valve repair or replacement.
 - Y is the patient involved in *SURGICAL-PROCEDURE*.
 - MEDICAL-EVALUATION* is a history and physical exam.
 - Y is the patient involved in *MEDICAL-EVALUATION*.
 - TIME* is less than 30 days.
 - SURGICAL-PROCEDURE* started *TIME* before or after *MEDICAL-EVALUATION*.
 - MEDICAL-EVALUATION* is before *SURGICAL-PROCEDURE*.

Add Group Remove Group



Context Edit... Results: All Time limit: 10 min Compute justifications?

Ask Report Schedule Save New Tab Stop

Answers Surgical procedure Medical evaluation

Task Info Concepts Queries

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

Clear Find

- patient
- heart valve repair or replacement
- 30 days
- history and physical exam
- diagnosing
- cardiac valve endocarditis

- Search Results
- patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis
 - Terms
 - Simple Fragments
 - _____ is before _____.
 - _____ is less than _____.
 - _____ occurs at the patient's _____.
 - An evaluation in _____ includes the diagnosis or finding of _____.
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 - _____ is a history and physical exam.
 - _____ is a heart valve repair or replacement.
 - _____ is cardiac valve endocarditis.
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 - What heart valve repair or replacements occurred less than 30 days after what cardiac valve endocarditis?
 - What heart valve repair or replacements occurred less than 30 days after what history and physical exams?
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 - Supplemental Fragments
 - CCF Query Library
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 - Search History

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Add Group Remove Group

Time Graph

MEDICAL-EVALUATI...

SURGICAL-PROCE...

MEDICAL-EVALUATI... SURGICAL-PROCE...

<30 days

Context: ... Edit... Results: All Time limit: 10 min Compute justifications? More

Ask Report Schedule Save New Tab Stop

Answers

Task Info Concepts Queries

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

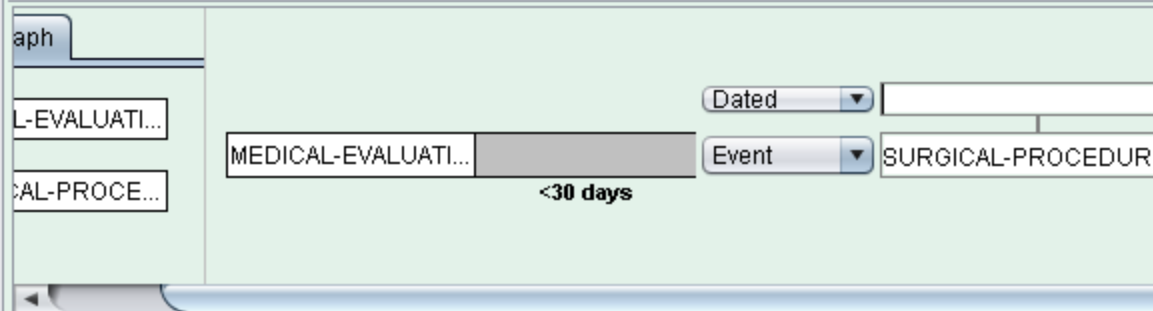
Clear Find

- patient
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- 30 days
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 - PATIENT* is the patient involved in *MEDICAL-EVALUATION*.

Add Group Remove Group



Context: ... Edit... Results: All Time limit: 10 min Compute justifications? More

Ask Report Schedule Save New Tab Stop

Answers

Task Info Concepts Queries

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

Clear Find

- patient
- heart valve repair or replacement
- 30 days
- history and physical exam
- diagnosing
- cardiac valve endocarditis

- Search Results
- patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis
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 - PATIENT* is the patient involved in *SURGICAL-PROCEDURE*.
 - MEDICAL-EVALUATION* is a history and physical exam.
 - PATIENT* is the patient involved in *MEDICAL-EVALUATION*.
 - TIME* is less than 30 days.
 - SURGICAL-PROCEDURE* started *TIME* before or after *MEDICAL-EVALUATION*.
 - MEDICAL-EVALUATION* is before *SURGICAL-PROCEDURE*.
 - The diagnosis in *MEDICAL-DIAGNOSIS-OR-FINDING* is cardiac valve endocarditis.
 - An evaluation in *MEDICAL-EVALUATION* includes the diagnosis or finding of *MEDICAL-DIAGNOSIS-OR-FINDING*.
 - PATIENT* is the patient involved in *MEDICAL-EVALUATION*.

Add Group Remove Group

Between _____ and _____

MEDICAL-EVALUATION Event SURGICAL-PROCEDURE

<30 days

Context: ... Edit... Results: All Time limit: 10 min Compute justifications? More

Ask Report Schedule Save New Tab Stop

Answers

Task Info Concepts Queries

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis [Clear] [Find]

- patient
- heart valve repair or replacement
- 30 days
- history and physical exam
- diagnosing
- cardiac valve endocarditis

Search Results

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

Terms

Simple Fragments

- _____ is before _____.
- _____ is less than _____.
- _____ occurs at the patient's _____.
- An evaluation in _____ includes the diagnosis or finding of _____.
- The diagnosis in _____ is cardiac valve endocarditis.
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General Fragments

Supplemental Fragments

CCF Query Library

Chris Deaton: CCF Medical Research using the CAE

Search History

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 - The diagnosis in *MEDICAL-DIAGNOSIS-OR-FINDING* is cardiac valve endocarditis.
 - An evaluation in *MEDICAL-EVALUATION* includes the diagnosis or finding of *MEDICAL-DIAGNOSIS-OR-FINDING*.
 - PATIENT* is the patient involved in *MEDICAL-EVALUATION*.

[Add Group] [Remove Group]

Between 1990 and 2008

MEDICAL-EVALUATION Event SURGICAL-PROCEDURE

<30 days

Context: ... Edit... Results: All Time limit: 10 min [x] Compute justifications? More

[Ask] [Report] [Schedule] [Save] [New Tab] [Stop]

Answers

Task Info Concepts Queries

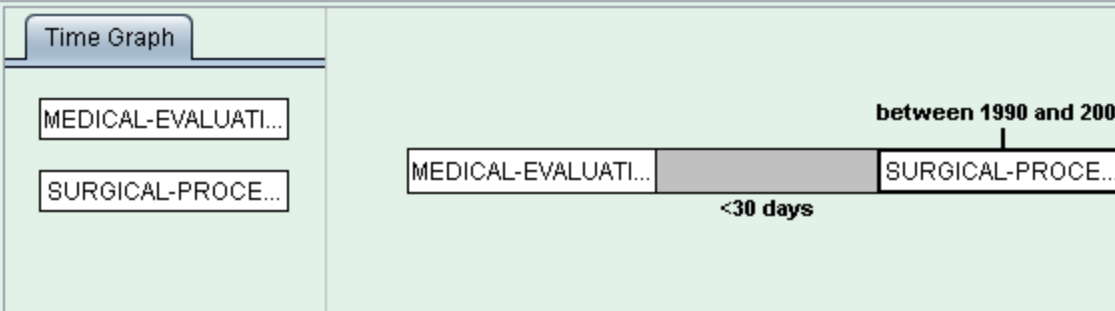
patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

- patient
- heart valve repair or replacement
- 30 days
- history and physical exam
- diagnosing
- cardiac valve endocarditis

- Search Results
- patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis
 - Terms
 - Simple Fragments
 - _____ is before _____.
 - _____ is less than _____.
 - _____ occurs at the patient's _____.
 - An evaluation in _____ includes the diagnosis or finding of _____.
 - The diagnosis in _____ is cardiac valve endocarditis.
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 - What heart valve repair or replacements occurred less than 30 days after what history and physical exams?
 - General Fragments
 - Supplemental Fragments
 - CCF Query Library
 - Chris Deaton: CCF Medical Research using the CAE
 - Search History

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 - PATIENT* is the patient involved in *MEDICAL-EVALUATION*.
 - TIME* is less than 30 days.
 - SURGICAL-PROCEDURE* started *TIME* before or after *MEDICAL-EVALUATION*.
 - MEDICAL-EVALUATION* is before *SURGICAL-PROCEDURE*.
 - The diagnosis in *MEDICAL-DIAGNOSIS-OR-FINDING* is cardiac valve endocarditis.
 - An evaluation in *MEDICAL-EVALUATION* includes the diagnosis or finding of *MEDICAL-DIAGNOSIS-OR-FINDING*.
 - PATIENT* is the patient involved in *MEDICAL-EVALUATION*.
 - SURGICAL-PROCEDURE* happened between 1990 and 2008.

Add Group Remove Group



Context: ... Edit... Results: All Time limit: 10 min Compute justifications?

Ask Report Schedule Save New Tab Stop

Answers

- patient
- patient
- 30 da
- diag

Email

From:

To:

Cc:

Schedule Query

Name:

Repeat

Not Recurring Daily Weekly Monthly Yearly

Precision:

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

: :

Email?

ory and physical with a diagnosis of valve endocarditis

es of *SURGICAL-PROCEDURE*, *MEDICAL-DIAGNOSIS-OR-FINDING* and *EVALUATION* such that:

Following are true

- AL-PROCEDURE* is a heart valve repair or replacement.
- T* is the patient involved in *SURGICAL-PROCEDURE*.
- L-EVALUATION* is a history and physical exam.
- T* is the patient involved in *MEDICAL-EVALUATION*.
- less than 30 days.

started *TIME* before or after *MEDICAL-EVALUATION*.

before *SURGICAL-PROCEDURE*.

DIAGNOSIS-OR-FINDING is cardiac valve endocarditis.

EVALUATION includes the diagnosis or finding

ING.

ed in *MEDICAL-EVALUATION*.

happened between 1990 and 2008.

between 1990 and 2008

MEDICAL-EVALUATI... SURGICAL-PROCE...

Time limit: Compute justifications?

- Search Results
- patients with a heart valve repair or replacement history and physical with a diagnosis of valve endocarditis
 - Terms
 - Simple Fragments
 - _____ is before _____
 - _____ is less than _____
 - _____ occurs at the patient's _____
 - An evaluation in _____ is _____
 - The diagnosis in _____ is _____
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 - _____ is a heart valve repair or replacement
 - _____ is cardiac valve endocarditis
 - Temporal Questions
 - What heart valve repair or replacement occurred after what cardiac valve endocarditis diagnosis?
 - What heart valve repair or replacement occurred after what history and physical exam?
 - General Fragments
 - Supplemental Fragments
 - CCF Query Library
 - Chris Deaton: CCF Medical Research
 - Search History

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

Clear Find

- patient
- heart valve repair or replacement
- 30 days
- history and physical exam
- diagnosing
- cardiac valve endocarditis

- Search Results
- patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis
 - Terms
 - Simple Fragments
 - _____ is before _____.
 - _____ is less than _____.
 - _____ occurs at the patient's _____.
 - An evaluation in _____ includes the diagnosis of _____.
 - The diagnosis in _____ is cardiac valve endocarditis.
 - The patient ID for _____ is _____.
 - _____ is a history and physical exam.
 - _____ is a heart valve repair or replacement.
 - _____ is cardiac valve endocarditis.
 - Temporal Questions
 - What heart valve repair or replacements occurred less than 30 days after what cardiac valve endocarditis?
 - What heart valve repair or replacements occurred less than 30 days after what history and physical exams?
 - General Fragments
 - Supplemental Fragments
 - CCF Query Library
 - Chris Deaton: CCF Medical Research using the CAE
 - Search History

Give the values of *SURGICAL-PROCEDURE*, *MEDICAL-DIAGNOSIS-OR-FINDING* and *MEDICAL-EVALUATION* such that:

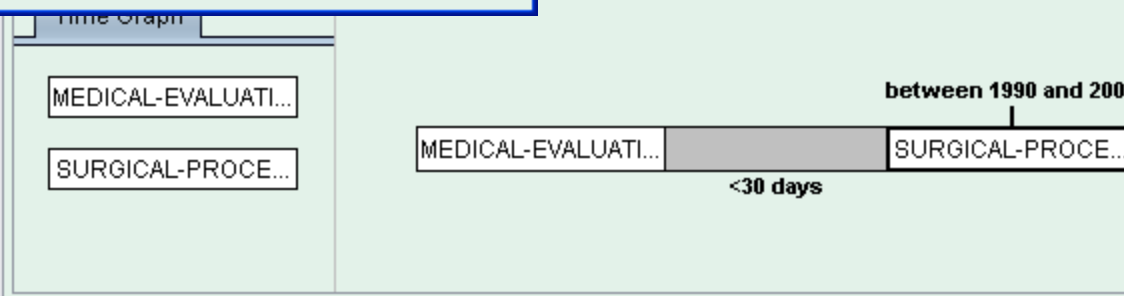
- All of the following are true
 - SURGICAL-PROCEDURE* is a heart valve repair or replacement.
 - PATIENT* is the patient involved in *SURGICAL-PROCEDURE*.
 - MEDICAL-EVALUATION* is a history and physical exam.
 - PATIENT* is the patient involved in *MEDICAL-EVALUATION*.
 - TIME* is less than 30 days.
 - SURGICAL-PROCEDURE* started *TIME* before or after *MEDICAL-EVALUATION*.
 - MEDICAL-EVALUATION* includes the diagnosis or finding *SURGICAL-PROCEDURE*.
- MEDICAL-EVALUATION* is cardiac valve endocarditis.
- TIME* is between 1990 and 2008.

Report

Choose a variable to report on.

?SURGICAL-PROCEDURE

OK Cancel



Context: ... Edit... Results: All Time limit: 10 min Compute justifications? More

Ask Report Schedule Save New Tab Stop

Answers

- patie
- patie
- 30 o
- diag
- Search
- patie
- histo
- Te
- Si
- Te
- Supplemental Fragments
- CCF Query Library
- Chris Deaton: CCF Medical Research using the CAE
- Search History

Define Report

- Give the values of *MEDICAL-EVALUATION* such that:
 - All of the following are true
 - SURGICAL-PROCEDURE* is a heart valve repair or replacement.
 - PATIENT* is the patient involved in *SURGICAL-PROCEDURE*.
 - MEDICAL-EVALUATION* is a history and physical exam.
 - PATIENT* is the patient involved in *MEDICAL-EVALUATION*.
 - TIME* is less than 30 days.
 - SURGICAL-PROCEDURE* started *TIME* before or after *MEDICAL-EVALUATION*.
 - MEDICAL-EVALUATION* is before *SURGICAL-PROCEDURE*.
 - The diagnosis in *MEDICAL-DIAGNOSIS-OR-FINDING* is cardiac valve endocarditis.
 - An evaluation in *MEDICAL-EVALUATION* includes the diagnosis or finding *MEDICAL-DIAGNOSIS-OR-FINDING*.
 - PATIENT* is the patient involved in *MEDICAL-EVALUATION*.
 - SURGICAL-PROCEDURE* happened between 1990 and 2008.

Type: Template:

Email to: Cc? Comma-delimited Tab-delimited

Answers

990 and 2008

L-PROCE...

itions? More

patients with a heart valve repair or replacement less than 30 days after a history and physical with a diagnosis of valve endocarditis

Clear Find

Define Report

- Give the values of *MEDICAL-EVALUATION* such that:
 - All of the following are true
 - *SURGICAL-PROCEDURE* is a heart valve repair or replacement.
 - *PATIENT* is the patient involved in *SURGICAL-PROCEDURE*.
 - *MEDICAL-EVALUATION* is a history and physical exam.
 - *PATIENT* is the patient involved in *MEDICAL-EVALUATION*.
 - *TIME* is less than 30 days.
 - *SURGICAL-PROCEDURE* started *TIME* before or after *MEDICAL-EVALUATION*.
 - *MEDICAL-EVALUATION* is before *SURGICAL-PROCEDURE*.
 - The diagnosis in *MEDICAL-DIAGNOSIS-OR-FINDING* is cardiac valve endocarditis.
 - An evaluation in *MEDICAL-EVALUATION* includes the diagnosis or finding *MEDICAL-DIAGNOSIS-OR-FINDING*.
 - *PATIENT* is the patient involved in *MEDICAL-EVALUATION*.
 - *SURGICAL-PROCEDURE* happened between 1990 and 2008.

Type: ad hoc report template Template: Adhoc Report All Variables

PRE_ASA...	PRE_BET...	PRE_STATIN_INT	PRE_NONSTATIN_I...	PRE_AFIB_DIAG	PRE_ASC_AOR_DI...	PRE_AOR_ACH...	PRE_DESC_THOR_DIAG
Exclud...	Exclud...	Included	Included	Included	Included	Included	Excluded

Email to: myemail@mydomain.com Cc?

- Comma-delimited
- Tab-delimited

Use of Cyc Knowledge

In answering *ad hoc medical* queries
by clinical researchers at CCF

- Converting the NL query → Understood “fragments”
- Combining the selected fragments into a full query
- Converting the query from HOL form (Cycl) into one or more SPARQL queries and sending them to the service
 - for efficiency of running the SPARQL queries, making judicious choices of, e.g., clause ordering
- Parse more complex fragments (esp. temporal ones)
- Persistent queries (triggers/schedules and actions)
- Ontologize new domains and align to new data sources
- Extend downward (patient data entry)
- Extend outward (generate internal and 3rd party external reports)

Lessons from that application

- Users will want to type unrestricted English queries.
 - Let them, but then partially parse the queries into fragments
 - The users say yes/no for the fragments (lesson: minimize the number of fragments presented, BUT it's worth guessing at “combines”)
 - Use domain knowledge, general common sense knowledge, and models of the user and the user's context (and discourse pragmatics) to semantically combine those fragments into a meaningful utterance
- Users often err when writing spatiotemporal constraints
 - Palette of objects/events they can drag around and graphically arrange into a configuration; i.e., 2D space (vs. 1D text) repr. 3D space + time

- Application provider (hospital) cares a lot about validation
 - Verifying that the results the Cyc-based CAE system obtained matched precisely the ones returned by their previous system, which involved multiple people (user + intermediary + DBA) and multiple emails.
 - The good news: high level of conformance (98%)
 - The interesting news: each discrepancy was interesting, no-fault, generally revealing some hitherto unsuspected ambiguity in terms
 - E.g., an “isolated” procedure; “insertion of an artificial mitral valve”; ...
- Why it may be useful to stream answers rather than waiting until the query runs to completion:
 - Even if the overall time to run a query to completion is increased 25%
 - First few answers reveal that the user mis-stated/forgot something

Lessons from that application

A 67-year-old woman suffering from ICM with elevated bilirubin, history of diabetes, body mass index of 39.5, NYHA function class III, mitral valve regurgitation grade (MVRG) of 2+, and no aortic valve regurgitation (AVR) is assigned to CABG surgery. RF+Cyc is consulted and the RF (random forest statistical reasoning) component, having been trained on a large database, identifies CABG alone as the most likely treatment option, citing

understand and know enough to calculate an answer

or else, if that fails,

partial understanding/knowledge → semantic search

or else, if that fails,

the final fallback: syntactic search (e.g., Google)

CABG+MVA. The patient dies 5 days later from complications due to surgery.

In this setting, RF+Cyc, if consulted, could have alerted the heart team to additional data that might have swayed their decision, thus potentially saving a life. RF+Cyc would have noted that while an MVRG of 3+ is consistent with CABG+MVA, the odds favoring CABG only marginally decrease from 2.6:1 to 1.7:1 when MVRG is upstaged for this patient from 2+ to 3+, and that surgery under CABG alone offers a 20% increase in median survival compared to CABG+MVA. RF+Cyc could further argue that intraoperative MVRG can falsely appear to be upstaged due to altered hemodynamics in anesthetized patients. A Cyc-assisted semantic search of the recent literature reveals that transesophageal transthoracic echocardiograms (TTE) more reliably reflect the degree of mitral regurgitation than TEE. That (+co-morbidities) argues for just CABG.

A 67-year-old woman suffering from ICM with elevated bilirubin, history of diabetes, body mass index of 39.5, NYHA function class III, mitral valve regurgitation grade (MVRG) of 2+, and no aortic valve regurgitation (AVR) is assigned to CABG surgery. RF+Cyc is consulted and the RF (random forest statistical reasoning) component, having been trained on a large database, identifies CABG alone as the most likely treatment option, citing

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partial understanding/knowledge → semantic search

- > fewer false positives (flesh eating bacteria attack heart)
- > fewer false negatives (Myocardial Infarctions, CABGs,...)
- > a little extra info to include (Gillinov graphs) or exclude
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consistent with CABG+MVA, the odds favoring CABG only marginally decrease from 2.6:1 to 1.7:1 when MVRG is upstaged for this patient from 2+ to 3+, and that surgery under CABG alone offers a 20% increase in median survival compared to CABG+MVA. RF+Cyc could further argue that intraoperative MVRG can falsely appear to be upstaged due to altered hemodynamics in anesthetized patients. A Cyc-assisted semantic search of the recent literature reveals that transesophageal transthoracic echocardiograms (TTE) more reliably reflect the degree of mitral regurgitation than TEE. That (+co-morbidities) argues for just CABG.

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Intelligent Search

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http://semanticsearch/ConceptSearch/index.jsp

Gmail - TRC request... NCSI: Technology C... University of Maryla... Metro - Trip Planner Google Hilton Alexandria M...

Intelligent Search

Intelligent Search - Mozilla Firefox

File Edit View History Bookmarks Yahoo! Tools Help

http://semanticsearch/ConceptSearch/index.jsp?searchString=heart+attack&action=Search

Gmail - TRC request... NCSI: Technology C... University of Maryla... Metro - Trip Planner Google Hilton Alexandria M...

Intelligent Search

Semantic Search Results

[Joseph F. Sabik III, M.D.](#)

Joseph F. Sabik III, M.D. Specialties: Adult cardiac surgery, valvular heart disease, coronary artery disease, thoracic aortic surgery, minimally invasive off-pump [coronary artery bypass surgery](#), mitral and aortic valve repair and [http://tomcat/html-content/sabik.html \(cached\)](http://tomcat/html-content/sabik.html)

[Jose L. Navia](#)

Jose L. Navia Specialties: Adult acquired heart disease, minimally invasive robotic and video-assisted cardiac surgery, off-pump [coronary artery by](#) invasive mitral and aortic valve surgery, heart transplantation, [http://tomcat/html-content/navia.html \(cached\)](http://tomcat/html-content/navia.html)

[Gonzalo Gonzalez-Stawinski, M.D.](#)

Gonzalo Gonzalez-Stawinski, M.D. Specialties: Adult cardiac surgery, heart and lung transplantation, reoperations, [coronary artery bypass graft sur](#) embolectomies, and valve surgery. Medical Degree: [http://tomcat/html-content/gonzalez-stawinski.html \(cached\)](http://tomcat/html-content/gonzalez-stawinski.html)

[A. Marc Gillinov, M.D.](#)

A. Marc Gillinov, M.D. Specialties: Minimally invasive mitral valve, aortic valve, and tricuspid valve surgery; mitral valve repair, surgical treatment and surgery for atrial fibrillation; off-pump [coronary artery bypass surgery](#) [http://tomcat/html-content/gillinov.html \(cached\)](http://tomcat/html-content/gillinov.html)

[Coronary Disease](#)

0% Mortality for reoperative [CABG](#) in 2006. PRIMARY ISOLATED CABG Primary isolated CABG refers to a patient's first [coronary artery bypass sur](#) without any other procedure. In 2006, Cleveland Clinic surgeons performed 538 primary isolated CABG [http://tomcat/html-content/Coronary Disease.html \(cached\)](http://tomcat/html-content/Coronary_Disease.html)

Intelligent Search

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coronary artery bypass graft is standard treatment for heart attacks

[Coronary Disease](#)

0% Mortality for reoperative [CABG](#) in 2006. PRIMARY ISOLATED CABG Primary isolated CABG refers to a patient's first [coronary artery bypass surgery](#) without any other procedure. In 2006, Cleveland Clinic surgeons performed 538 primary isolated CABG [http://tomcat/html-content/Coronary Disease.html \(cached\)](http://tomcat/html-content/Coronary_Disease.html)

[Minimally Invasive](#)

Isolated valve procedure [CABG](#) + valve procedure valve procedure + other cardiac procedure other cardiac procedure [CABG](#) + other
[http://tomcat/html-content/Minimally_Invasive_.html \(cached\)](http://tomcat/html-content/Minimally_Invasive_.html)

[Cardiomyopathy](#)

Septal Myectomy + [CABG](#) Septal Myectomy + Other Septal Myectomy
[http://tomcat/html-content/Cardiomyopathy_.html \(cached\)](http://tomcat/html-content/Cardiomyopathy_.html)

[Valve Disease](#)

Isolated MV MV Repair or Replace + [CABG](#) MV Repair or Replace + Other AV Repair or Replace + Other AV Repair or Replace + [CABG](#) Isolated... v
repair/replacement with [CABG](#), valve repair/replacement with aorta surgery, and valve repair/replacement
[http://tomcat/html-content/Valve_Disease_.html \(cached\)](http://tomcat/html-content/Valve_Disease_.html)

Text Search Results

[Lung Transplant](#)

. DISTRIBUTION OF LUNG TRANSPLANT PROCEDURES [Heart](#) - Lung Transplant... 2006 Distribution by State, [heart](#) transplants and lung transplant
[http://tomcat/html-content/Lung_Transplant_.html \(cached\)](http://tomcat/html-content/Lung_Transplant_.html)

[Tomislav Mihaljevic, M.D.](#)

: Minimally invasive cardiac surgery, robotic cardiac surgery, image-guided cardiac surgery, [heart](#) failure, mitral and aortic valve repair and replacement
disease, beating [heart](#) revascularization, Maze procedure, [heart](#) and lung transplantation, ventricular assist devices, and adult congenital
[http://tomcat/html-content/mihaljevic_.html \(cached\)](http://tomcat/html-content/mihaljevic_.html)

[Heart Transplant](#)

1,285 [Heart](#) transplants performed at Cleveland Clinic since inception of the Cardiac Transplant Program [HEART](#) TRANSPLANT VOLUME Cleveland
2006, 76 [heart](#) transplants were performed (including two [heart](#)-lung and one [heart](#)-liver
[http://tomcat/html-content/Heart_Transplant_.html \(cached\)](http://tomcat/html-content/Heart_Transplant_.html)

[Nicholas G. Smedira, M.D.](#)

Nicholas G. Smedira, M.D. Specialties: [Heart](#) and [heart](#)-lung transplantation, ventricular assist devices, ECMO, [heart](#) failure surgery, aortic and mitral
replacement, off-pump coronary artery bypass grafting, myectomy, reoperations
[http://tomcat/html-content/smedira_.html \(cached\)](http://tomcat/html-content/smedira_.html)

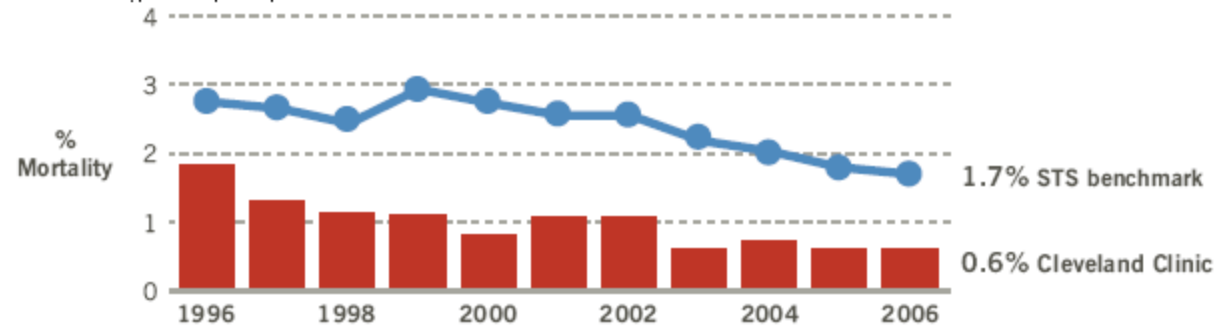
Coronary Disease

0%

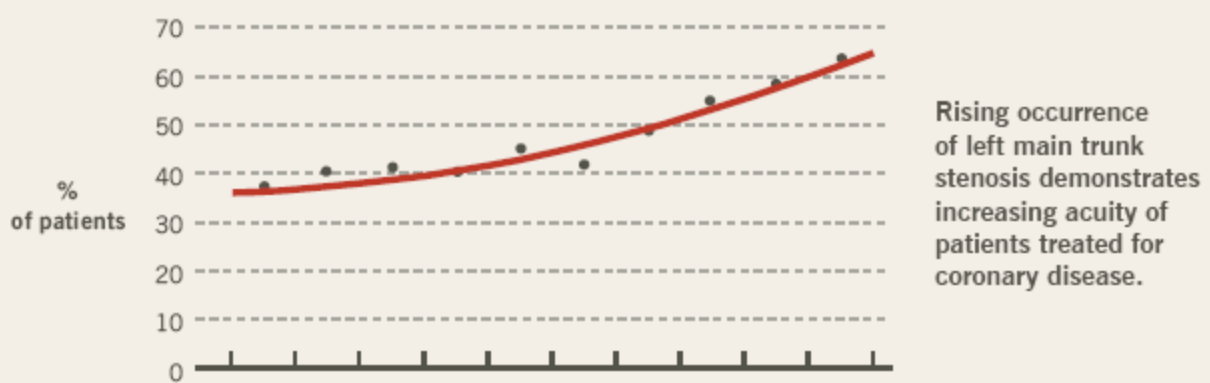
Mortality for reoperative CABG in 2006.

PRIMARY ISOLATED CABG

Primary isolated CABG refers to a patient's first coronary artery bypass surgery when performed without any other procedure. In 2006, Cleveland Clinic surgeons performed 538 primary isolated CABG procedures. Mortality was 0.6%, well below the national benchmark established by The Society of Thoracic Surgeons' (STS) national database.



Left Main Trunk Stenosis



A. Marc Gillinov, M.D.

Specialties: Minimally invasive mitral valve, aortic valve, and tricuspid valve surgery; mitral valve repair, surgical treatment and minimally invasive surgery for atrial fibrillation; off-pump coronary artery bypass surgery; and high-risk mitral valve surgery.

Medical Degree: Johns Hopkins University School of Medicine, Baltimore, Maryland

Special Training: Johns Hopkins University School of Medicine, Baltimore, Maryland

A native Clevelander, Dr. Gillinov spent the summers of 1978 to 1980 dividing his time between working at Cleveland Clinic and playing tennis. He still enjoys both activities.



Intelligent Search - Mozilla Firefox

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http://semanticsearch/ConceptSearch/index.jsp?searchString=heart+valve+repair&action=Search

Gmail - TRC req... NCSI: Technolo... University of M... Metro - Trip Pla... Google Hilton Alexandri... Intelligent... Coronary D

Intelligent Search

Semantic Search Results

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A. Marc Gillinov, M.D. Specialties: Minimally invasive mitral valve, aortic valve, and tricuspid valve surgery; mitral [valve repair](#), surgical... Gillinov, M.D. [heart-valve repair](#) operations at http://tomcat/html-content/gillinov_GillinovHeartValveRepair.html (cached)

[Valve Disease](#)

[AV Repair](#) or Replace + Other [AV Repair](#) or Replace + CABG Isolated [AV Repair](#) or Replace Aortic Valve Procedures In 2006, 89% of our... AV Sp... Replacements AV = Aortic http://tomcat/html-content/Valve_Disease_.html (cached)

[Nicholas G. Smedira, M.D.](#)

Nicholas G. Smedira, M.D. Specialties: Heart and heart-lung transplantation, ventricular assist devices, ECMO, heart failure surgery, aortic and mitral replacement, off-pump coronary artery bypass grafting, myectomy, reoperations, http://tomcat/html-content/smedira_.html (cached)

[Joseph F. Sabik III, M.D.](#)

Joseph F. Sabik III, M.D. Specialties: Adult cardiac surgery, valvular heart disease, coronary artery disease, thoracic aortic surgery, minimally invasive off-pump coronary artery bypass surgery, mitral and [aortic valve repair](#) and http://tomcat/html-content/sabik_.html (cached)

[Eric E. Roselli, M.D.](#)

Eric E. Roselli, M.D. Specialties: Adult cardiac surgery, thoracic aortic surgery, endovascular approaches to cardiothoracic diseases, minimally invasive replacement, high-risk valve surgery, peripheral vascular surgery, http://tomcat/html-content/roselli_.html (cached)

A. Marc Gillinov, M.D.

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Gillinov, M.D. has performed 125 heart-valve repair operations at the Cleveland Clinic Foundation since 1998.



This graph, based on a small sample of patient data, is given for demonstration purposes only.

Coronary Disease

0%

Mortality for reoperative CABG in 2006.

Coronary Artery Procedure Volumes for Gillinov, M.D.

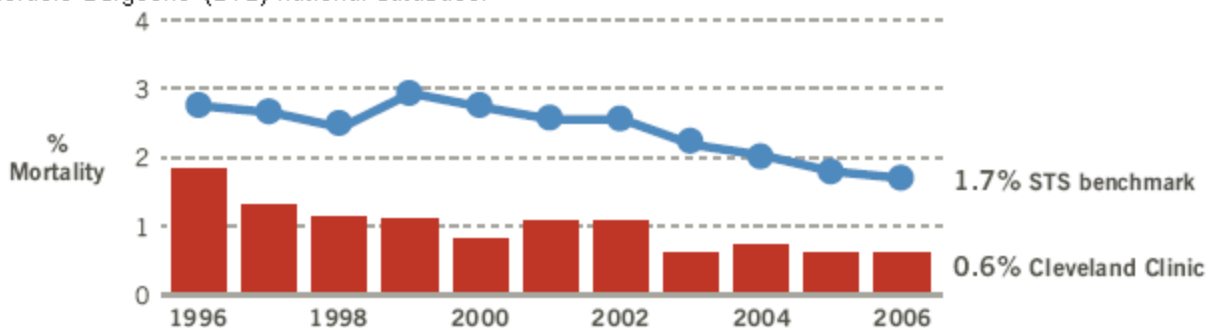
Gillinov, M.D. has performed 316 coronary artery operations at the Cleveland Clinic Foundation since 1998.



This graph, based on a small sample of patient data, is given for demonstration purposes only.

PRIMARY ISOLATED CABG

Primary isolated CABG refers to a patient's first coronary artery bypass surgery when performed without any other procedure. In 2006, Cleveland Clinic surgeons performed 538 primary isolated CABG procedures. Mortality was 0.6%, well below the national benchmark established by The Society of Thoracic Surgeons of Thoracic Surgeons' (STS) national database.



Left Main Trunk Stenosis

A 67-year-old woman suffering from ICM with elevated bilirubin, history of diabetes, body mass index of 39.5, NYHA function class III, mitral valve regurgitation grade (MVRG) of 2+, and no aortic valve regurgitation (AVR) is assigned to CABG surgery. RF+Cyc is consulted and the RF (random forest statistical reasoning) component, having been trained on a large database, identifies CABG alone as the most likely treatment option, citing

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Doug Lenat

Lenat@cyc.com



5th generation
Media
MC
Semantics
Web

- What AI did wrong before Cyc
- What CYC has done wrong
- What ___ will do wrong next

CYC introduced the process of large-scale ontological engineering in 1984.

We learned a large number of useful lessons during those 25 years

(1000 person-years = 2 million person-hours building the ontology)

Errors in representation, in methodology, in inference, in scale.

Traps we fell into, decisions we had to back out of, half-finished off-ramps to nowhere.



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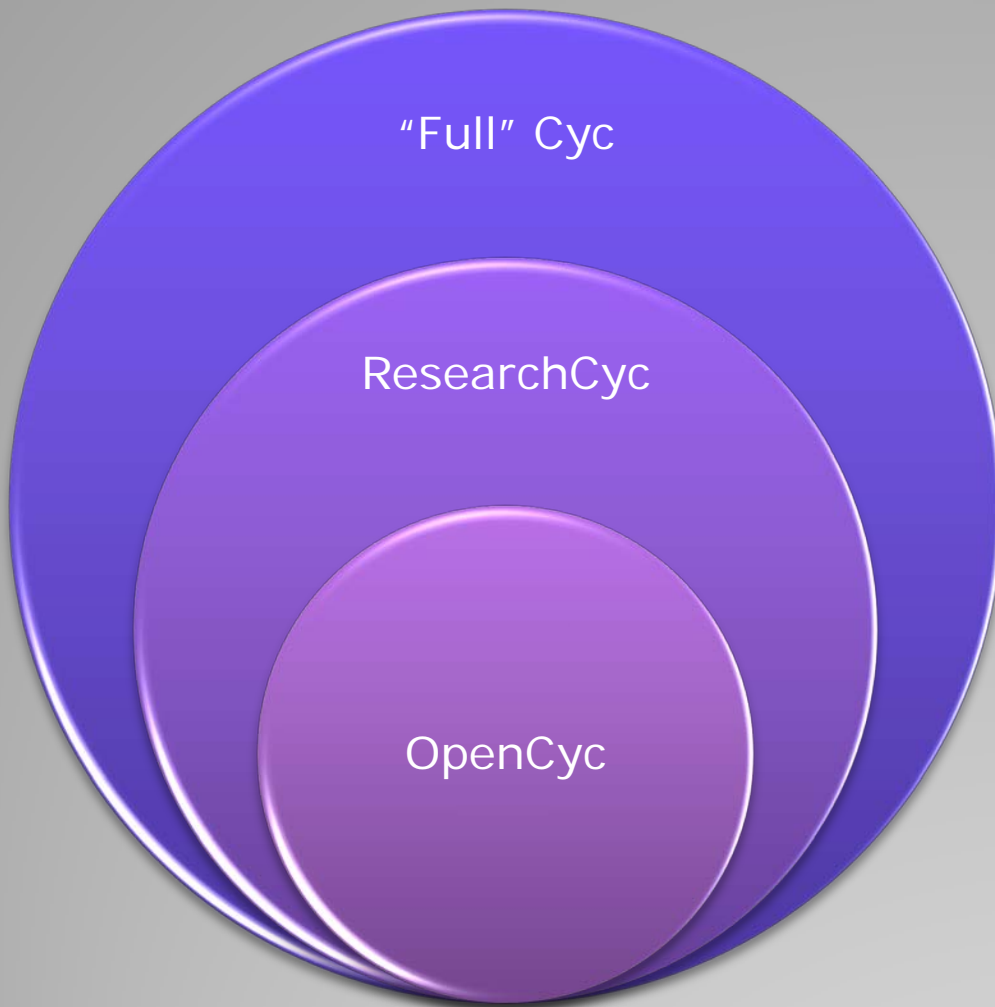


ResearchCyc

- Complete Cyc ontology and KB
- Cyc inference engine
- Natural language recognition and generation
- Ability to connect to external data sources
- **No-cost license available for research-only purposes**

Versions of Cyc

Versions of Cyc



OpenCyc

- Complete Cyc ontology and KB
- All Cyc concepts and comments
- Taxonomic relations
- Constraints on relations
- English for concepts
- Cyc inference engine
- Unrestricted usage (research/commercial)
- OWL version available
- Available at OpenCyc.org or SourceForge

Versions of Cyc

Versions of Cyc

- OpenCyc
 - Access or download via www.opencyc.org
 - Available for Windows XP and Linux
 - New OWL file will be available shortly
- ResearchCyc
 - License available at researchcyc.cyc.com
 - Java version available
 - Requires:
 - JRE
 - 64-bit OS
 - 8GB RAM (recommended)

Acquiring and Using Cyc