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DEVELOPING A "*SENSE OF AGENCY*" IN IOT SYSTEMS:
PRELIMINARY EXPERIENCES IN A SMART HOME SCENARIO

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What is the Sense of Agency?

- Learning the effects of own actions in the surrounding environment
  - “Playing” with hands (effectors) to see what happens
  - Learning simple tasks
  - Developing a sense of self
- Takes place by intrinsically motivated exploration

The Sense of Agency Ladder

- At the **individual** level
  - **Perception**
    - Only observing variables → not of interest here
  - **Exploration**
    - Do actions and observe variables
  - **Planning**
    - Given a Goal (set of variables), Select right actions
- At the **collective** level
  - **Recognition of non-self**
    - What variables are not under my control (other agents)
  - **Strategic thinking**
    - Act based on what others are doing
  - **Multiagent interactions**
    - Act based on agreement among multiple agents

The Model

- Given an agent *X*
  - Can observe a set of n environmental variables $\boldsymbol{v}=(v_1, v_2, v_n)$
  - Can select a set of actions $\boldsymbol{a}=(a_1, a_2, \ldots, a_m, null)$
- Start selecting (randomly, or combinatorially) actions
- Observe the effects on variables
  - Build a model of actions-effects: $(a_i, \boldsymbol{v}_t) \rightarrow \boldsymbol{v}_{t+1}$
  - Typically probabilistic: $P(\boldsymbol{v}_{t+1} | a_i, \boldsymbol{v}_t)$
  - The result is a Bayesian network with embedded causal relations (due to the possibility of controlling causes, i.e., actions ***a***)
- Learn to achieve goals
  - Given $\boldsymbol{v}_t$ and a goal $\boldsymbol{v}_G$
  - Select appropriate set of actions $(a_i, a_j, \ldots a_k)$

This is Not Reinforcement Learning

- Reinforcement Learning
  - Driven by rewards → goal-oriented
  - The goal is more on exploitation then exploration
  - Learn a policy π:$\boldsymbol{v}$→a without necessarily building a model of the world

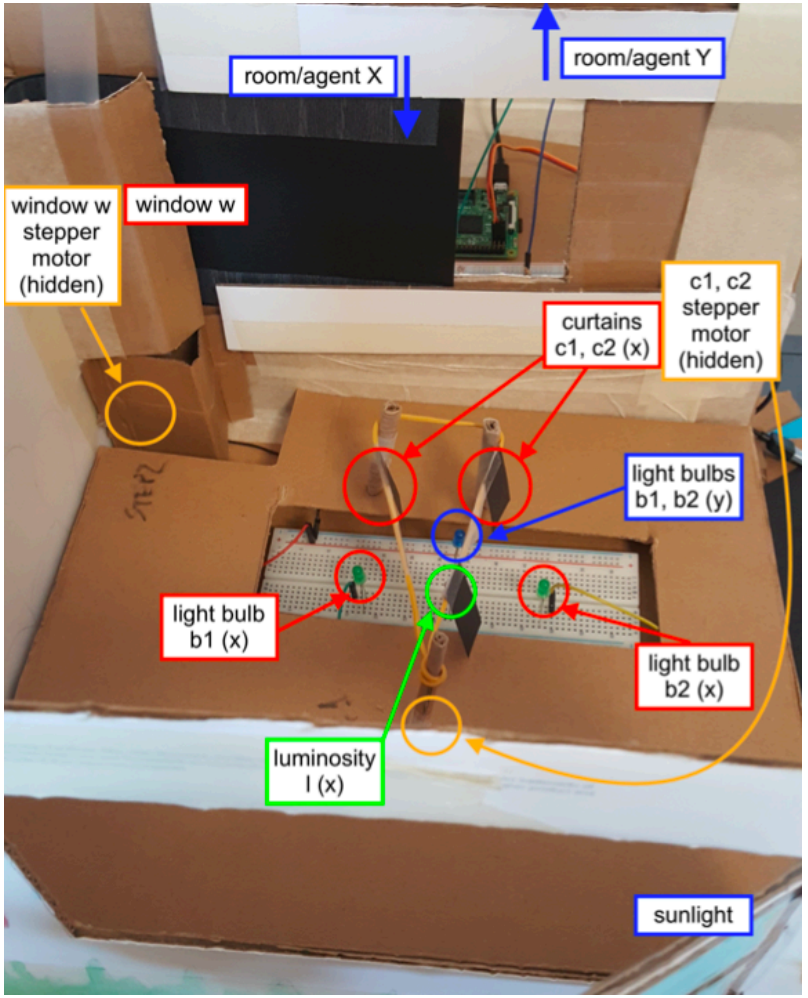
- Sense of agency
  - Driven by curiosity → intrinsic rewards
  - The goal is exploration → understanding how the world works and how I can affect it
  - It eventually builds a model of the world μ:$(a_i, \boldsymbol{v}_t)$ → $\boldsymbol{v}_{t+1}$
  - Autonomous mental development, self vs non-self

Related Work

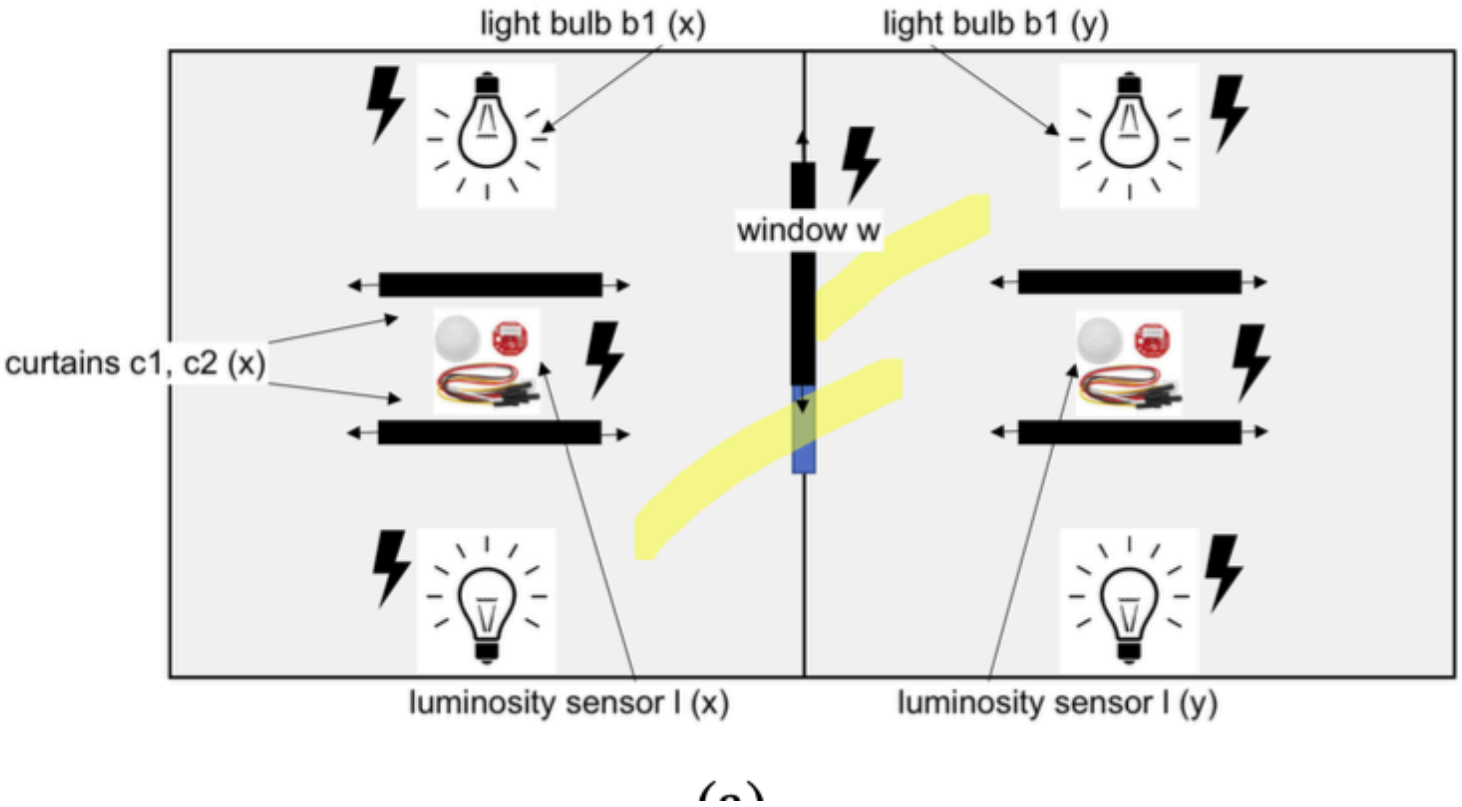
- Curriculum-based Reinforcement Learning
  - Learn starting from simple tasks in simple environments
  - To exploit the cumulated knowledge in increasingly complex environments
- Auto-curricula
  - Multiple agents in the environment
  - Contributing to autonomously increase the complexity of the environment
- Learning based on intrinsic motivation
  - Very similar to our approach
  - But we do intend to build an explicit (and explainable) causal model of the world
- Causal reasoning
  - Learning causal models of the world → not necessarily agent-oriented
  - We focus on agents and the sense of agency

The Smart Home Prototype

- Cardboard model of two adjacent rooms
- Two Arduinos, one for each room
- Lights
- Light sensors
- Actuator for curtains



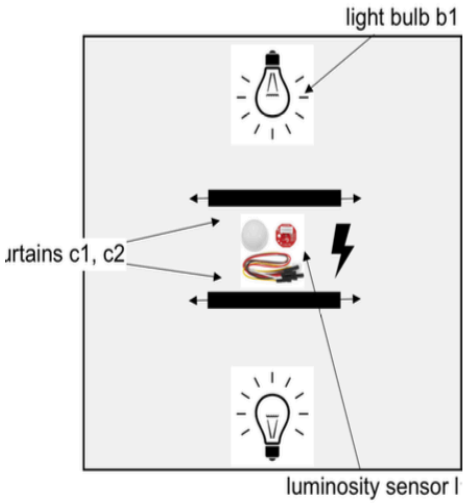
Smart Home Scheme

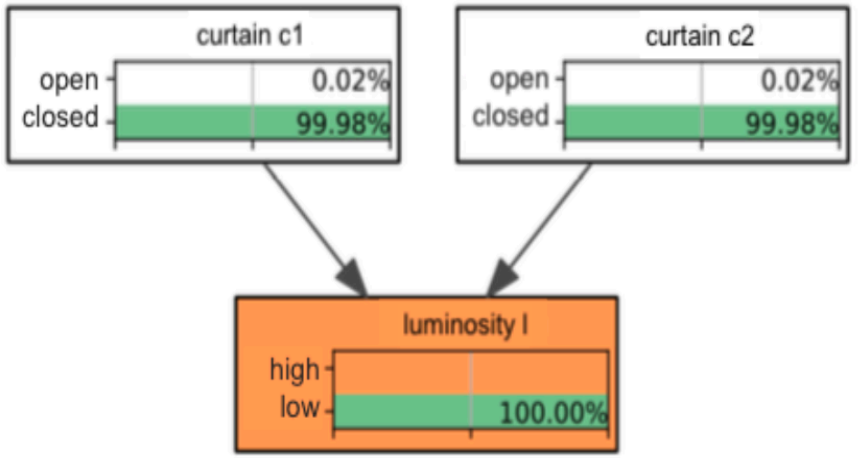


Experiments: Single Room (1)

- Assume the curtain between the two rooms is closed
- Each room can be dealt with independently as a single room

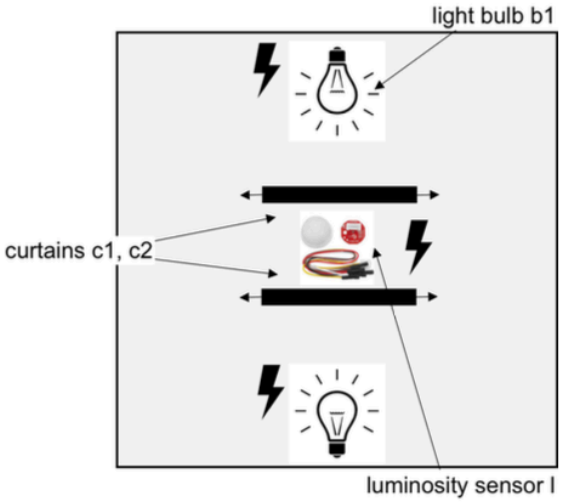
- If the light bulbs are not actuable
- The room autonomically discovers how to actuate curtains to achieve darkness

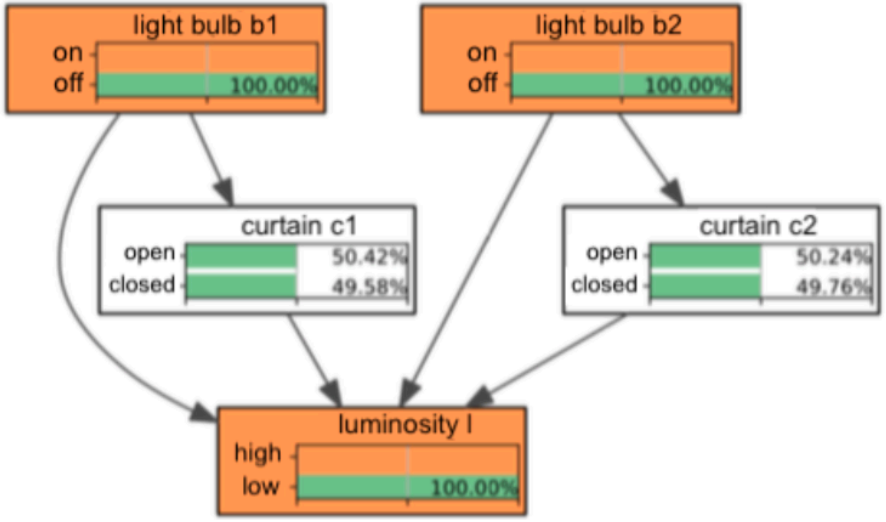




Experiments: Single Room (2)

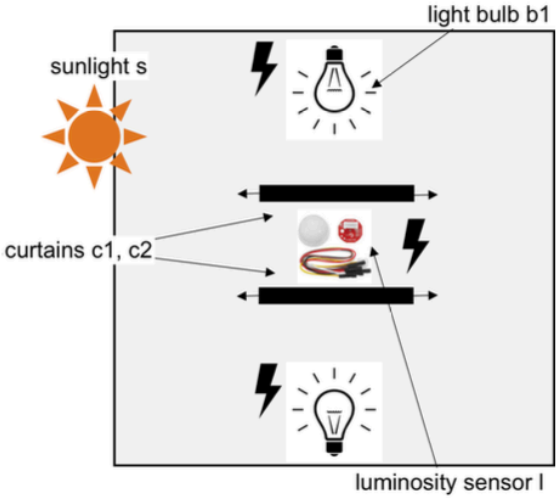
- If the light bulbs are actuable
- The room autonomically discover that is can achieve darkness by acting either on light bulbs or on curtains

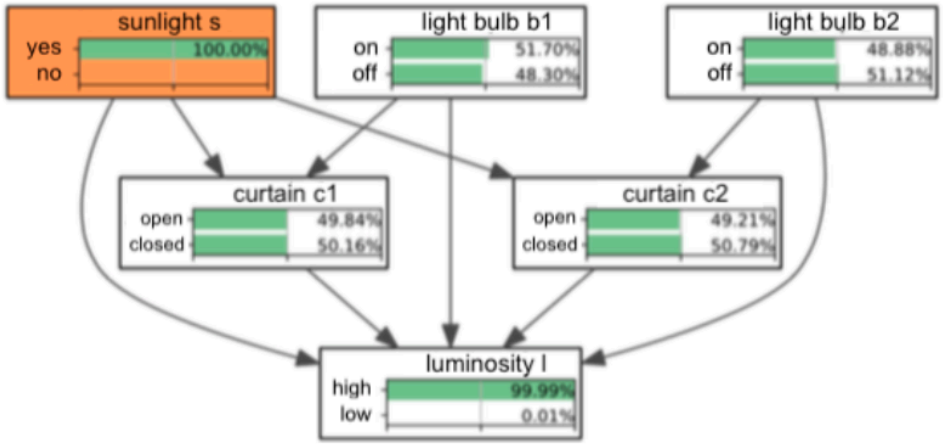




Experiments: Single Room (3)

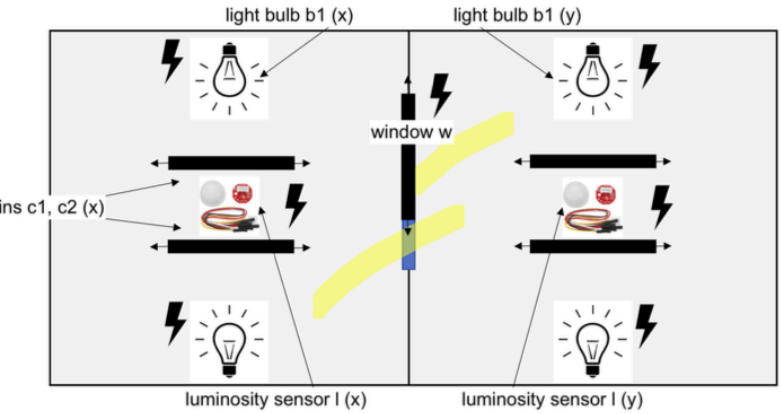
- If there is a windows letting sunlight in
- The room discovers that it can achieve darkness only probabilistically
- Or, by placing an external light sensor, that it cannot achieve darkness in the presence of external light

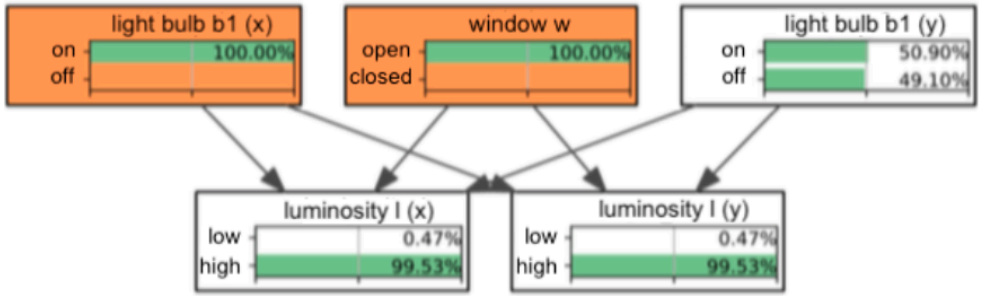




Experiments: Two Rooms (1)

- The two rooms are connected by a window, with a curtain
- The rooms both discover that they can achieve darkness only
  - When the window curtain is closed OR,
  - When the lights bulbs in the other room are off

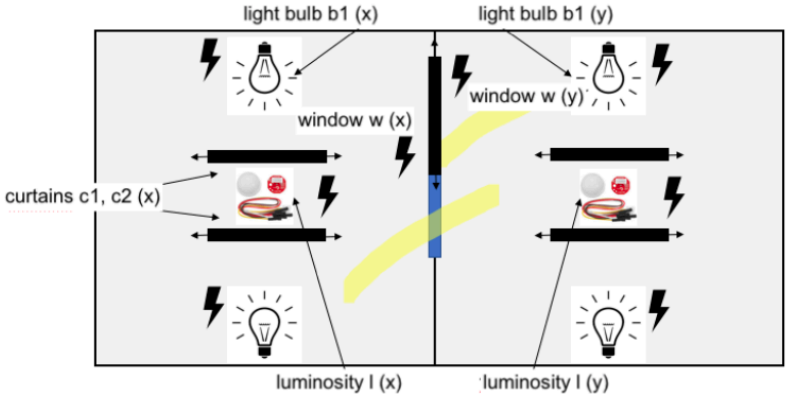




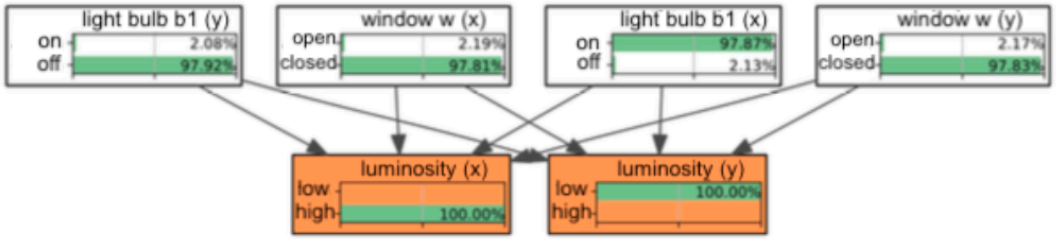
(b)

Experiments: Two Rooms (2)

- Eventually
- The two rooms discover that they can achieve their own individual goals (darkness or light) by agreeing on closing the window curtain



(a)



Conclusions

- The proposed approach seems promising
  - Early signs of the development of the “sense of agency”
  - Early capabilities of achieving simple goals
  - Early capabilities of emergent multiagent cooperation

- Future work
  - Experiment with more complex scenarios
  - Let agents test with “counterfactuals” to improve learning
  - Moving from simple goals to complex goal plannings