“Evacuation simulation based on a cognitive decision making model in a socio-technical system”

DS-RT 2011
15th International Symposium on Distributed Simulation and Real Time Applications
September 4-7, 2011, Salford/Manchester, UK
Introduction: Project „SOCIONICAL“

Research agenda
- Development of complexity science based modeling, prediction and simulation methods for socio-technical systems
- Scenario: crowd dynamics of humans in evacuation

Socio-technical system (STS) [def.]
- “Social-technical systems arise when cognitive and social interaction is mediated by information technology rather than the natural world” [1]
- Combining social and technical components of a computing system is a challenging task (due to domain differences)
- These challenges are due to lack of knowledge, e.g. long term behavioral change, due to persistence of technology in the environment
- STS are there to fill this knowledge gap (modeling, simulation)

Socio-Technical Systems: Application for Crowd-based Phenomena

Scenario
- large evacuating crowd in which each individual has (ideally) a unique social/cognitive character
- subset of the crowd is technology-assisted (expressed as percentage)
- each individual is affected by what he/she perceives in its surrounding

Behavioral challenges
- behavioral variation, i.e., how a crowd behaves in an evacuation situation? (depends on individuals, environment, situation, etc.)
- empirical evidence, e.g., it may be impossible to find evidence related to a specific scenario
- trials, only small scale and controlled trials are possible to document the reaction of crowd towards technology they have access to (or find in the surrounding)

Modeling challenges
- behavioral diversity/individual models → modeling on agent granularity a must
- Interaction extent, i.e., each agent must interact with its surrounding all the time
- Scale must be, according to the scenario, sufficiently large (range ~10^4-10^7)
Socio-Technical Systems: Technology Assistance

**Personal Ambient Intelligence (AmI)**
- mobile assistants
- cell phones
- wearables

**Environmental AmI**
- interactive displays/floors
- pos./navigation systems

**Technology for humans**
- issues getting attention
  - privacy
  - (further) isolation of individuals (away from social interaction)
- arising challenges
  - sensing and modeling of emotions
  - conflicts between individual feelings and AmI recommendations
  - trust in technology

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Evacuation Simulation: A Cognitive Decision Making Model

**Contribution (this paper)**

- study the effect of *change in beliefs* of agents
  > from potentially a less efficient *(nearest) exit*
  > towards a more *efficient (recommended) exit*
  
  (do recommendations of surrounding agents change the belief of an agent?)

- agent based evacuation simulation
  > microscopic CA based locomotive rules *(evidence based)*
  > *decision making* model *based on emotions* *(theoretical social/cognitive/psychological model)*

- *different behavioral rule sets* for AmI-assisted and “normal” agents

- **trust on information**
  > in (AmI-assisted) evacuation scenarios, trust on the source of information may have an influence on individual emotions, intentions, decisions
  > trust may exist in the following forms
    - trust on not AmI-assisted, agents (unknown, friends, family, firefighters)
    - trust on AmI-assisted agents (e.g., firefighters wearing a “LifeBelt”)
    - trust on the technology for AmI-assisted agents (e.g., firefighter’s trust on “LifeBelt”) *(“2nd level trust”)*
Evacuation Simulation: A Cognitive Decision Making Model

Scenario: Evacuation of Linz Main Station (Austrian railway, ÖBB)

- **building structure:** 3 levels (floors) with several exits on all levels
  - (i) **tram station**
    - two platforms connected with main hall through staircases and escalators
  - (ii) **main hall**
    - two staircases connecting main hall to the transit hall
    - two sides connected with tunnels to the main railway platforms
  - (iii) **transit hall**
    - having many central exits
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Aml: “LifeBelt” (silent directional guidance based on vibro-tactile stimulation)

- **variation of** (i) vibrating frequency, (ii) attenuation, (iii) mode

- **notification of distance and orientation**

  **distance**: attenuation + location

  **orientation**: location + frequency

Evacuation Simulation: A Cognitive Decision Making Model

Linz main station: Experiment “Trust in technology”

- **limited perception**
  - **auditory distraction**: different levels of noise, screaming, etc. delivered via headphones
  - **visual restrictions**: ski goggles with foil inlay (varying level of blurring and transparency)

- **limited crowd psychology**
  - group of people (n=10) always circling the test person
  - crowd either went “with” test person, or turned around during a walk
  - test person either went “with” the crowd, or turned around during a walk on technology guidance (=by recommendation)

- **findings**
  - most of the people trusted the recommendations provided by “LifeBelt” (88%)
  - the experimental results (modeling, traces) are conform to most of the famous theories of trust (in the given situation)
Evacuation Simulation: A Cognitive Decision Making Model

Cognitive agent model ("which exit?")

- a general affective decision making model to model cognitive processes of an agent (with cognitive attributes related to evacuation situation) include:
  - **intension**: "trust" towards neighboring agents and "belief" for options (=exits)
  - **emotions**: "fear" / "hope" for options, and resulting "attraction" for options
  - **individualism**: "expressiveness", "openness" and "contagion"

- the cognitive model is based on a number of theories from neuropsychology, social science and psychology (*many of which were empirically validated*)

![Diagram of emotional decision making model for the option to move to exit "E"](image)
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Locomotion rules ("how to reach the exit")
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Cognitive attributes of movable agents

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neigh</td>
<td>Number</td>
<td>Current number of neighbours of an agent</td>
</tr>
<tr>
<td>Fear</td>
<td>Table</td>
<td>Value of fear for each possible exit</td>
</tr>
<tr>
<td>Hope</td>
<td>Table</td>
<td>Value of hope for each possible exit</td>
</tr>
<tr>
<td>Attract</td>
<td>Table</td>
<td>Value of attraction for each possible exit</td>
</tr>
<tr>
<td>Belief</td>
<td>Table</td>
<td>Value of belief for each possible exit</td>
</tr>
<tr>
<td>Delta</td>
<td>Table</td>
<td>Value of trust for each possible intractable agent</td>
</tr>
<tr>
<td>Beta-hope</td>
<td>Number</td>
<td>Personal attribute of hopefulness</td>
</tr>
<tr>
<td>Beta-fear</td>
<td>Number</td>
<td>Personal attribute of fearfulness</td>
</tr>
<tr>
<td>Beta-att</td>
<td>Number</td>
<td>Personal attribute of attraction</td>
</tr>
<tr>
<td>Gamma</td>
<td>Number</td>
<td>Personal attribute of trustworthiness</td>
</tr>
</tbody>
</table>

Global variables defining populations

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-of-agents</td>
<td>Number</td>
<td>Total number of agents = tram-station-agents + incoming-tunnel-agents + main-hall-agents</td>
</tr>
<tr>
<td>Fractionalincoming-count</td>
<td>Number</td>
<td>Distribution of incoming agents (from tunnels and tram station) into entry points</td>
</tr>
<tr>
<td>Agents-count-in-EA-EXIT-ID</td>
<td>Number</td>
<td>Number of agents in respective exit area</td>
</tr>
<tr>
<td>Cluster-size</td>
<td>Number</td>
<td>Size of cluster around an agent considered as neighbourhood.</td>
</tr>
<tr>
<td>Ambient</td>
<td>Number</td>
<td>Percentage of ambient device enabled agents</td>
</tr>
</tbody>
</table>
Evacuation Simulation: A Cognitive Decision Making Model

Environmental variables

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure-type</td>
<td>Text</td>
<td>Set to one of following values: obstacle, exit, floor or wall. Agents take many decisions based on the type of cell they are residing or types of nearby cells.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Obstacles = gray</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Floor = white</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Exit = red</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Wall = black</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The stripes of cells represented in green are “entry points” of the populations entering during the simulation from platforms (in tunnels) and tram station (in centre). Currently hard-coded in the implementation.</td>
</tr>
<tr>
<td>Walkable?</td>
<td>Boolean</td>
<td>Inferred variable from structure-type; can survive without it. Some structures are walkable some are not.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>White, red and green are walkable.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Black and gray are not walkable.</td>
</tr>
<tr>
<td>Region</td>
<td>Text</td>
<td>Different regions of the layout. A cell belongs to which region. Centre, service, tunnel, corridor</td>
</tr>
<tr>
<td>Exit-ID</td>
<td>Text</td>
<td>Identity of an exit cell or cells. A cell belonging to exit area also knows the identity of exit it is related with.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Red strips corresponding to exit width.</td>
</tr>
<tr>
<td>Is-EA?</td>
<td>Boolean</td>
<td>Whether a cell is part of an exit area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shown with dashed areas around exits</td>
</tr>
<tr>
<td>Doms</td>
<td>Table</td>
<td>Direction of motions towards all accessible exits</td>
</tr>
<tr>
<td>Steps-to-exits</td>
<td>Table</td>
<td>Steps (hops) to all accessible exits</td>
</tr>
<tr>
<td>EA-range (Global)</td>
<td>Numeric</td>
<td>Describes how much area around an exit would be considered as exit area range</td>
</tr>
<tr>
<td>T-ExitID (Global)</td>
<td>Numeric</td>
<td>Affective exit area for exit ExitID, excluding non walkable patches</td>
</tr>
</tbody>
</table>
Evacuation Simulation: A Cognitive Decision Making Model

Implementation of the cognitive model

for each agent a
  1. if has device? and intentions update required?
     1. update intentions
  2. DSM
     3. update proximity parameters
     4. for each unit u:
        1. dist = belief(u)
        2. al = dist / steps where steps = 1
        3. ad = best_hops * belief(u) * al
        4. al = belief(u) * ad + al
        5. best_hops = belief(u) * al
     6. if (neighbor_count > 0):
        1. hopq = dist / (best_hops * belief(u) * al)
        2. dist = dist - hopq
     7. else
        1. hopq = al / (1 + al)
        8. temp = al
        9. al = 1
        10. if temp < al
            1. best_hops = best_hops * belief(u) * al
            11. al = best_hops / belief(u) * al
            12. if (neighbor_count = 0):
                1. hopq = (1 - belief(u) * ghor) / (1 - belief(u) * ghor) + 0
                2. alter_cost(a) = alter_cost(a) + 1
                3. if (neighbor_count < 0):
                    1. hopq = 0
          13. if (neighbor_count < 0):
              1. alter_cost(a) = alter_cost(a) + 1
              2. if (alter_cost(a) > 0):
                  1. choose_val = choose_val - 1
                  2. choose_val = choose_val + 1
                  3. alter_cost(a) = alter_cost(a) - 1

update intentions; called for 'a' with has-device? = true and update required?
  1. ox = gen_optimal-act
  2. reset beliefs: reset beliefs to all exit equal to 0.1, except for u, for which belief is set to 0.3
  3. update proximity parameters
  4. for each agent n in the neighborhood of a:
     1. if N1 has device? belief is only updated for normal agents
        1. belief(o) = belief(o) + belief(o) / (belief(o) + belief(o))
     2. if has device:
        1. true-o = true-o + belief(o) / (belief(o) + belief(o))
        2. if there is more than one true-o:
            1. alter_cost(o) = alter_cost(o) + 1
            2. if alter_cost(o) > 0:
                1. choose_val = choose_val - 1
                2. choose_val = choose_val + 1
                3. alter_cost(o) = alter_cost(o) - 1

update proximity parameters; called for 'a' with NOT has-device? Or NOT update required?
  1. for each agent n in the neighborhood of a:
     1. if true-o > 0:
         1. belief(o) = belief(o) + belief(o) / (belief(o) + belief(o))
     2. if there is more than one true-o:
        1. alter_cost(o) = alter_cost(o) + 1
        2. if alter_cost(o) > 0:
            1. choose_val = choose_val - 1
            2. choose_val = choose_val + 1
            3. alter_cost(o) = alter_cost(o) - 1

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Exit choice strategies

- **strategy 1 “nearest exit”**
  > all the agents follow the nearest exit based on random deployment
  > no AmI-assistance is considered in this case

- **strategy 2 “optimal exit”**
  > each agent is provided with a “recommended exit” in each time stamp based on its location and exit area (EA) dynamics

- **strategy 3 “following”**
  > in this case, the agents are either of type “AmI-assisted” or “simple agents”
  > AmI-assisted agents set their beliefs based on “optimal exit”-calculations, i.e., 0.9 for the optimal exit, 0.1 for other exits; then each of this agents \( a \) updates emotions of each of the \( n \) neighbors within interaction range
  > after updating the emotions, each of the AmI-assisted agent \( a \) would update intentions of the neighbors; the update of belief (for each exit \( e \)) would only be performed for simple agents, whereas update of trust would be performed for AmI-assisted agents as well
  > with newly updated trust, belief and aggregation of emotions nearby, the choice of an exit by each agent would be performed
  > the exit with maximum attraction value would be selected as the exit of choice which would heavily be dependent on belief of an agent set by an AmI-assisted agent but it would also be influenced by emotions in the surrounding
Evacuation Simulation: A Cognitive Decision Making Model

Simulation setup – 3 cases (population size)
- in each parameter setting (see below), all the agents are required to evacuate through one of four available exits on the main hall ("e13", "e15", "left", "right")
- the emotion of agents starting from main hall is entirely different from that of agents joining in from tram station (with extreme fear and less hope) or from platforms (considerably relaxed)

Parameter settings ("cases")
- **500** (case 1)/**1,000** (case 2)/**2,000** (case 3) agents in the main hall
- additionally, **250/500/750** agents each, joining in during the simulation from tram station and train platforms, respectively
- Initial hope, fear, attraction, etc.

<table>
<thead>
<tr>
<th>Agent at</th>
<th>Beta_Hope</th>
<th>Beta_Fear</th>
<th>Beta_Attraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main hall</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Tram station</td>
<td>0.1</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td>Platforms</td>
<td>0.8</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Evacuation Simulation: A Cognitive Decision Making Model

Simulation results

Case 1 (1,000 agents): Almost no effect of increase in AmI assisted %age due to too sparse population of agents.

most agents move to “left” exit → crowd builds up → evacuation is delayed
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Simulation results

Case 2 (2,000 agents): Optimum exit usage (=benchmark) achieved with 100% AmI assisted agents. The higher the %age (from 1% to 10%), the better the exit usage compared to the benchmark.
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Simulation results

Case 3 (3,500 agents): Behavior similar to case 2. The higher the quantity of agents (3,500 compared to 2,000 in case 2), the better the replication of optimum exit usage (already in case of lower Aml assistant agents).
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Summary of simulation results

- with an increase in the population size, and as the \%age of Aml-Assisted agents increases, the exit utilization tend to optimize

<table>
<thead>
<tr>
<th>Agents</th>
<th>Exit</th>
<th>1000</th>
<th></th>
<th>2000</th>
<th></th>
<th>3500</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>e15</td>
<td>5.764967</td>
<td>7.206208</td>
<td>61.19734</td>
<td>25.83149</td>
<td>4.603434</td>
<td>8.54133</td>
</tr>
</tbody>
</table>
Evacuation Simulation: A Cognitive Decision Making Model

Conclusions

- focusing on an evacuation situation, we have integrated agent based cognitive decision making model based on psychological, neurological and social aspects into CA simulation to analyze the effect of AmI assisted (with technological assistance) agents on the intention of normal agents.

- simulation results validate the following arguments
  - technologically assisted agents emerge as leaders during evacuation – changing the intentions of many agents within their influence.
  - even a small population of such leaders is sufficient to guarantee a remarkable difference; particularly improving usage of possible under-utilized exits, e.g.,
    - in case of a fairly large population of agents (3,500) with 10% being AmI-assisted, there is less than 2.5% difference in the utilization of the exits when compared with 100% AmI-assistance.

- in addition to simulating the model for a real large scale, we have to improve the model by incorporating more heterogeneity in the behavior +social character of agents.
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