Rule-based Contextual Reasoning in Ambient Intelligence

Antonis Bikakis

Department of Information Studies
University College London

Dem@Care Summer School on Ambient Assisted Living

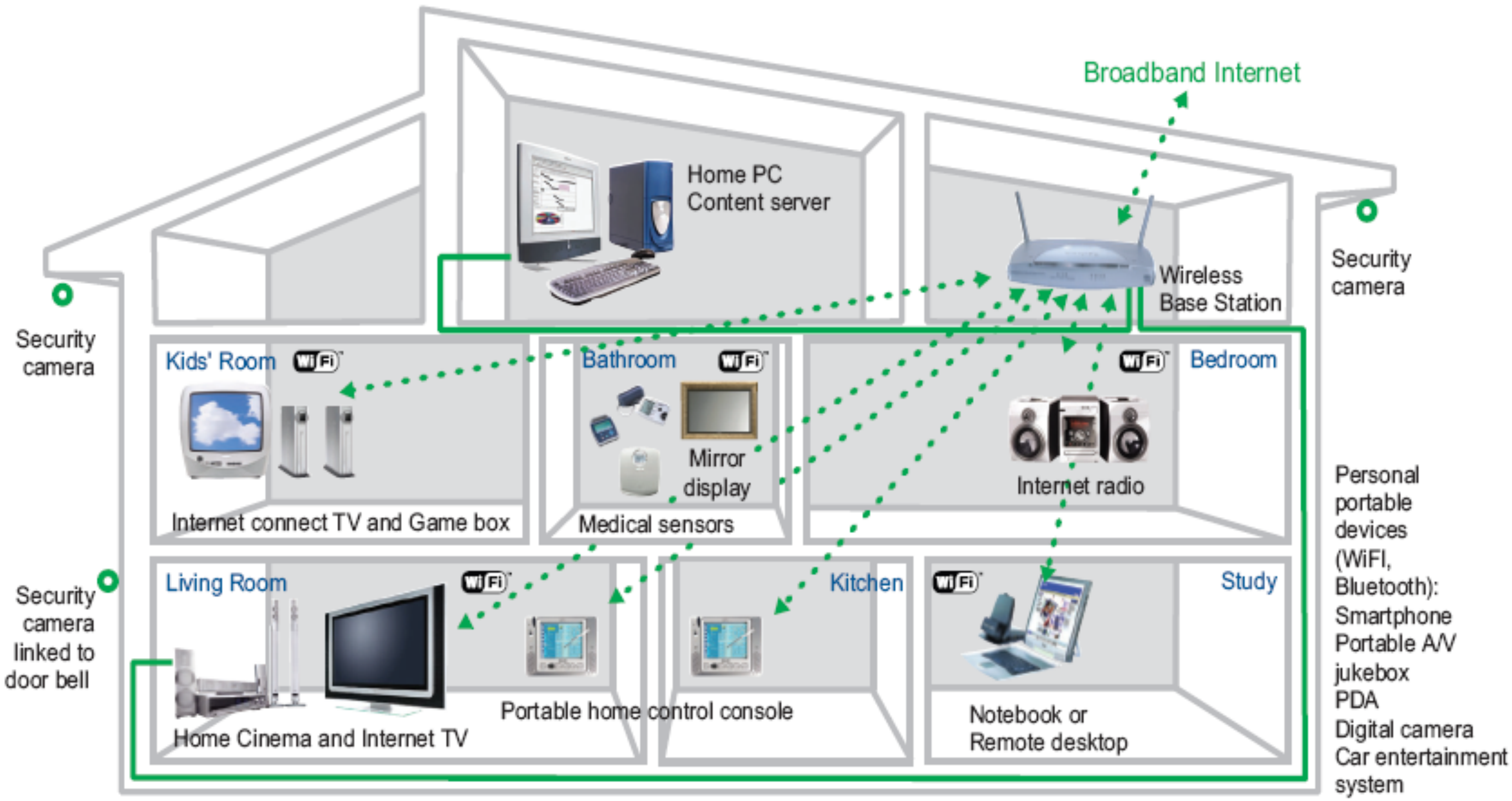
Chania, Crete, September 2013

Outline

- **Context and Contextual Reasoning in Ambient Intelligence**
- A Centralized Reasoning Framework
- R-CoRe – A Distributed Approach
- Centralized vs. Distributed Reasoning
- Open Problems

Ambient Intelligence

- **Goal**: Transform our living and working environments into smart spaces
- **Requirement**: Augment environments with sensing, computing, communication and reasoning capabilities



Context

Context is any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and application, including the user and applications themselves

[Dey and Abowd, 1999]

Context Representation

- Key-value models
  - Service: list of attributes in a key-value manner
- Markup scheme models
  - XML-based
- Graphical models
  - UML like
- Object oriented models
  - Context data encapsulated in data objects
- Logic-based models
  - First Order Logic, Logic Programming
- Ontology-based models
  - Based on Description Logics

Contextual Reasoning

- Aims
  - Inference of high-level context knowledge
  - Consistency checking
  - Context-aware decision making
- Challenges
  - Imperfect context information
  - Heterogeneous entities
  - Highly dynamic and open environments
  - Distributed context information
  - Unreliable wireless communications
  - …restricted by the range of transmitters

Contextual Reasoning (cont'd)

- Approaches
  - Ontological reasoning
    - DL rules used to derive implicit knowledge
    - \+ Natural integration with ontology model
    - – Limited reasoning capabilities
  - Rule-based reasoning
    - More expressive rule languages
    - FOL, Logic Programming, Defeasible Logic
  - Probabilistic reasoning
    - Explicit model uncertainty, confidence values, causal relationships
    - \+ Rich expressive capabilities
    - – High complexity

Rule-based Contextual Reasoning

- Benefits
  - Simplicity & Flexibility
  - Formality
  - Expressiveness
  - Modularity
  - High-level abstraction & Information hiding
  - Integration with ontology languages

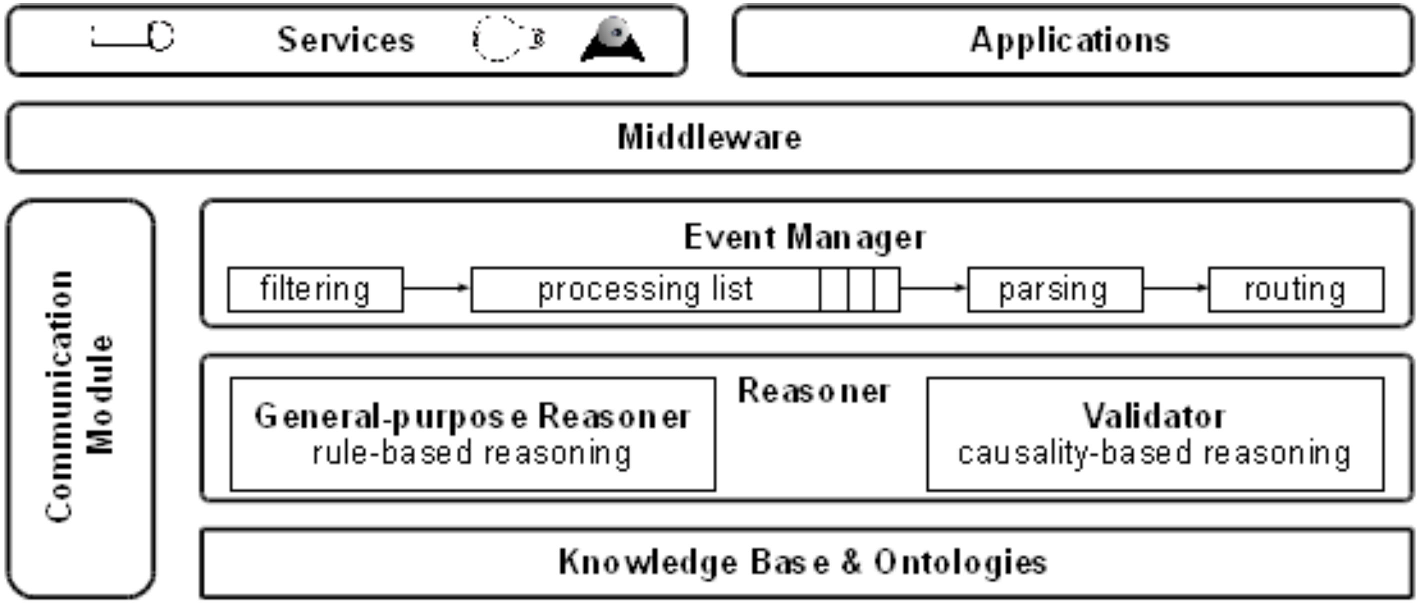
Outline

- Context and Contextual Reasoning in Ambient Intelligence
- **A Centralized Reasoning Framework**
- R-CoRe – A Distributed Approach
- Centralized vs. Distributed Reasoning
- Open Problems

Aims & Architecture

- Part of a large-scale Ambient Intelligence facility developed for the needs of the ICS-FORTH **Ambient Intelligence Programme**

- Design Goals
  - efficient representation, monitoring, dissemination of context
  - reasoning about the available information
  - context-aware decisions



Rule Types

- Inference rules
  - Triggered by new assertions in the KB
  - Assert new relations in the KB
- Action rules
  - Reactive (to events) or Triggered (by assertions in the KB)
  - Assert new relations in the KB
  - Determine and send commands for actions
- Rule Scheme (ECA)

```
event(E),/* received from middleware and added as fact in KB */
precondition(C1),…, precondition(Ck) /* relations in KB */
 -> action(A1),…, action(An) /* functions for KB update or
                                 commands for actions sent to middleware */
```

Special Features

- Seamless Interaction
  - Adjust services to user's context
  - Achieved through
    - Sensing – keep track of user's context
    - high-level context inference – identify state / situation
    - context-aware reasoning – situation-based policies
- Vast amount of context information
  - Context Classification
  - Context Segmentation
- Inconsistency Resolution
  - Conflicts due to competing policies
  - Priority-based rule classification

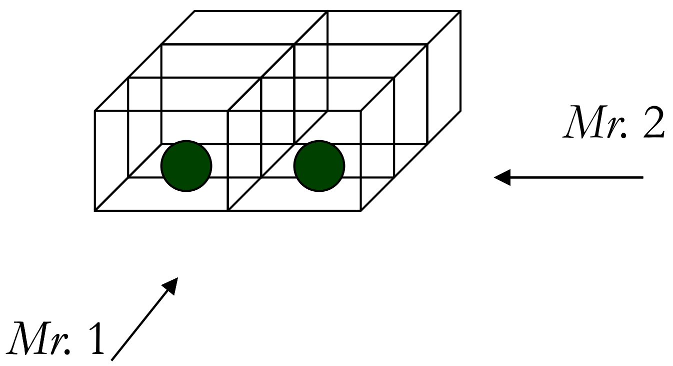
Outline

- Context and Contextual Reasoning in Ambient Intelligence
- A Centralized Reasoning Framework
- **R-CoRe: A Distributed Approach**
- Centralized vs. Distributed Reasoning
- Demo

Features & Underlying Technologies

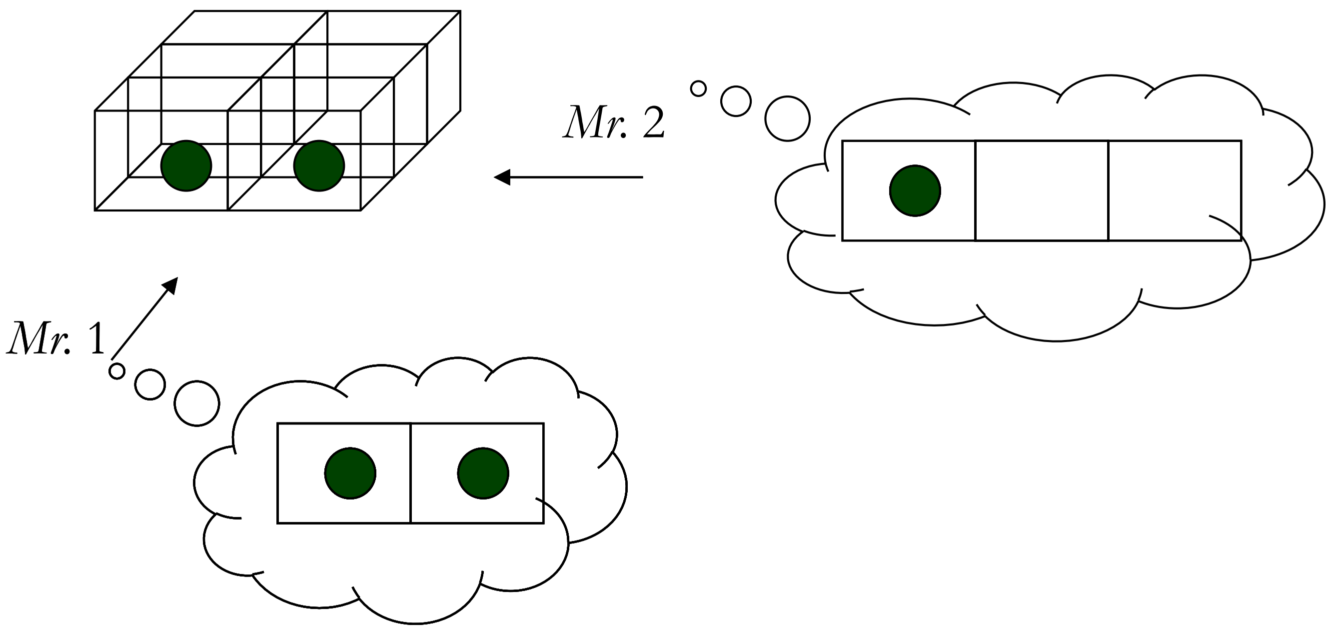
- **R-CoRe**: A **R**ule-based **Co**ntextual **Re**asoning Platform for AmI
- Developed with SnT Luxembourg for the needs of the **CoPAInS** (**Co**nviviality and **P**rivacy in **A**mbient **In**telligence **S**ystems) project
  - Funded by FNR Luxembourg
- Main Features
  - **Distributed**
  - **Rule-based**
  - **Non-monotonic**
  - **Preference-based conflict resolution**
  - **Dynamic & Adaptive**
- Underlying technologies
  - **Multi-Context Systems**
  - **Contextual Defeasible Logic (CDL)**
  - **Kevoree**

Multi-Context Systems: The *magic box* example

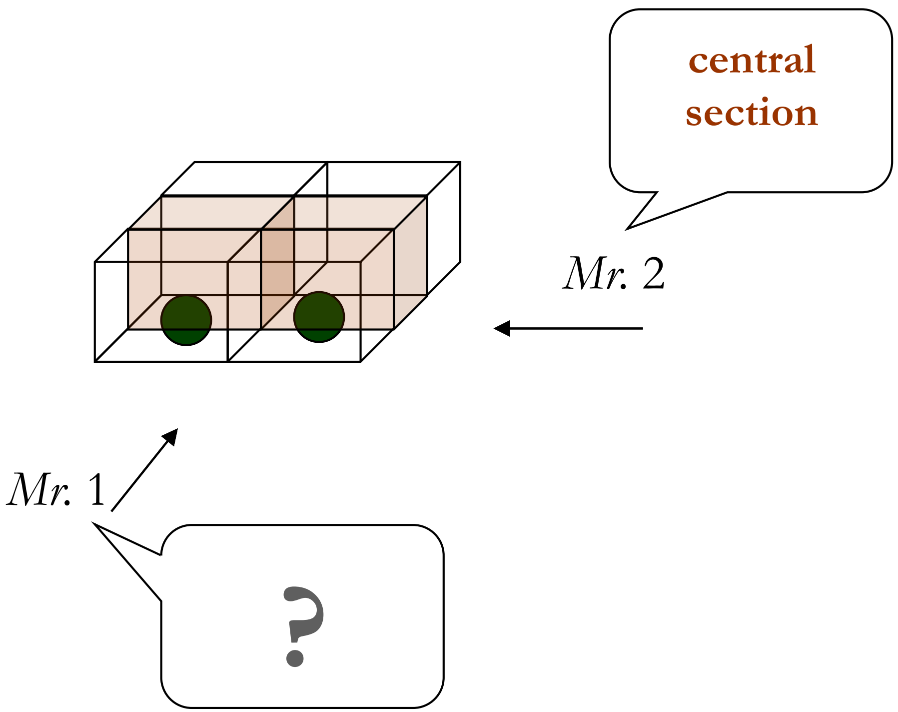


Multi-Context Systems: The *magic box* example

- None of the observers can make out the depth of the box

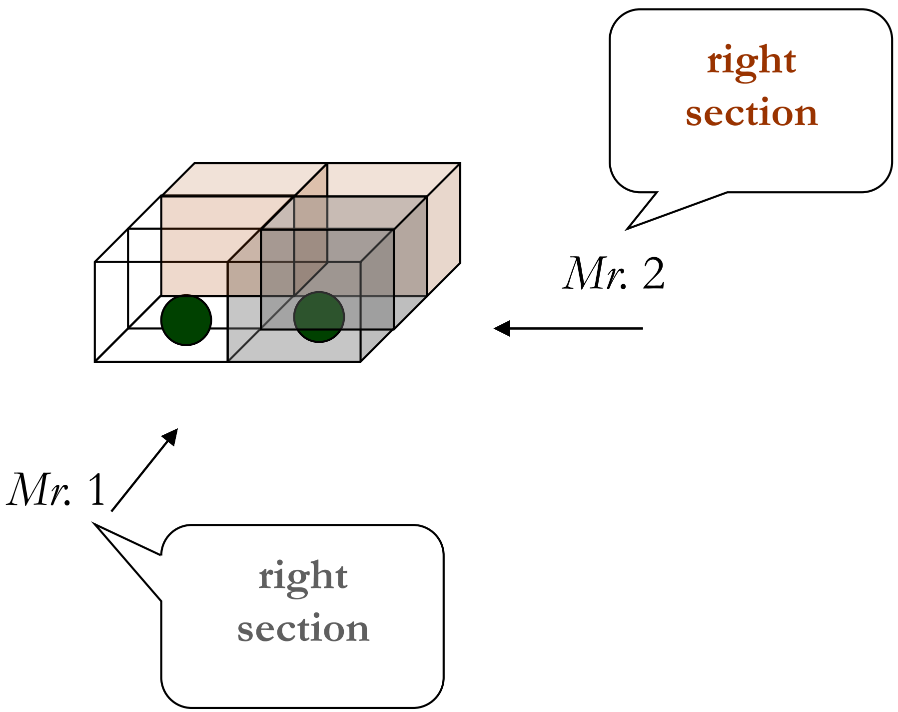


Multi-Context Systems: The *magic box* example



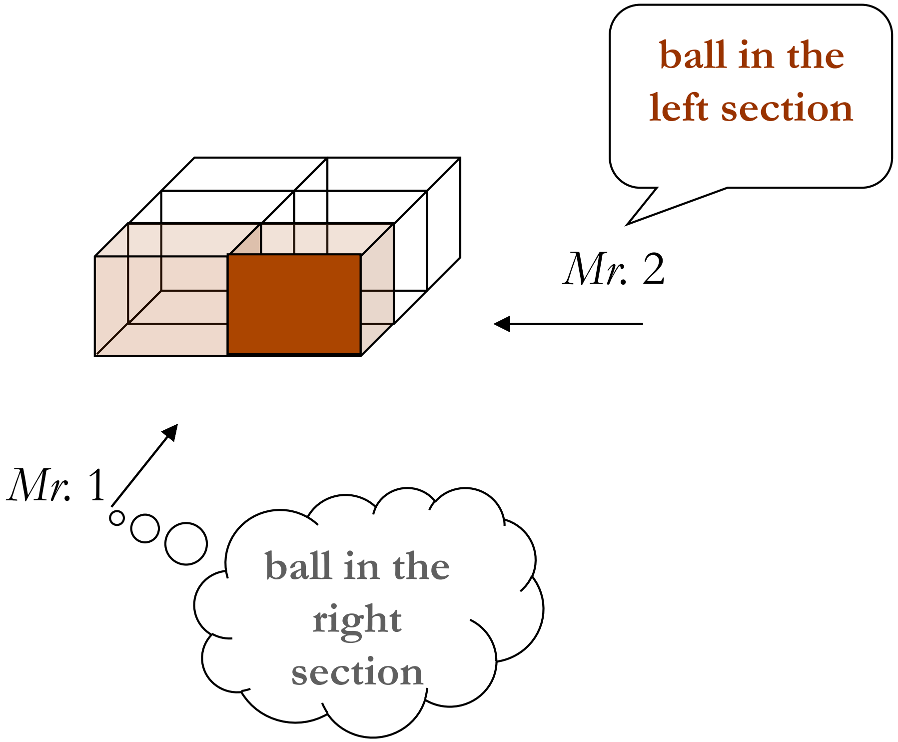
- None of the observers can make out the depth of the box
- Mr. 1's beliefs may regard concepts that are meaningless for Mr.2 and vice versa

Multi-Context Systems: The *magic box* example



- None of the observers can make out the depth of the box
- Mr. 1's beliefs may regard concepts that are meaningless for Mr.2 and vice versa
- Mr. 1 and Mr. 2 may use common concepts but interpret them in different ways

Multi-Context Systems: The *magic box* example



- None of the observers can make out the depth of the box
- Mr. 1's beliefs may regard concepts that are meaningless for Mr.2 and vice versa
- Mr. 1 and Mr. 2 may use common concepts but interpret them in different ways
- The observers may have partial access to each other's beliefs about the box.

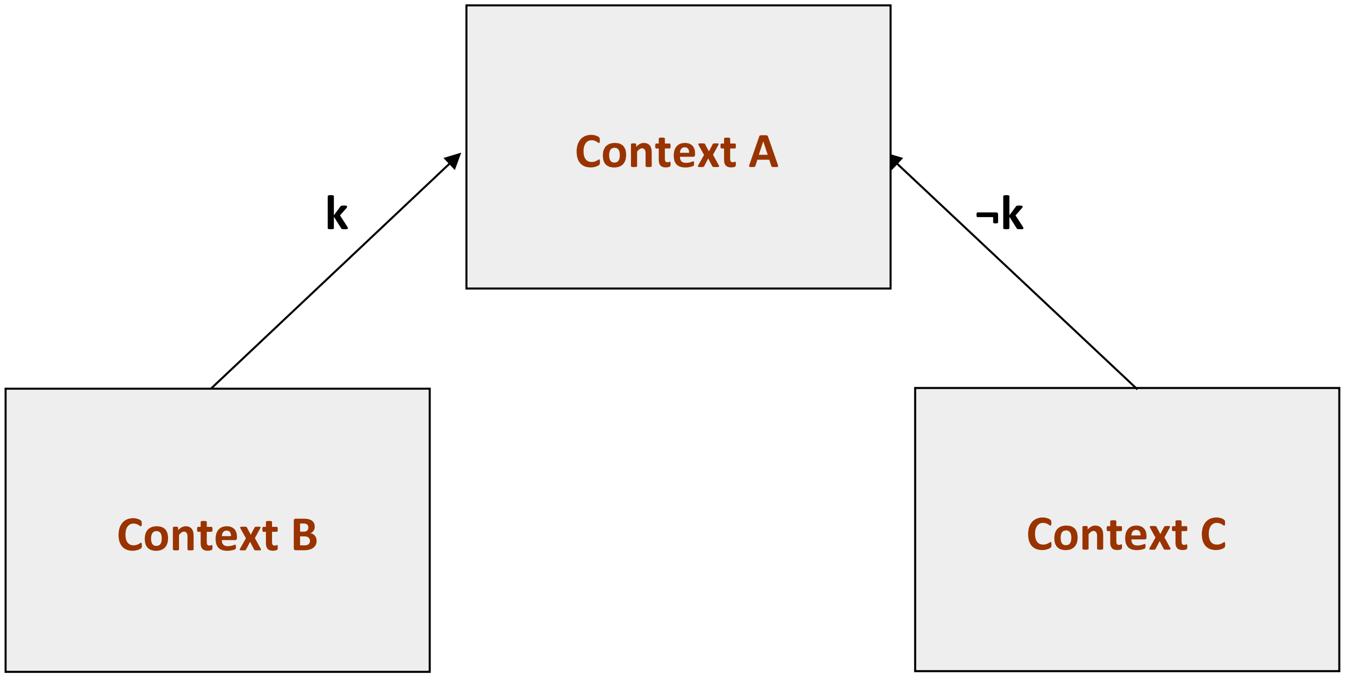
Multi-Context Systems: Intuitions and Model

- Context
  - A **partial** and **approximate** theory of the world from some individual's **perspective**
  - A logical theory – a set of axioms and inference rules

- Multi-Context Systems
  - **Distributed context theories** connected through **mappings** that enable information flow between different contexts
  - Mappings modeled as inference rules with premises and consequences in different contexts

Nonmonotonic MCS

- MCS enriched with **nonmonotonic** features to handle imperfections, e.g. incomplete knowledge, inconsistencies



Contextual Defeasible Logic

A Defeasible MCS C is a collection of contexts C_i

Each context C_i is a tuple (V_i, R_i, T_i)

- V_i : vocabulary used by C_i
- R_i : set of rules
- T_i : preference ordering on C

V_i : a set of literals of the form $a, \neg a$

Contextual Defeasible Logic (cont'd)

Three types of rules in R_i

- Strict local rules

  $r_i^l : (c_i : a^1), \ldots, (c_i : a^{n-1}) \rightarrow (c_i : a^n)$

- Defeasible local rules

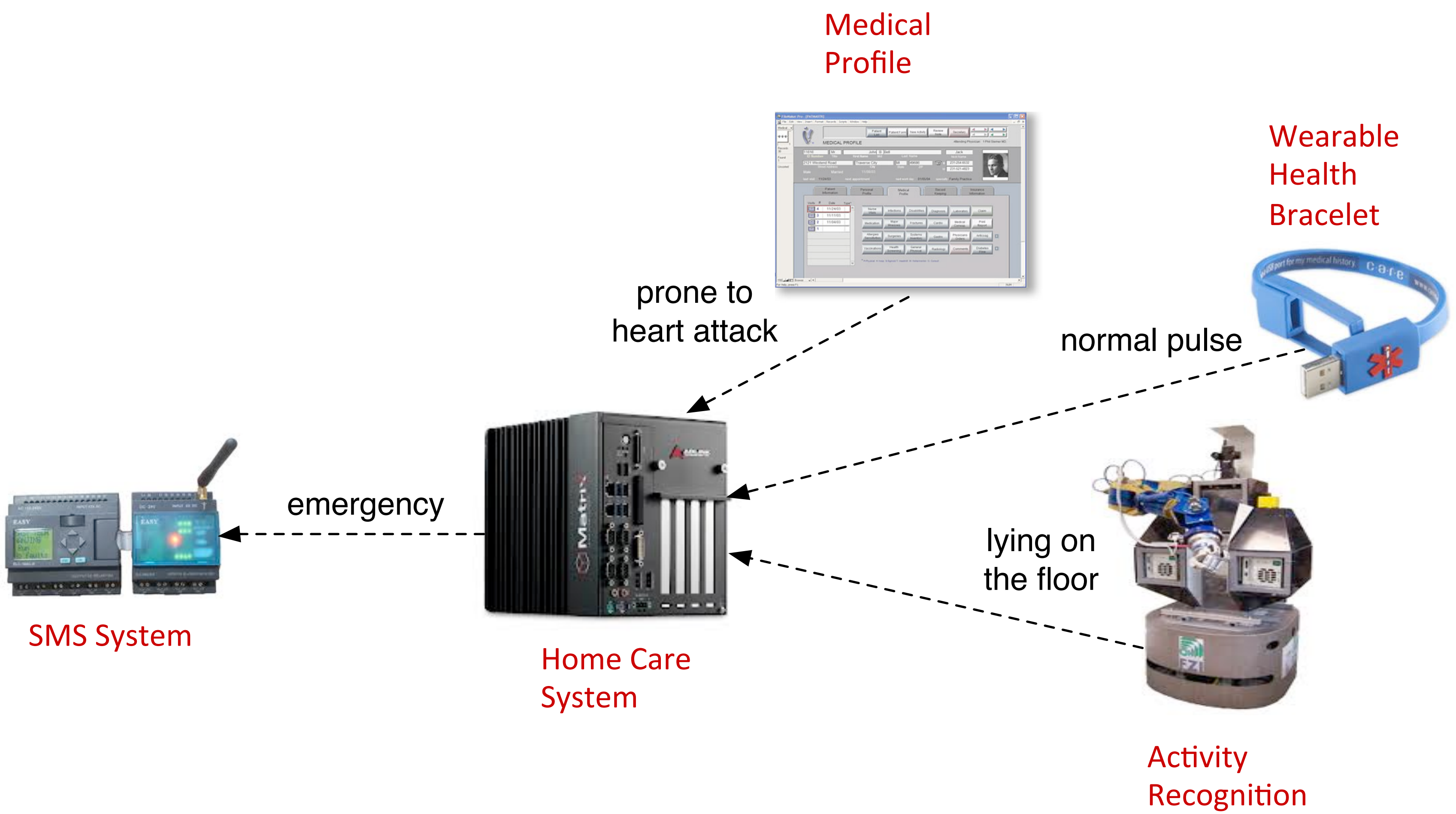
  $r_i^d : (c_i : a^1), \ldots, (c_i : a^{n-1}) \Rightarrow (c_i : a^n)$

- Mapping rules

  $r_i^m : (c_j : a^1), \ldots, (c_k : a^{n-1}) \Rightarrow (c_i : a^n)$

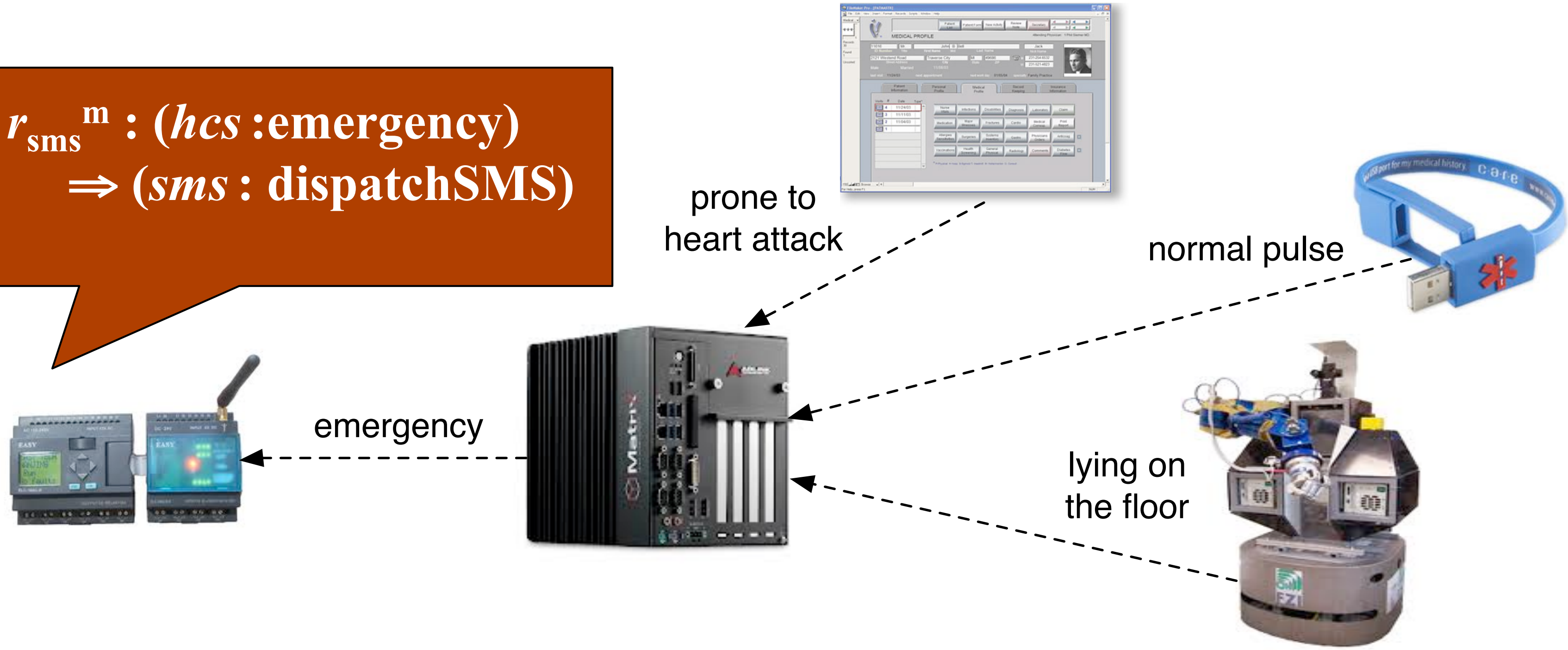
T_i is a partial preference ordering on C modeled as a Directed Acyclic Graph

AAL Example Scenario



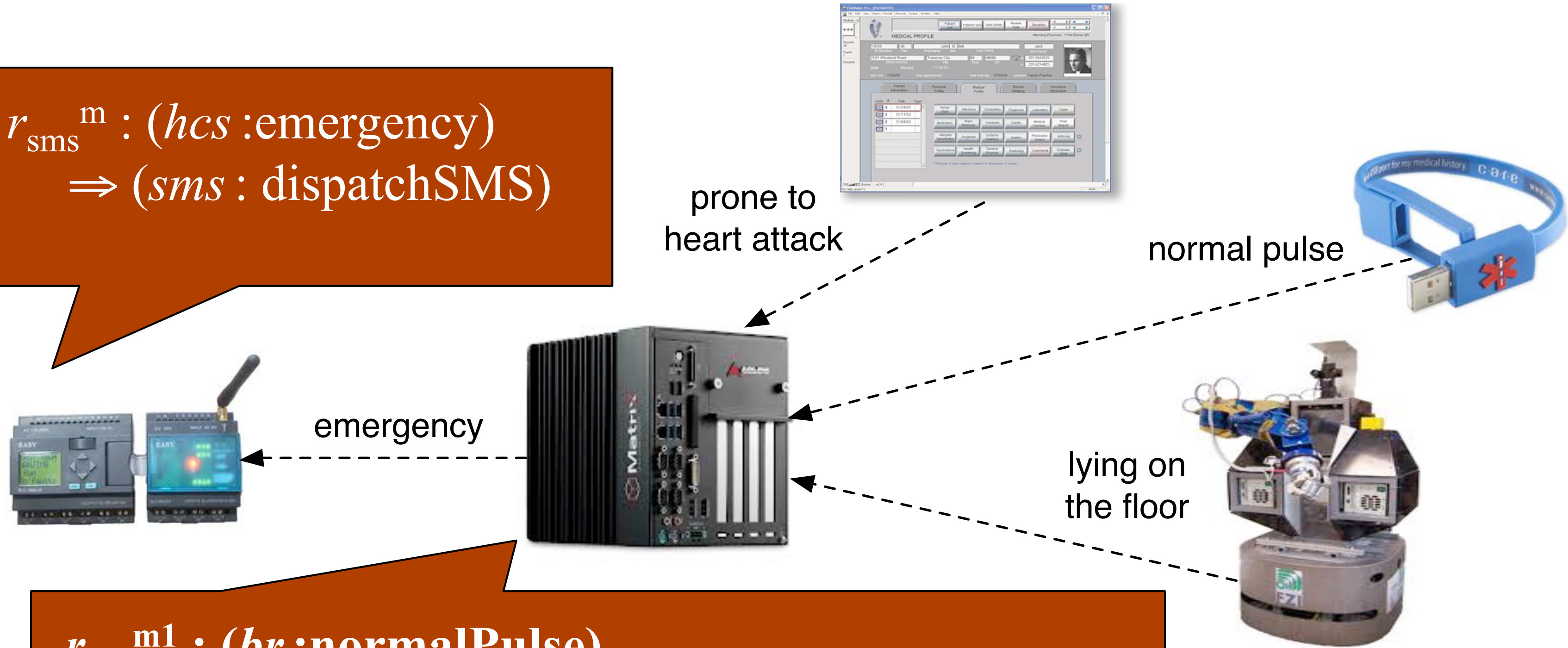
Example Scenario in CDL terms

$$r_{sms}^{m} : (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS})$$



Example Scenario in CDL terms

$$r_{sms}^{m} : (hcs : \mathrm{emergency}) \Rightarrow (sms : \mathrm{dispatchSMS})$$



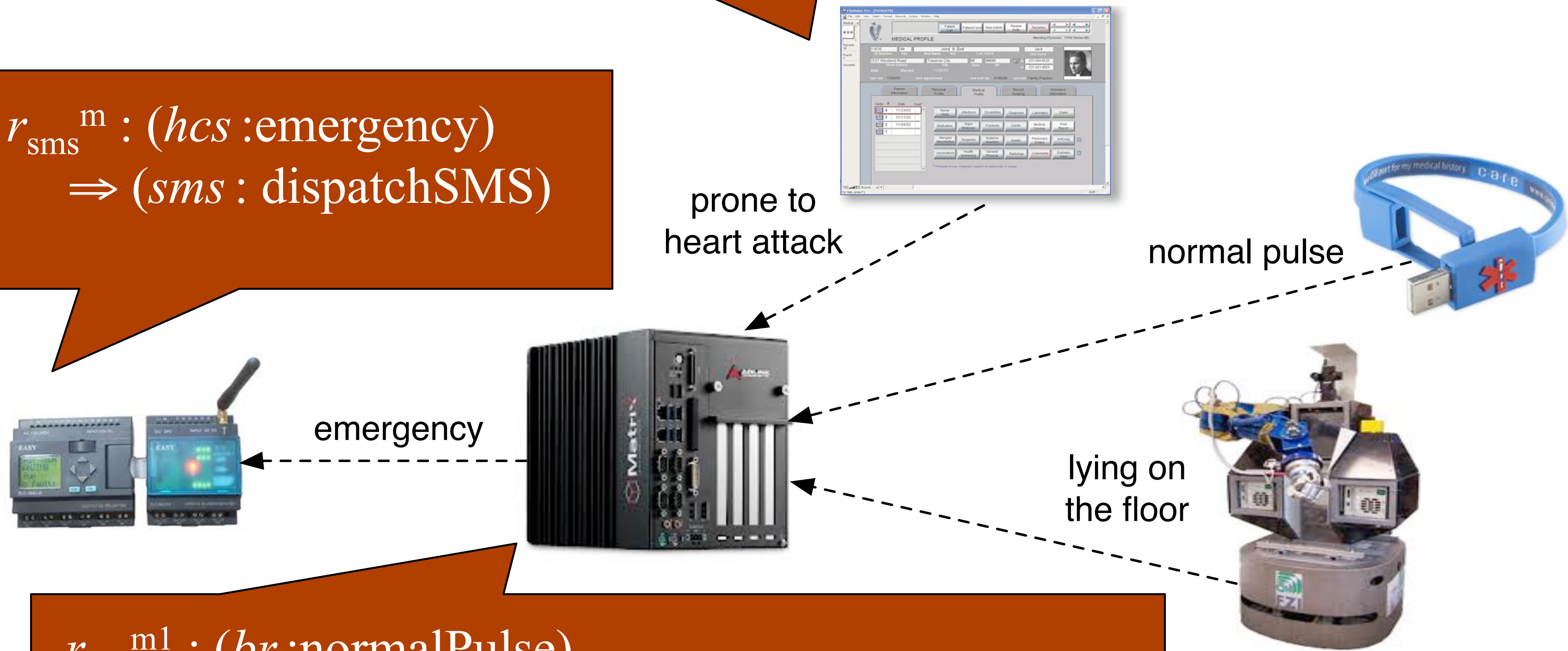
$$r_{hcs}^{m1} : (br : \mathrm{normalPulse}) \Rightarrow (hcs : \neg\ \mathrm{emergency})$$

$$r_{hcs}^{m2} : (arm : \mathrm{lyingOnFloor}), (med : \mathrm{proneToHA}) \Rightarrow (hcs : \mathrm{emergency})$$

Example Scenario in CDL terms

$$r_{\mathrm{med}}^{\mathrm{l}} : \rightarrow (med : \mathrm{proneToHA})$$

$$r_{\mathrm{sms}}^{\mathrm{m}} : (hcs : \mathrm{emergency}) \Rightarrow (sms : \mathrm{dispatchSMS})$$



$$r_{\mathrm{hcs}}^{\mathrm{m1}} : (br : \mathrm{normalPulse}) \Rightarrow (hcs : \neg\, \mathrm{emergency})$$

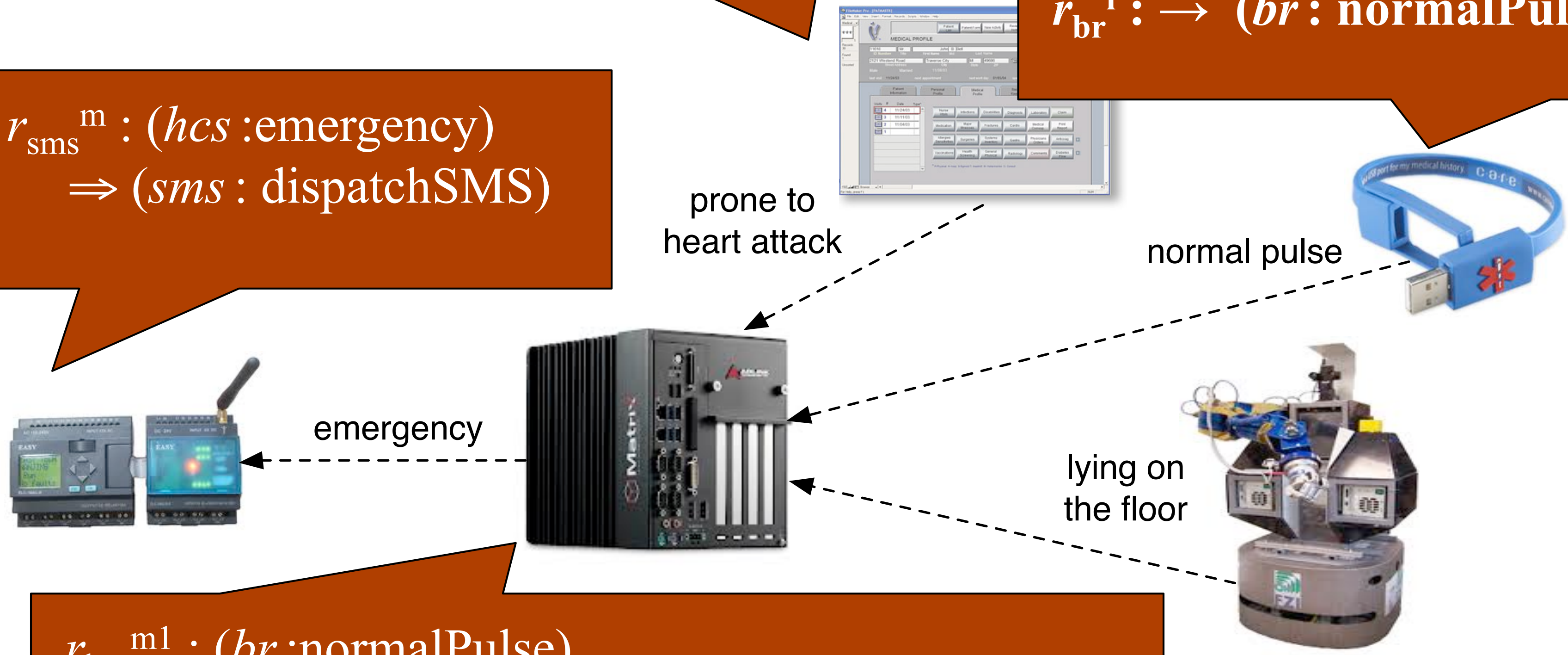
$$r_{\mathrm{hcs}}^{\mathrm{m2}} : (arm : \mathrm{lyingOnFloor}), (med : \mathrm{proneToHA}) \Rightarrow (hcs : \mathrm{emergency})$$

Example Scenario in CDL terms

$r_{med}^{1} : \rightarrow (med : \text{proneToHA})$

$r_{br}^{1} : \rightarrow (br : \textbf{normalPulse})$

$r_{sms}^{m} : (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS})$



$r_{hcs}^{m1} : (br : \text{normalPulse}) \Rightarrow (hcs : \neg\, \text{emergency})$

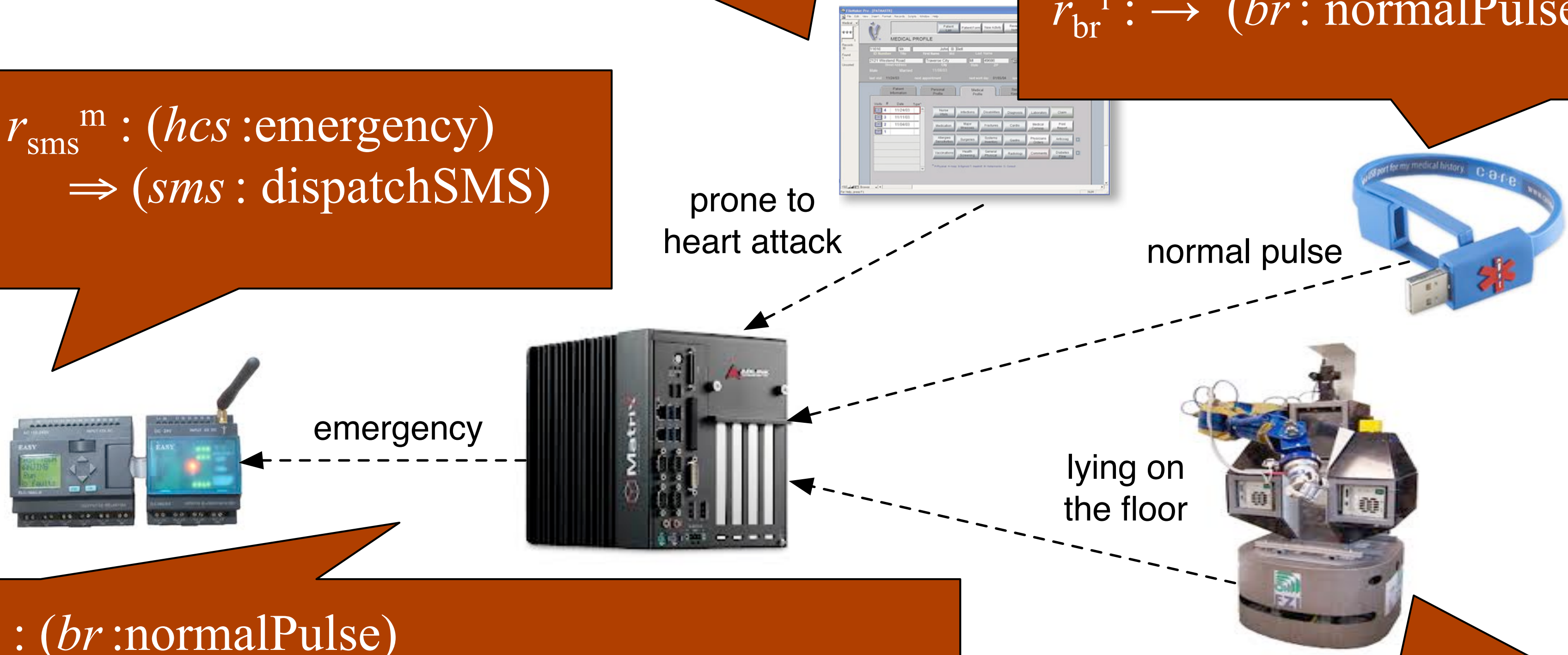
$r_{hcs}^{m2} : (arm : \text{lyingOnFloor}), (med : \text{proneToHA}) \Rightarrow (hcs : \text{emergency})$

Example Scenario in CDL terms

$r_{med}^{1} : \rightarrow (med : \mathrm{proneToHA})$

$r_{br}^{1} : \rightarrow (br : \mathrm{normalPulse})$

$r_{sms}^{m} : (hcs : \mathrm{emergency}) \Rightarrow (sms : \mathrm{dispatchSMS})$



$r_{hcs}^{m1} : (br : \mathrm{normalPulse}) \Rightarrow (hcs : \neg\, \mathrm{emergency})$

$r_{hcs}^{m2} : (arm : \mathrm{lyingOnFloor}), (med : \mathrm{proneToHA}) \Rightarrow (hcs : \mathrm{emergency})$

$\boldsymbol{r_{arm}^{1} : \rightarrow (arm : \mathrm{lyingOnFloor})}$

Distributed Query Evaluation

- When a context receives a query for one of its local literals q
  - Evaluates answer based on local knowledge

  If not possible

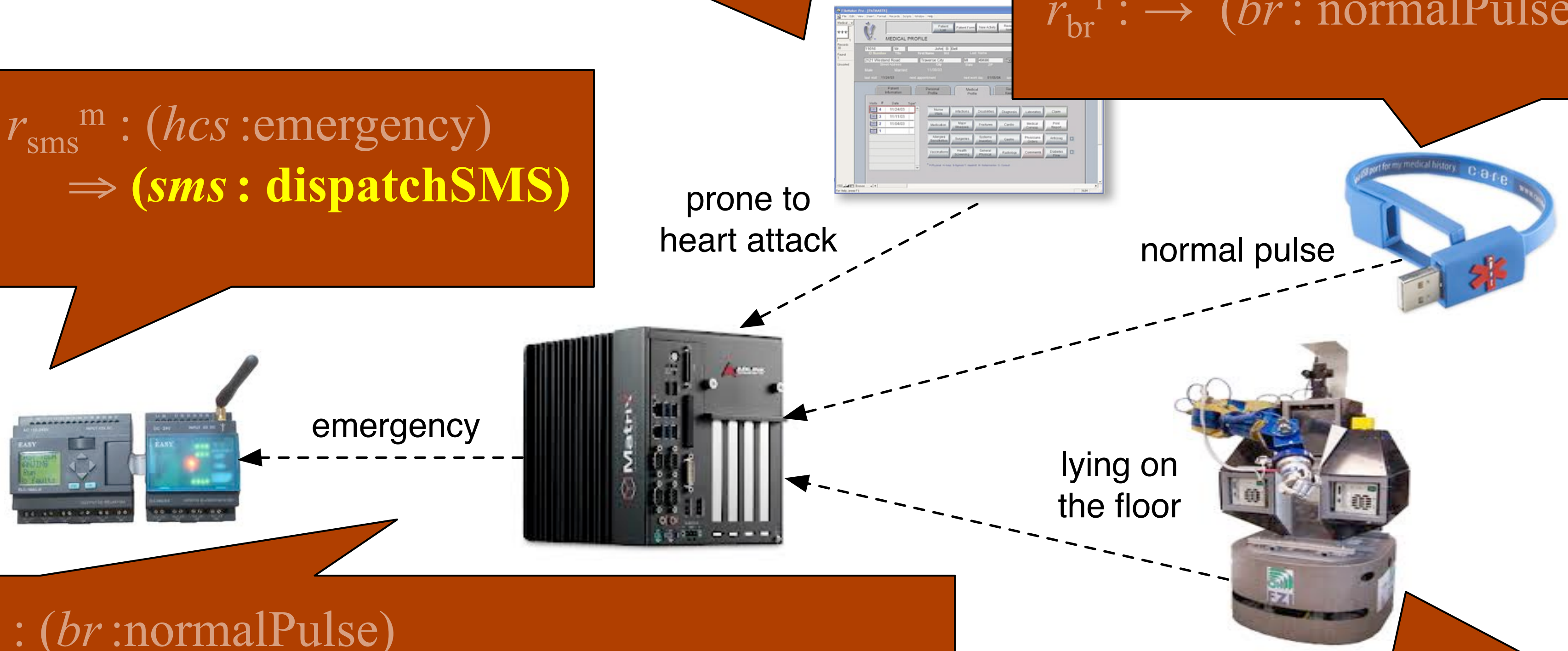
  - Collects relevant information from other contexts through mappings
  - Checks applicability of rules *for* and *against* q
  - Evaluates answer based on
    - Applicable rules
    - Preferences

Example Scenario: Query Evaluation

$r_{\text{med}}^{1} : \rightarrow\ (med : \text{proneToHA})$

$r_{\text{br}}^{1} : \rightarrow\ (br : \text{normalPulse})$

$r_{\text{sms}}^{m} : (hcs : \text{emergency})$
$\quad \Rightarrow \mathbf{(\mathit{sms} : dispatchSMS)}$



$r_{\text{hcs}}^{m1} : (br : \text{normalPulse})$
$\quad \Rightarrow (hcs : \neg\ \text{emergency})$
$r_{\text{hcs}}^{m2} : (arm : \text{lyingOnFloor}), (med : \text{proneToHA})$
$\quad \Rightarrow (hcs : \text{emergency})$

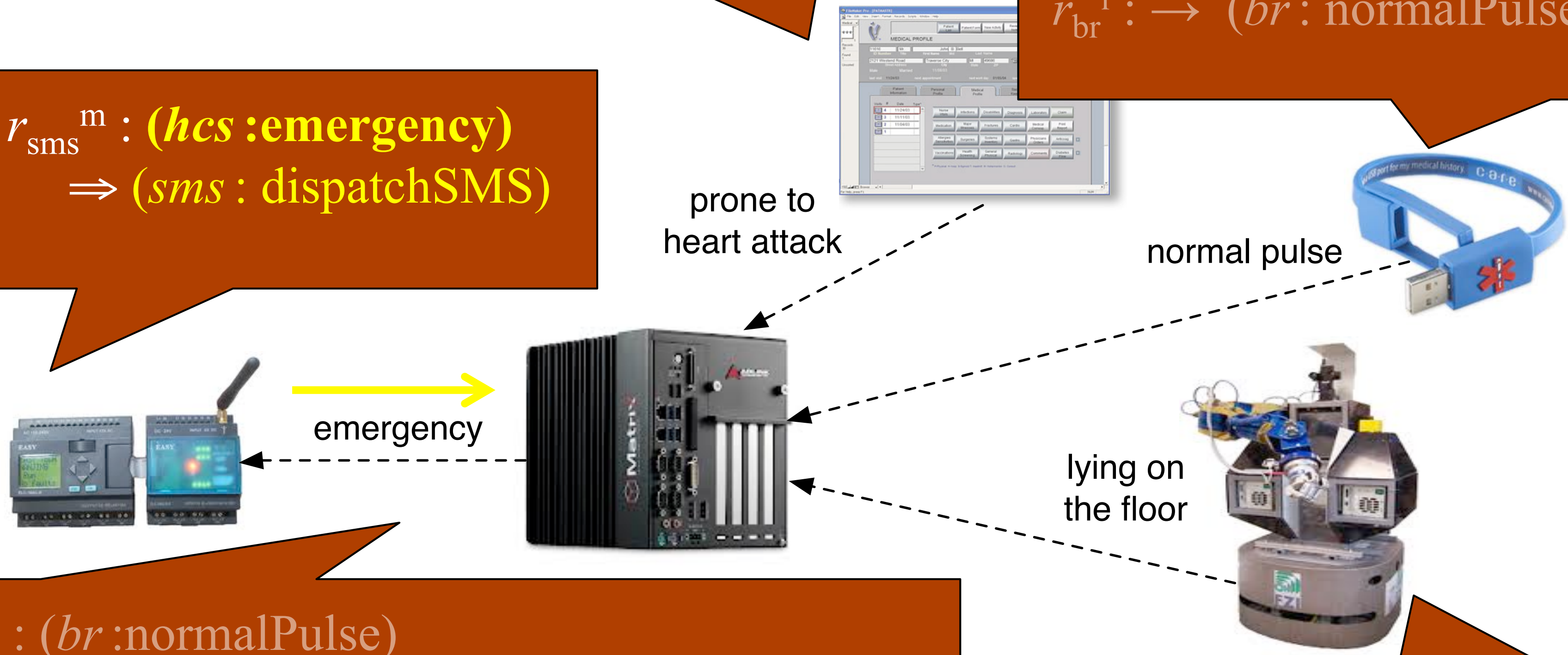
$r_{\text{arm}}^{1} : \rightarrow\ (arm : \text{lyingOnFloor})$

Example Scenario: Query Evaluation

$r_{med}^{1}: \rightarrow (med : \text{proneToHA})$

$r_{br}^{1}: \rightarrow (br : \text{normalPulse})$

$r_{sms}^{m}: (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS})$



$r_{hcs}^{m1}: (br : \text{normalPulse}) \Rightarrow (hcs : \neg\, \text{emergency})$

$r_{hcs}^{m2}: (arm : \text{lyingOnFloor}), (med : \text{proneToHA}) \Rightarrow (hcs : \text{emergency})$

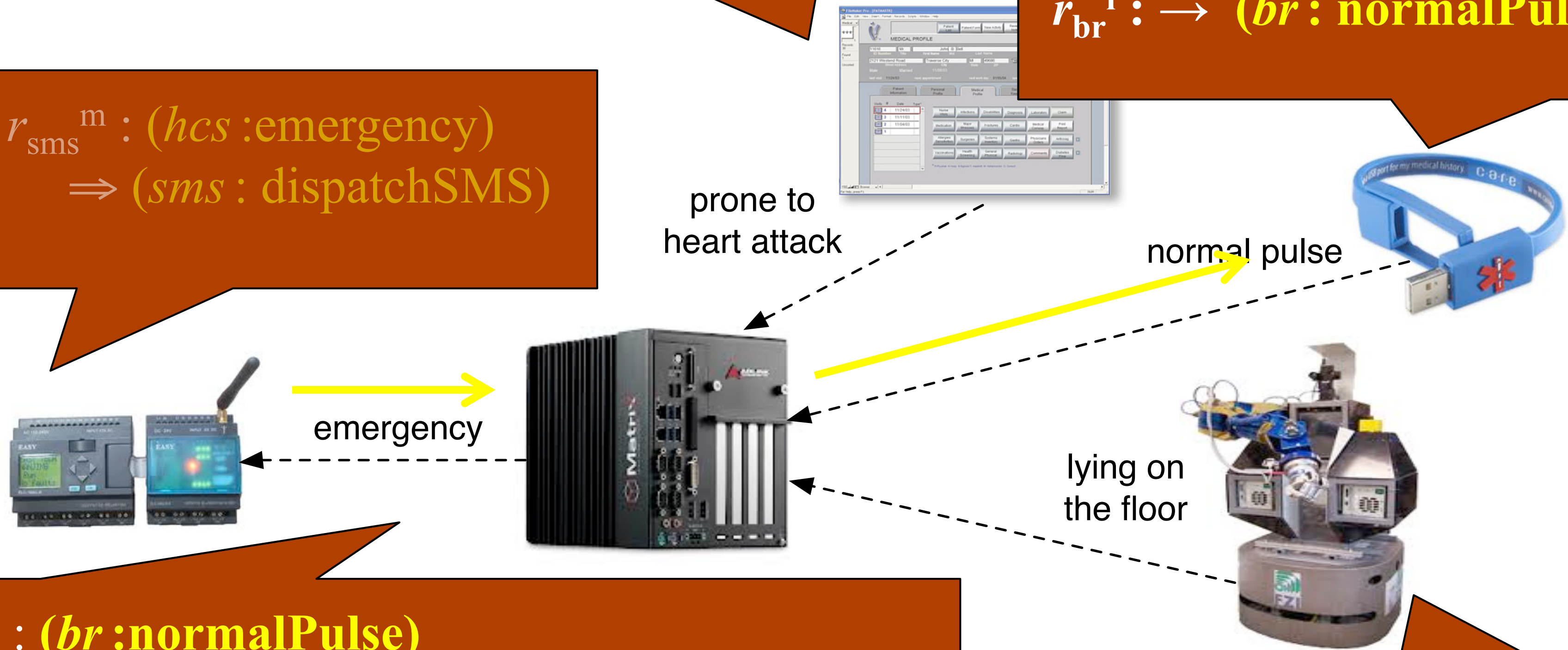
$r_{arm}^{1}: \rightarrow (arm : \text{lyingOnFloor})$

Example Scenario: Query Evaluation

$r_{med}^{1} : \rightarrow (med : \text{proneToHA})$

$r_{br}^{1} : \rightarrow (br : \text{normalPulse})$

$r_{sms}^{m} : (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS})$



$r_{hcs}^{m1} : (br : \text{normalPulse}) \Rightarrow (hcs : \neg\, \text{emergency})$

$r_{hcs}^{m2} : (arm : \text{lyingOnFloor}), (med : \text{proneToHA}) \Rightarrow (hcs : \text{emergency})$

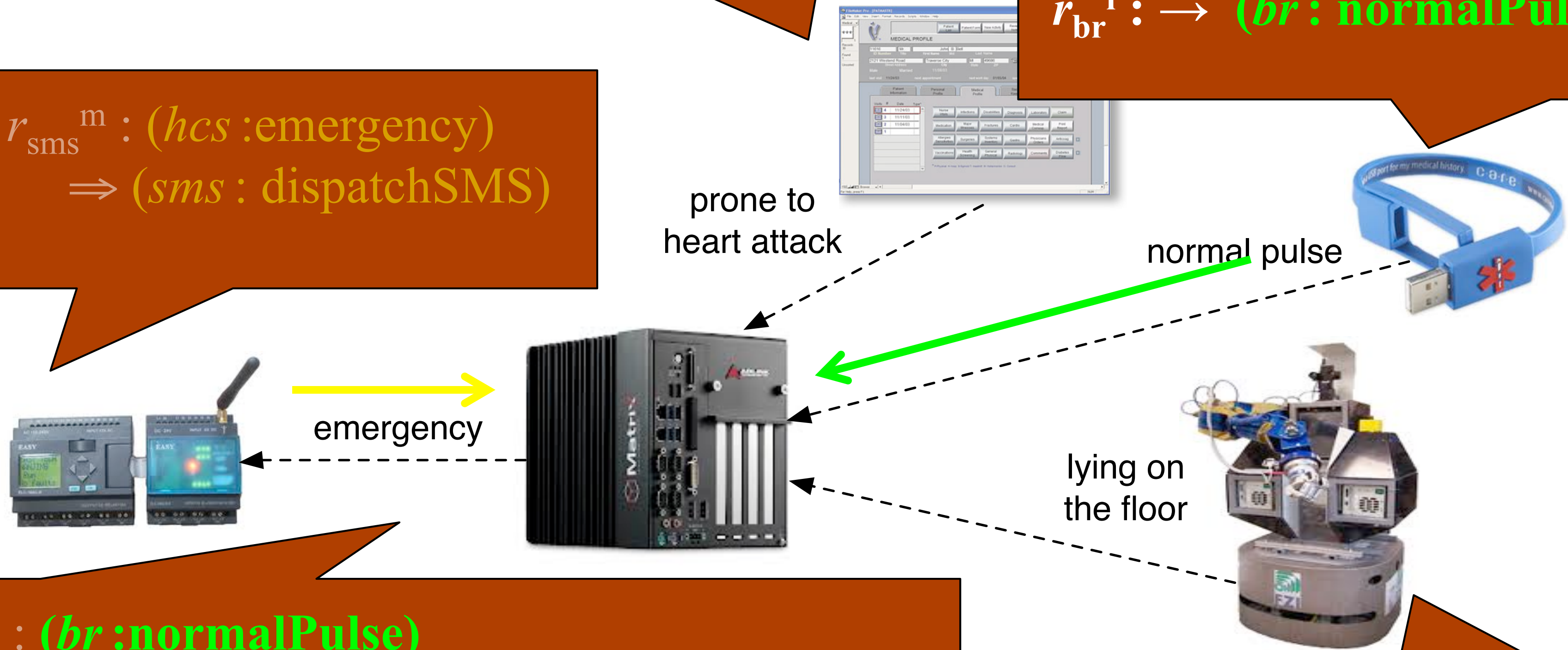
$r_{arm}^{1} : \rightarrow (arm : \text{lyingOnFloor})$

Example Scenario: Query Evaluation

$r_{med}^{1} : \rightarrow \ (med : \mathrm{proneToHA})$

$r_{br}^{1} : \rightarrow \ (br : \mathrm{normalPulse})$

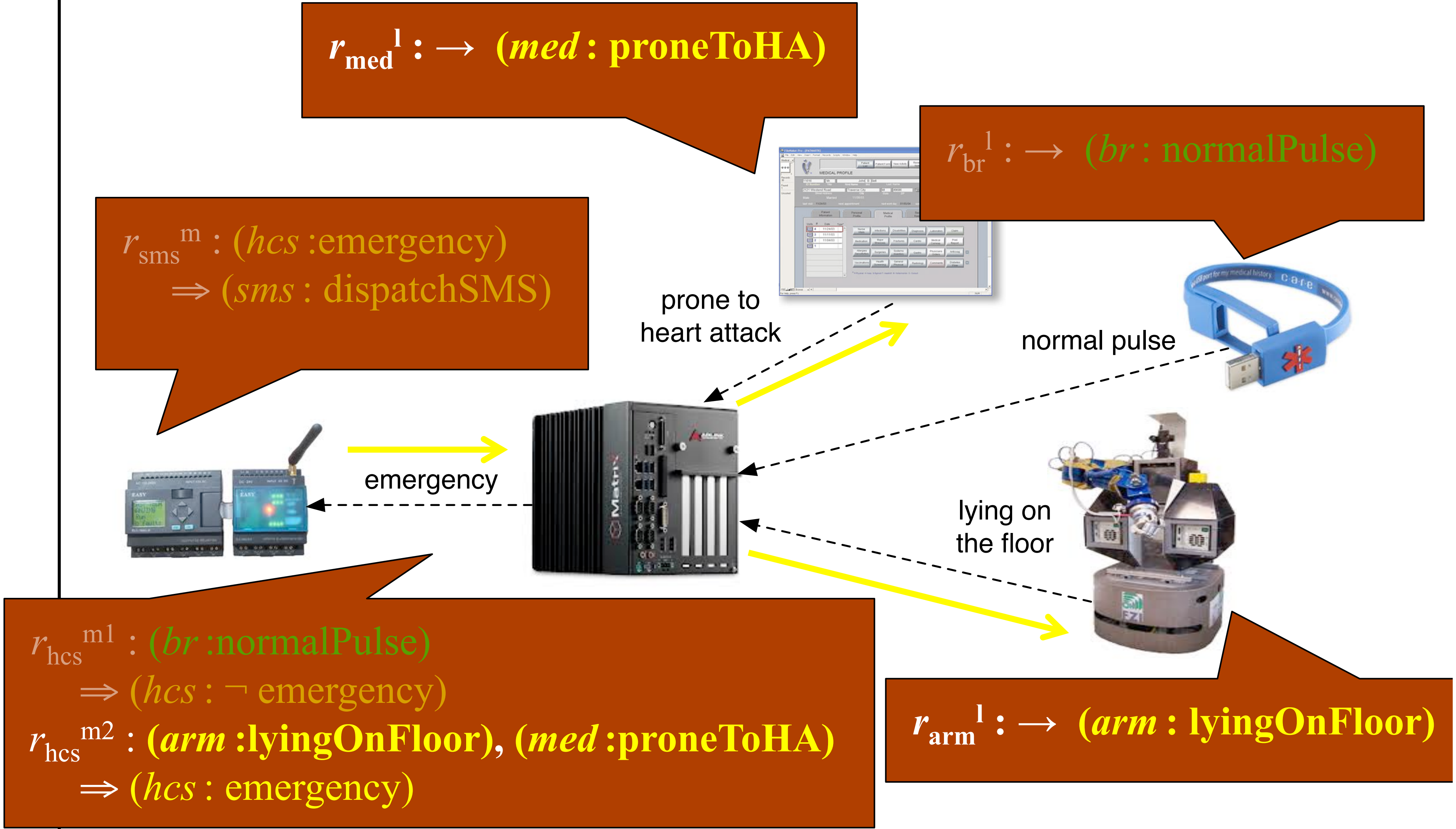
$r_{sms}^{m} : (hcs : \mathrm{emergency})$
$\Rightarrow (sms : \mathrm{dispatchSMS})$



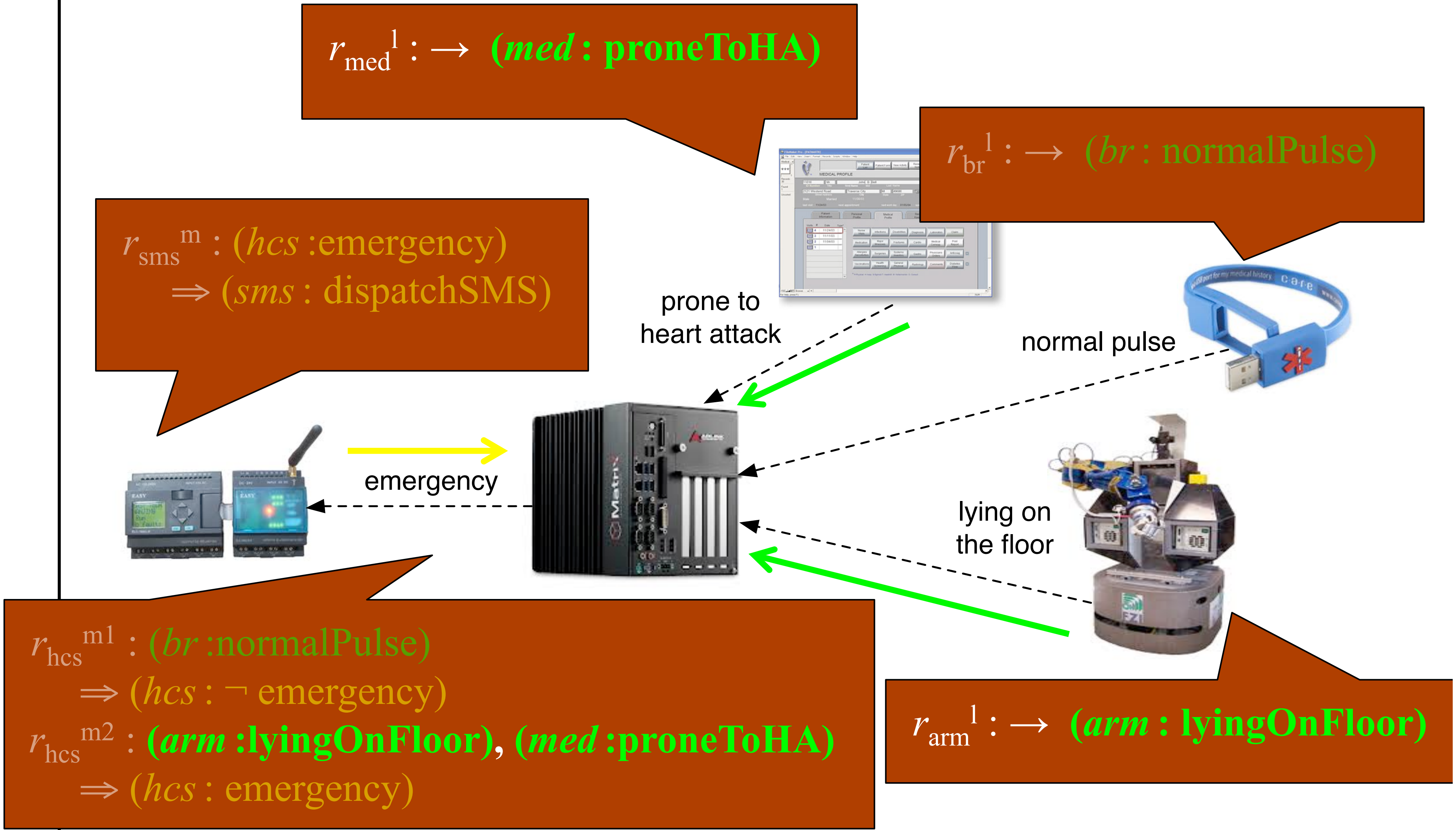
$r_{hcs}^{m1} : (br : \mathrm{normalPulse})$
$\Rightarrow (hcs : \neg\ \mathrm{emergency})$
$r_{hcs}^{m2} : (arm : \mathrm{lyingOnFloor}), (med : \mathrm{proneToHA})$
$\Rightarrow (hcs : \mathrm{emergency})$

$r_{arm}^{1} : \rightarrow \ (arm : \mathrm{lyingOnFloor})$

Example Scenario: Query Evaluation

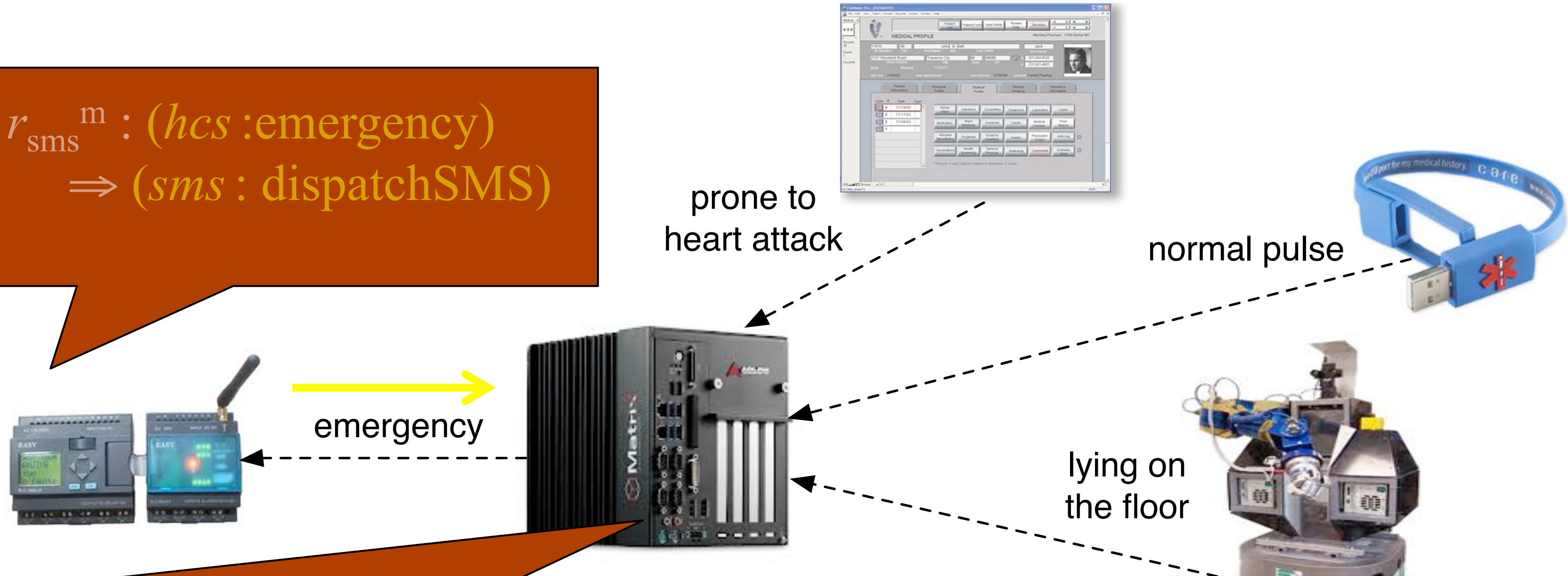


Example Scenario: Query Evaluation



Example Scenario: Query Evaluation

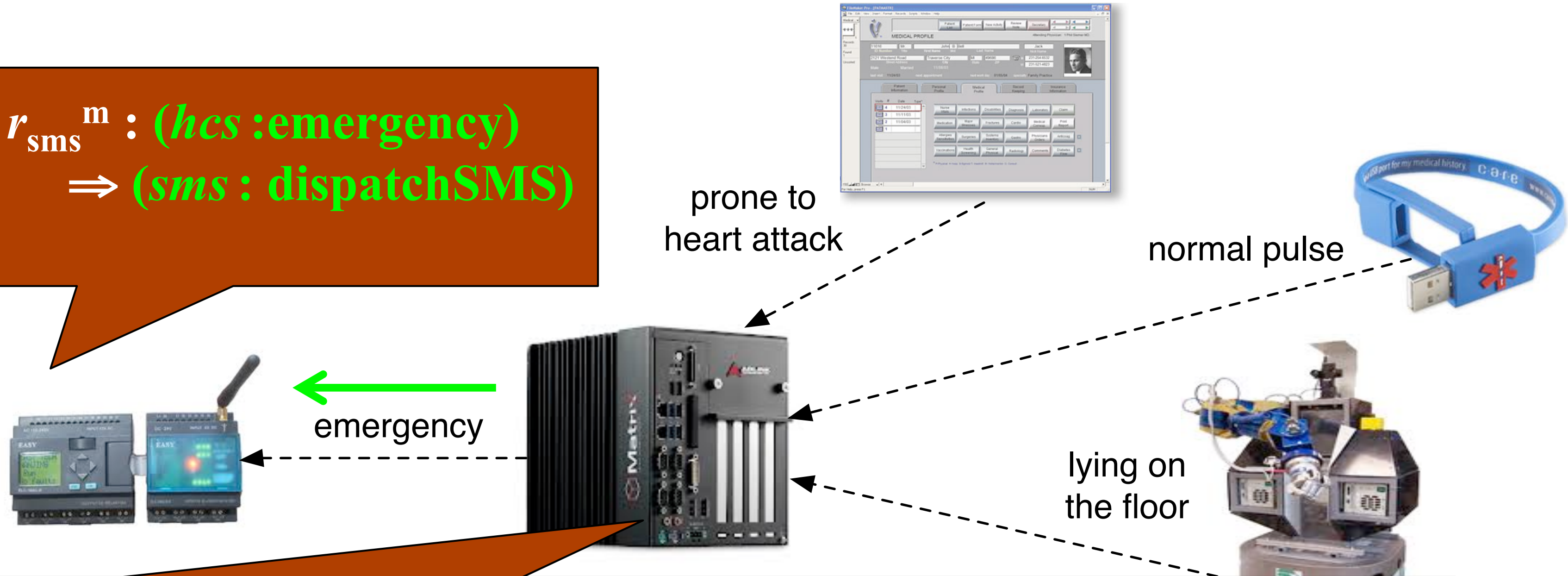
r_{sms}^{m} : (hcs :emergency)
$\Rightarrow$ (sms : dispatchSMS)



r_{hcs}^{m1} : (br :normalPulse)
$\Rightarrow$ (hcs : $\neg$ emergency)
r_{hcs}^{m2} : (arm :lyingOnFloor), (med :proneToHA) $T_{hcs}=[med,arm,br]$
$\Rightarrow$ (hcs : emergency)

Example Scenario: Query Evaluation

r_{sms}^{m} : $(\textit{hcs} : \text{emergency}) \Rightarrow (\textit{sms} : \text{dispatchSMS})$



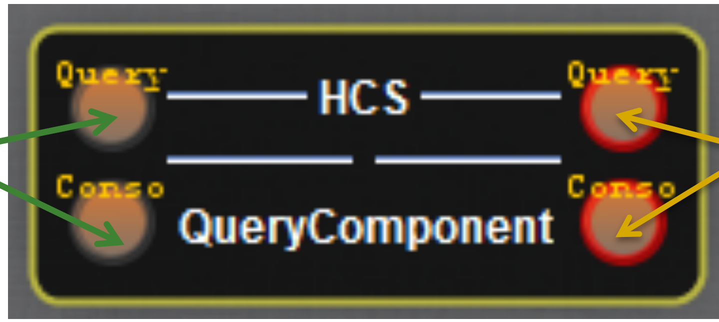
r_{hcs}^{m1} : $(\textit{br} : \text{normalPulse}) \Rightarrow (\textit{hcs} : \neg\, \text{emergency})$

r_{hcs}^{m2} : $(\textit{arm} : \text{lyingOnFloor}), (\textit{med} : \text{proneToHA}) \Rightarrow (\textit{hcs} : \text{emergency})$ $T_{hcs} = [\textit{med}, \textit{arm}, \textit{br}]$

Kevoree

- **Open source project available at: www.kevoree.org**
  - Enables distributed reconfigurable software development
  - Any sensor, software application, web service can be represented as a **component** (with I/O) in Kevoree
  - The set of services/applications offered by a single entity (e.g. device) is represented as a Kevoree **node**
  - **Channels** represent different types of communication among components (TCP/IP, email, SMS, etc.)

Input ports



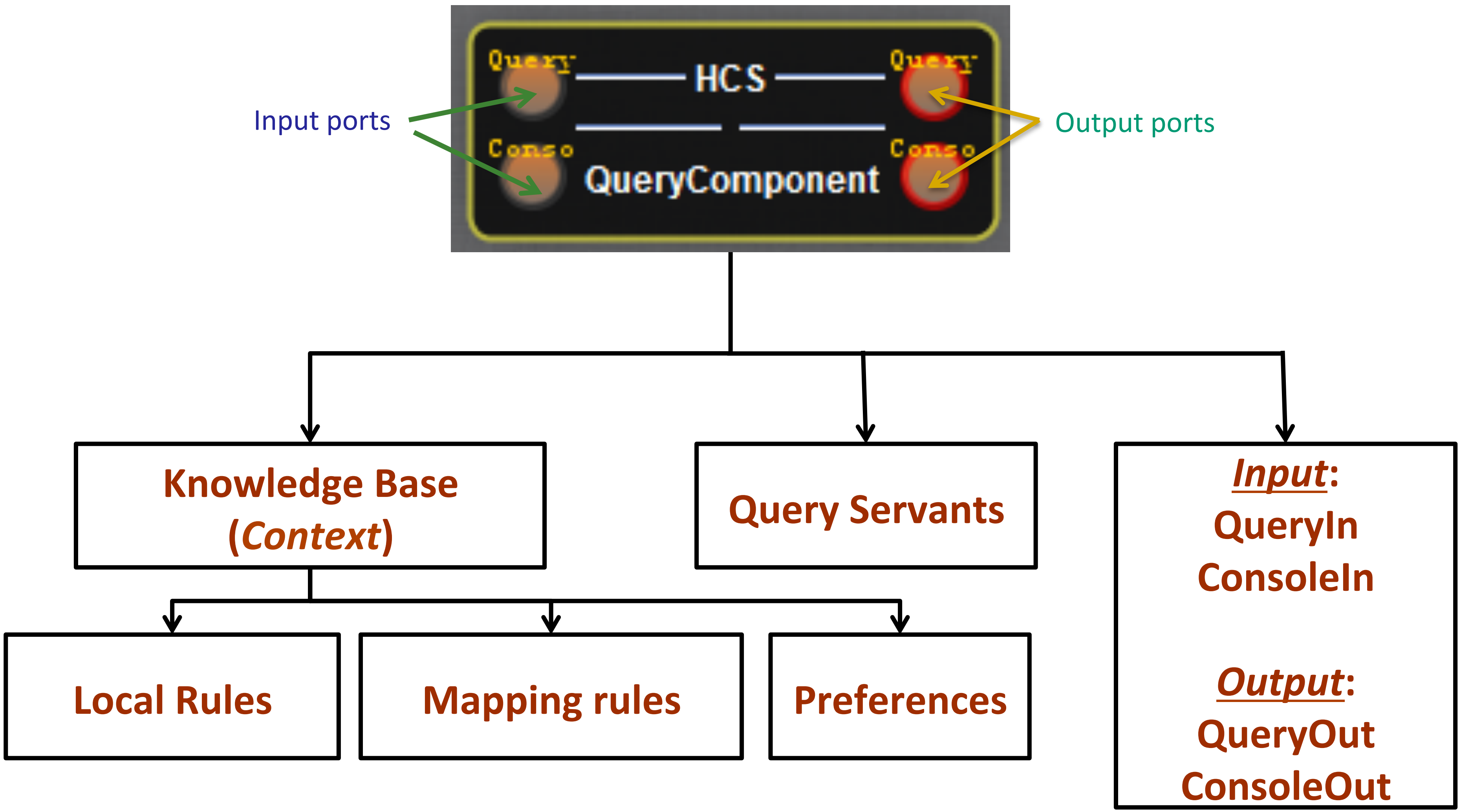
Output ports

A Kevoree component

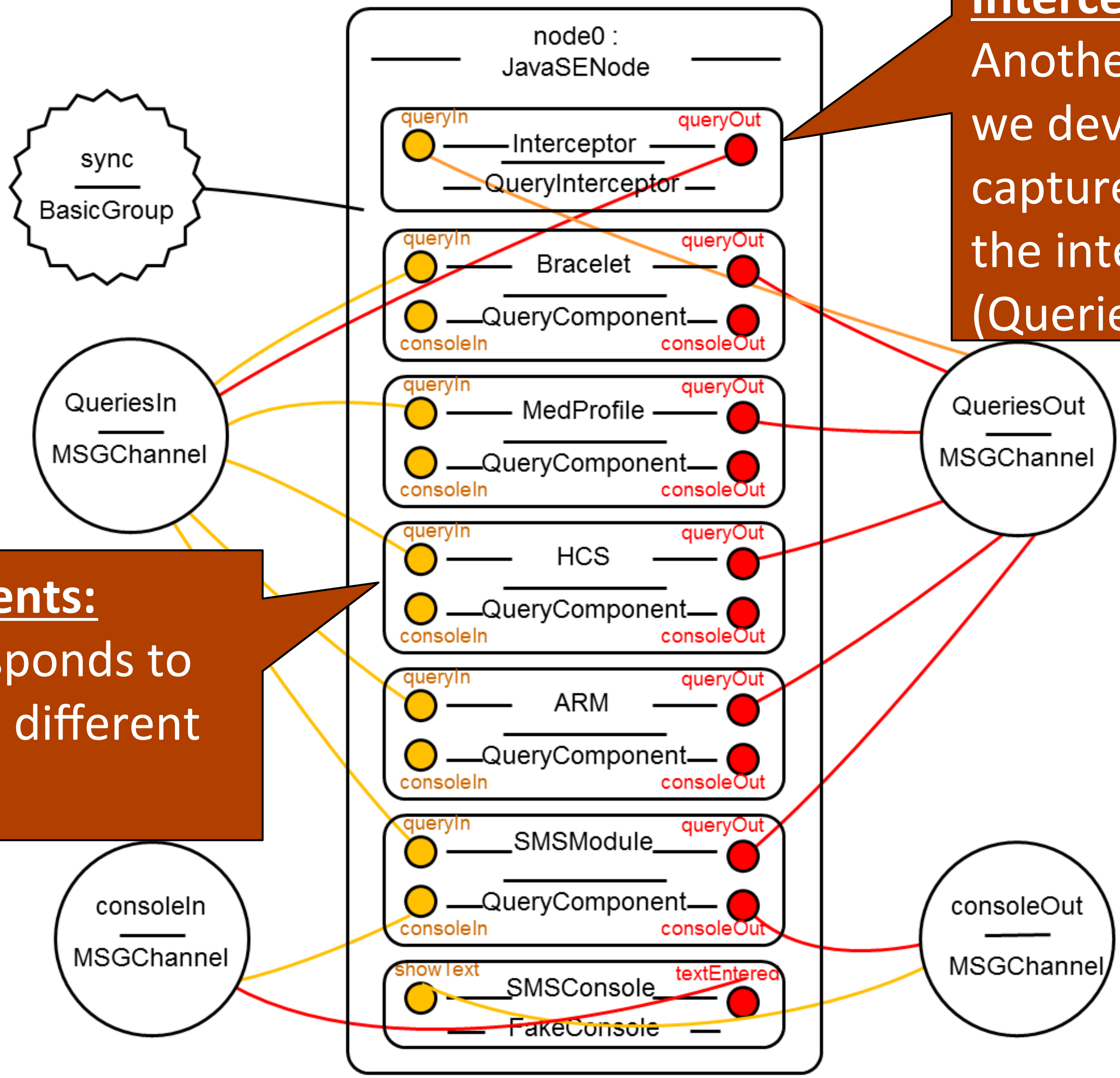
Kevoree in R-CoRe

- Each entity (mobile computing device) is implemented as a Kevoree node.
- Each context is implemented as a Kevoree component.
- Kevoree channels enable exchange of information (messages) between different components.
- Kevoree's adaptive and auto-discovery capabilities enable detecting new nodes and adapting to any context changes.

R-CoRe Architecture



Example Scenario: in R-CoRe terms



Interceptor:
Another component we developed to capture and display all the interactions (Queries/responses)

Query components:
Each one corresponds to the context of a different entity

Example Scenario: in R-CoRe terms (cont'd)

File Name	File contents
smsModuleKB.txt	M1: (hcs:emergency) $\rightarrow$ (sms:dispatchSMS)
BraceletKB.txt	L1: $\rightarrow$ (br:normalPulse)
MedProfileKB.txt	L1: $\rightarrow$ (med:proneToHA)
ArmKB.txt	L1: $\rightarrow$ (arm:lyingOnFloor)
HCSKB.txt	M1: (br:normalPulse) $\Rightarrow$ $\neg$(hcs:emergency) M2: (arm:lyingOnFloor), (med:proneToHA) $\Rightarrow$ (has:emergency)
HCSPref.txt	med, arm, br

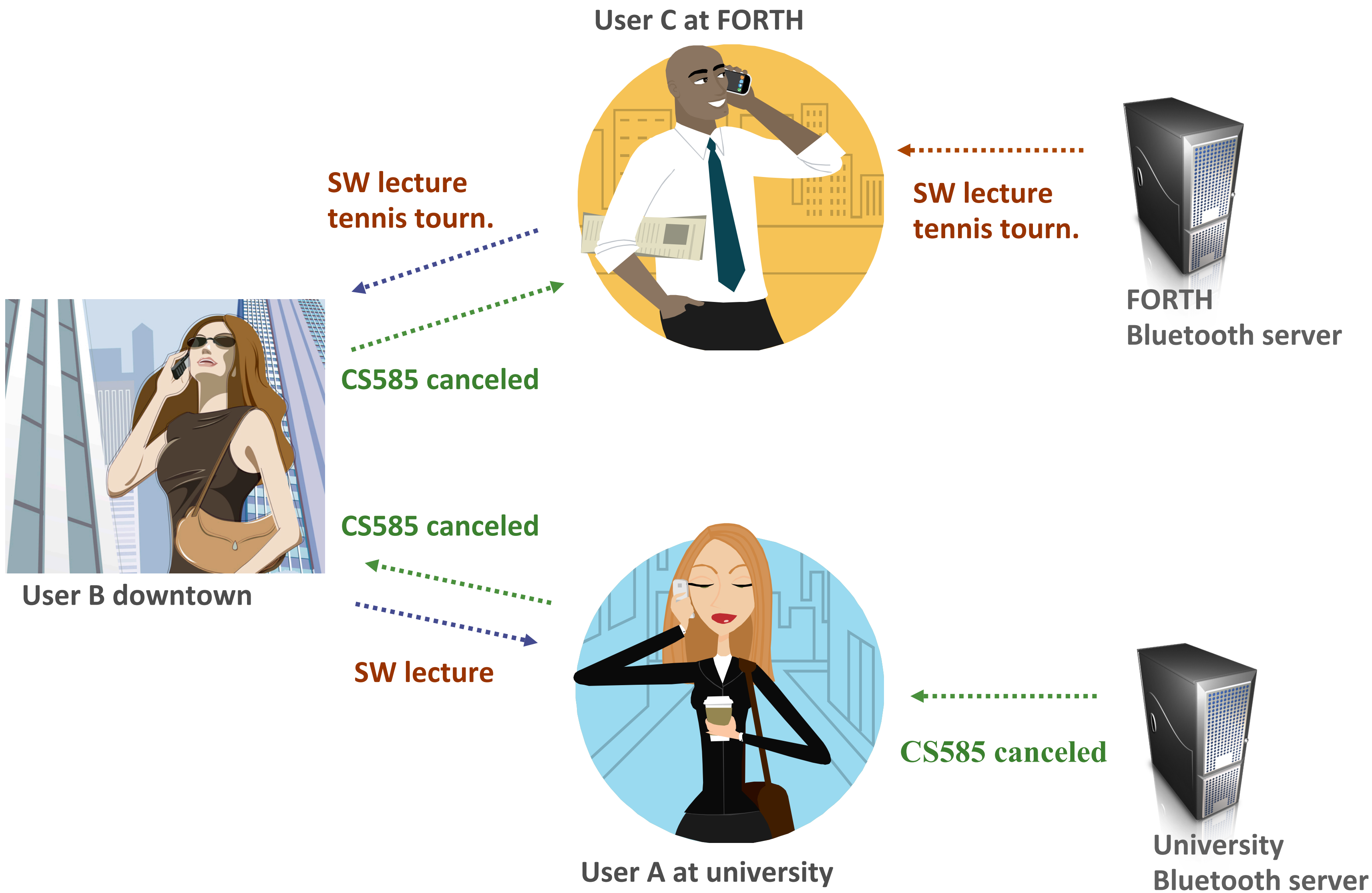
Rule bases and preferences in the example scenario

R-CoRe: Demo

- You can download the demo and test it yourself from
  https://github.com/securityandtrust/ruleml13

A Smart Classroom Scenario

A Social Mobile Computing Scenario



Outline

- Context and Contextual Reasoning in Ambient Intelligence
- A Centralized Reasoning Framework
- R-CoRe: A Distributed Approach
- **Centralized vs. Distributed Reasoning**
- Open Problems

Centralized vs. Distributed Reasoning

- Distribution of knowledge
- Reasoning with the whole picture
- Scalability
- Computational Issues
  - Single powerful computer

    vs.
  - Devices with limited resources
- Communication Issues
  - Small size of messages

    vs.
  - Small number of messages
- Points of failure
- Privacy

Outline

- Context and Contextual Reasoning in Ambient Intelligence
- A Centralized Reasoning Framework
- R-CoRe: A Distributed Approach
- Centralized vs. Distributed Reasoning
- **Open Problems**

Open Problems

- Privacy – Security
  - Open environments
  - Unnoticeable access to personal data
- Conviviality
  - Means and incentives for cooperation
  - Reconciling conviviality with privacy
- Planning
  - Common plans
  - Efficient Plan Execution
- Learning
  - Identify user's needs and intentions
  - Computational Benefits
- Verification & Validation

Rule-based Contextual Reasoning in Ambient Intelligence