Simulation of the Behaviour of Elderly Persons in their Living Environment using Decision Theory

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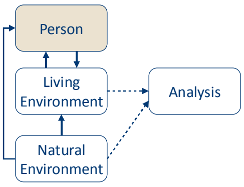
Empirical product testing, especially if based on rare and unpredictable events, requires a very large sample size to gain acceptable statistical accuracy. For example, to test an autonomous personal emergency response system one has to wait for rare emergencies to occur which requires long observation periods and may be unethical. As an alternative solution, we develop verification methods by means of simulation, where empirical data is used to build the model and exceptions can be simulated in significant numbers. Our goal is a model to recreate life-like behaviour of elderly persons in their living environments: Activities of Daily Living (ADL).

Keywords: Social Simulation, Decision Theory, Utility Theory, Multinomial Regression, Needs-based Model, Risk- and Cost-function, ADL;

1. Introduction

We build the ADL-model in three layers:

1. The simulated **Person** and her/his daily routines.
2. The person's house or **Living Environment**, all its devices and possible sensors. Everything in this layer is influenced by the person and yields measurable data like temperatures, motions and electricity consumption.
3. The **Natural Environment** which contain external parameters that cannot be influenced by the person like time or the weather.

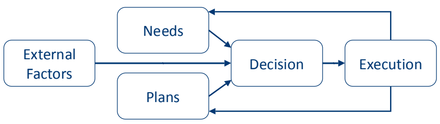


We cannot obtain data from the person directly. Instead, only measurements from the other layers are used. Unusual events like incidents or emergencies are found through interpretation of these measurements combined with behavioural patterns.

We focus on modelling these patterns.

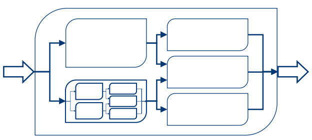
2. The Human Model

The human model consists of three systems, which provide the inputs for the central decision engine. **Needs**, **Plans** and **External Factors** influence each decision. The **Decision** system chooses one of k target actions. The next outstanding action of a plan towards this target action is then **Executed**. The decision process is repeated after completing this action.



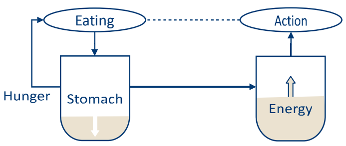
3. Needs

- Goal of the needs-system is to represent the multitude of human needs as a collection of numbers $b_1, \ldots, b_m$.
- Maslow's hierarchy of needs prioritises physiological needs.
- Physiological needs can be modelled as a fundamental system with input streams, a processing "tank" and output streams.
- Most of these complex systems have to be divided into a set of simpler sub-systems:



EXAMPLE: HUNGER

- If the stomach is empty, hunger increases. A high hunger level results very often into the decision to eat something.
- By eating something, the stomach is quickly refilled resulting in a slow increase in energy level.
- Every action needs energy, i.e. burns calories and decreases the energy level.



4. External Factors

- "External Factors" is a very general term for variables $x_1, \ldots, x_n$, which are no needs and no plans, but influence the decision.
- Examples of external factors are:
  - Time: time of day, weekday or season;
  - Weather, temperature or lighting conditions;
  - Other persons or pets.

5. Plans

1. A plan $a = (a_1, a_2, \ldots, a_{|a|-1}, a_T)^T$ is a sequence of actions with a target action at the end. A plan represents an activity of daily living (ADL).
2. A target action $a_T \in A_T \subset A$ is a special action which reduces a certain need.
3. An action $a \in A$ as an element which can be executed but cannot be split into smaller actions.

- To construct a plan, we use pre-defined actions and conditions.
- An action can be executed when its conditions are met.
- To meet conditions, actions must be executed.

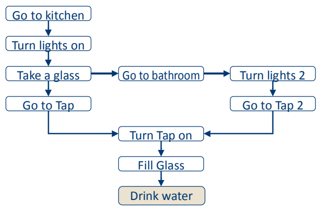
- A plan is built recursively starting with the target action.

$$Plan = State \mapsto a_{T\text{-}n} \frown .. \frown a_{T\text{-}2} \frown a_{T\text{-}1} \frown a_T \mapsto Target$$

- There can be different plans leading to the same target action.
- The plan-system determines the optimal plan for each target action with respect to the expected effort and estimated risk.

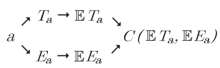
EXAMPLE: DRINKING WATER

Two partially different plans leading to the same target action.



Effort

- Every action a requires effort which depends on the execution time T_a and the consumed energy E_a.



- The real effort cannot be calculated deterministically, therefore one has to determine the expected values $\mathbb{E}\,T_a$ and $\mathbb{E}\,E_a$.
- The cost function assigns the time and energy to one cost value $c = C(T, E)$. The cost function can be defined as:

$$C(T, E) = \gamma_1 T + \gamma_2 E + \gamma_3 T{\cdot}E \quad \text{with } \gamma_1, \gamma_2, \gamma_3 \geq 0$$

Risk

- The risk is the probability that an execution fails. The risk is normally unknown and it must be estimated.
- The execution of an action X can either fail or succeed. This process is modelled with a Bernoulli distribution.

$$X|p \sim Be(p)$$

We use a beta distribution as a prior for p.

$$p \sim Beta(\alpha, \beta)$$

- The posterior $p|X$ is also beta distributed with the following parameters:

$$p|X = 0 \sim Beta(\alpha_1 = \alpha; \beta_1 = \beta + 1)$$
$$p|X = 1 \sim Beta(\alpha_1 = \alpha + 1; \beta_1 = \beta)$$

- Now, the estimated risk of a complete plan $a = (a_1, a_2, \ldots, a_n)^T$ can be calculated as:

$$r = \hat{R}(a) = P(X_1 = 1 \vee \ldots \vee X_n = 1)$$

$$= 1 - \prod_{i=1}^{n} (1 - p_i)$$

6. Decisions

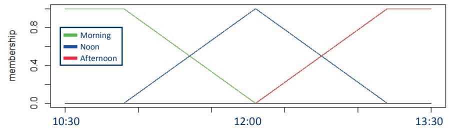
- A decision is the selection of a target action.
- The system considers every relevant predictor
  $$\theta = (b_1, \ldots, b_m, x_1, \ldots, x_n, c_1, \ldots, c_k, r_1, \ldots, r_k)^T$$
  and makes the optimal decision, from the simulated persons point view.
- We discretise the predictors by means of "fuzzification".
- One way to achieve this goal, is to use an utility function $U(\theta, a)$.

Fuzzification

- Fuzzification defines membership functions, that map the continuous predictors into some pre-defined categories with a certain degree of membership.

EXAMPLE: TIME OF DAY

- The predictor "time" has to be classified into the categories night, morning, noon, afternoon and evening.



Utility function

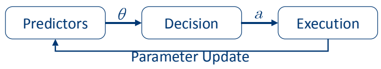
- The fuzzificated predictors θ_i can now be interpreted as discrete distributions. With these the expected utility is calculated as:

$$\mathbb{E}U(\theta_1, .., \theta_p; a)$$
$$= \int U(\theta_1, .., \theta_p; a)\, dF_\theta(\theta)$$
$$= \sum_{i_1=1}^{n_1} .. \sum_{i_p=1}^{n_p} U(\theta_{i1} .. \theta_{ip}; a)\, P(\theta_1 = \theta_{i1} .. \theta_p = \theta_{ip})$$

- The decision system chooses the target action with the highest expected utility value.

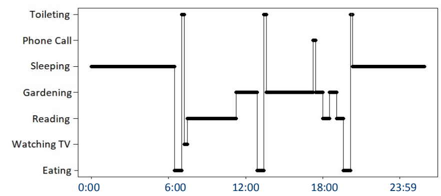
7. Execution

- In the execution system, the first action of a chosen plan is executed and affected parameters are updated.
- We repeat the decision process after every action.



EXAMPLE: A SIMULATED DAY

- The following figure visualizes an example with seven possible target actions (a_T)



- External factors, like temperature, brightness, rain and one random telephone call influenced the chosen decisions.

8. Future work and conclusions

- With the help of decision theory, we achieve human-like behaviour under many conditions.
- To simulate numerous daily routines of many different persons in a very short time the proposed method will be implemented in a computer program.
- Empirical data allows us to verify and optimise the model.
  - Multinomial Regression with latent utility variables.
  - With a Bayesian approach, we use multinomial regression even without much data.
- With this simulation approach we can simulate normal activities of daily living and also introduce rare and unpredictable events. Therefore, we can use this model to verify and optimise our autonomous personal emergency response system.

P.SYS caring systems

- P.SYS caring systems KG is developing a system to handle incidents in the lives of independently living elderly persons.
- The response system is non-invasive and self-learning. In emergencies it must react fast and reliably.
- After detection of the problem a dynamic social network is used to find the optimal assistance.
- This work is supported by the FFG and KWF in a three year project.

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