SPATIAL TUPLES

Augmenting Physical Reality with Tuple Spaces

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OUTLINE

- Background & Motivation
  - Tuple spaces, Physical worlds & space, Augmented Worlds
- The **Spatial Tuples** model
  - concepts & coordination language
  - simple coordination patterns and examples
- Formalisation and Implementation - Sketches
- Related and Future work

BACKGROUND

COORDINATION MODELS & LANGUAGES for MULTI-AGENT SYSTEMS

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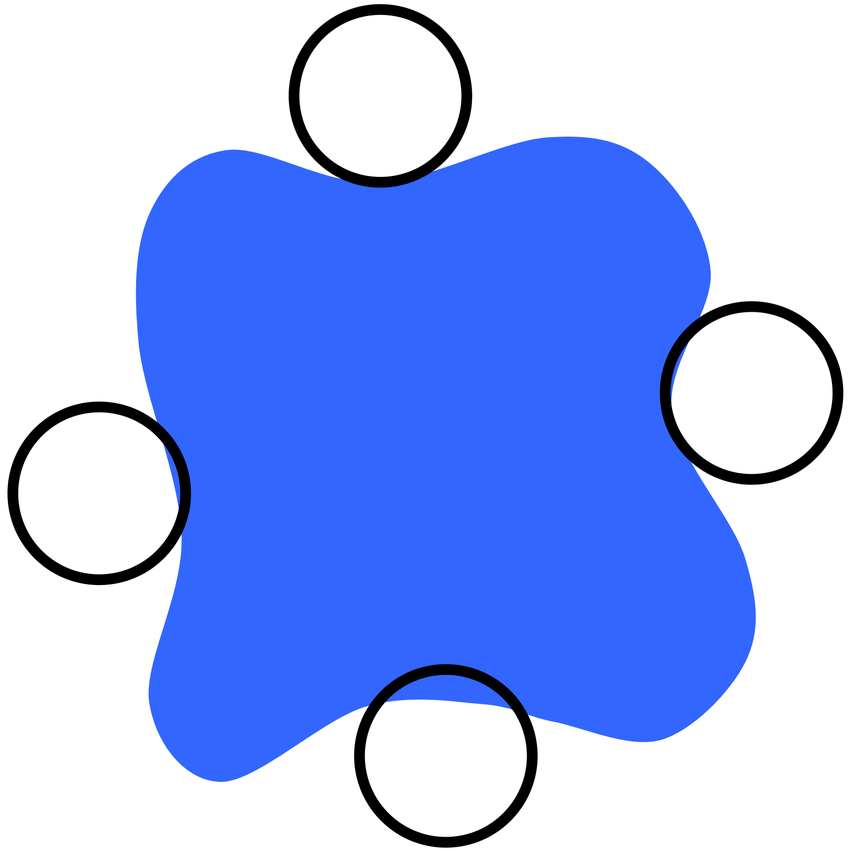
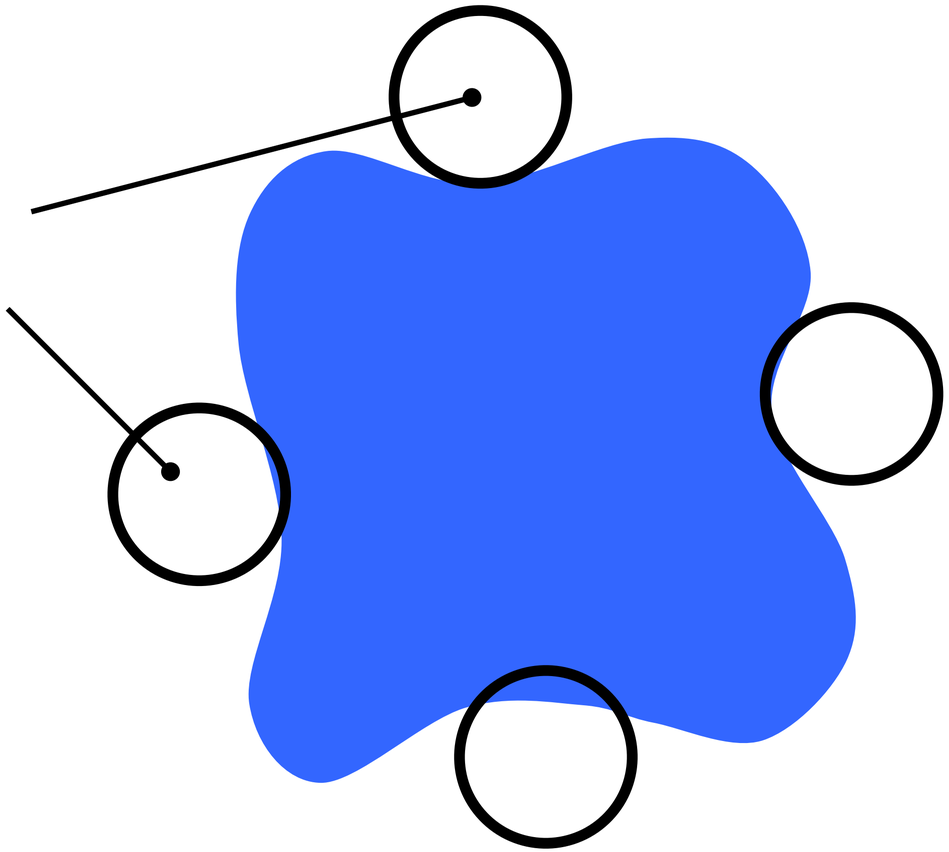


COORDINATION MODELS & LANGUAGES for MULTI-AGENT SYSTEMS

autonomous agents as *coordinables*



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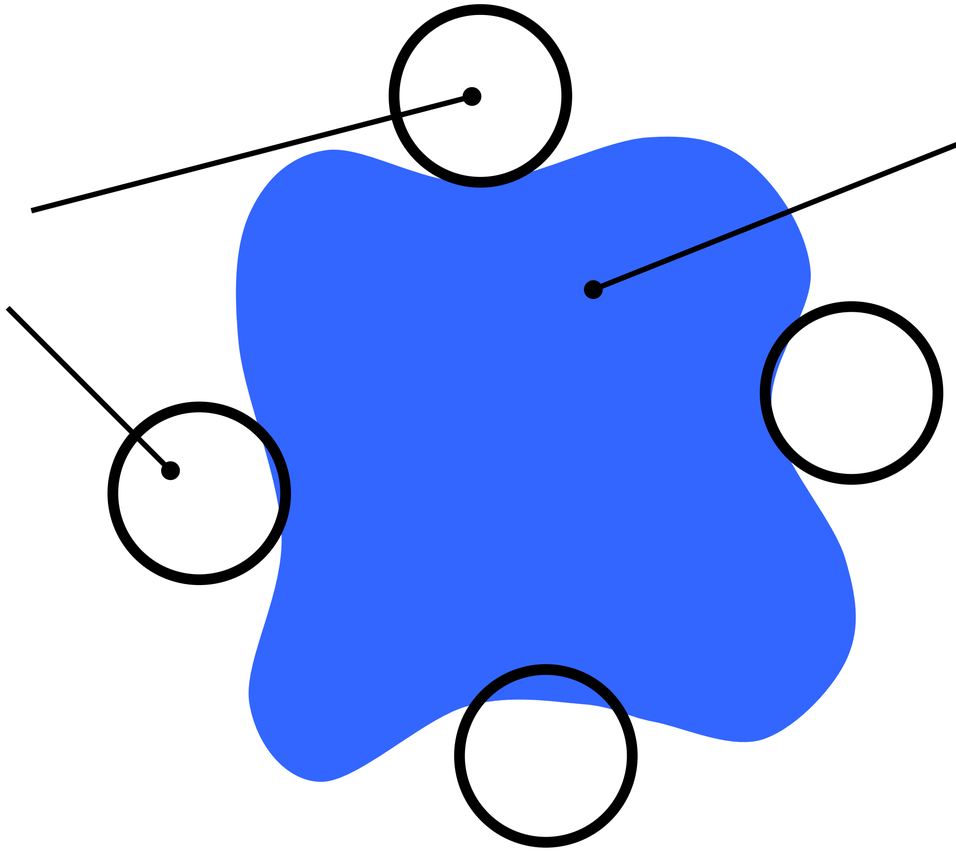
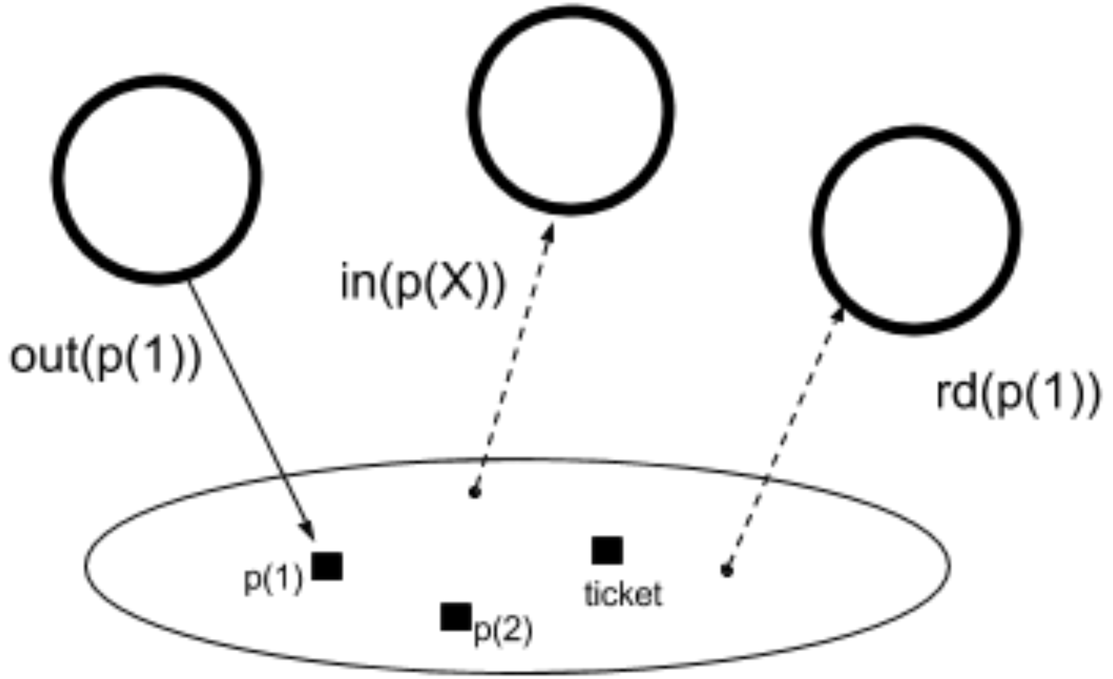


coordination *medium*

what enable & govern interactions
- encapsulating coordination laws

TUPLE SPACES
(GELERNTER et al.)

- **Space-based** coordination
  - information spaces as coordination media
- **Linda** coordination language
  - **out**(t), **in**(tt), **rd**(tt)
  - predicative: inp(tt), rdp(tt)
- **Generative communication**
  - *temporal and spatial uncoupling*



SEVERAL EXTENSIONS

- Extending the *coordination language*
  - e.g., bulk primitives: rdall, inall
- Different kind of *communication languages*
  - logic-based tuples, objects, XML, ..
- Tuples space(s) *structure*
  - multiple tuple spaces, nesting, mobile,…
- …

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Tuple Centres &
TuCSoN
(Omicini et al.)

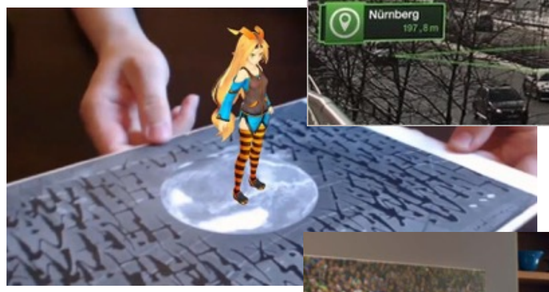
> tuple centres as *programmable* tuple spaces
> TuCSoN infrastructures

PHYSICAL WORLD & SPACE IN THE LOOP

- **Spatial location/extension** as first-class aspect in several application domains
  - Mobile & wearable computing
  - Pervasive Computing/IoT/Ambient Intelligence
  - Location-based applications and context-aware computing

AUGMENTED, MIXED REALITIES

- Blending the digital/virtual world and the physical reality
  - hands-free systems



- Recent technology boost
  - see Microsoft Hololens, Meta2, Smartglass devices..

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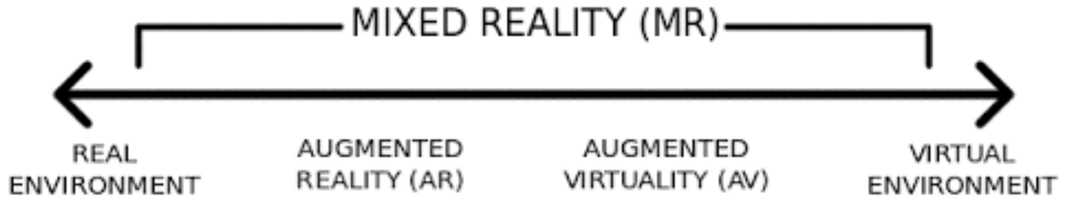

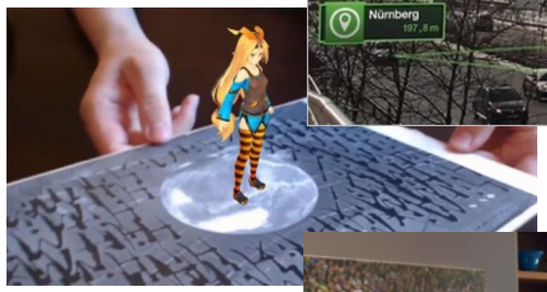

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  - modeling augmented worlds in terms of societies of agents situated in mixed reality environments
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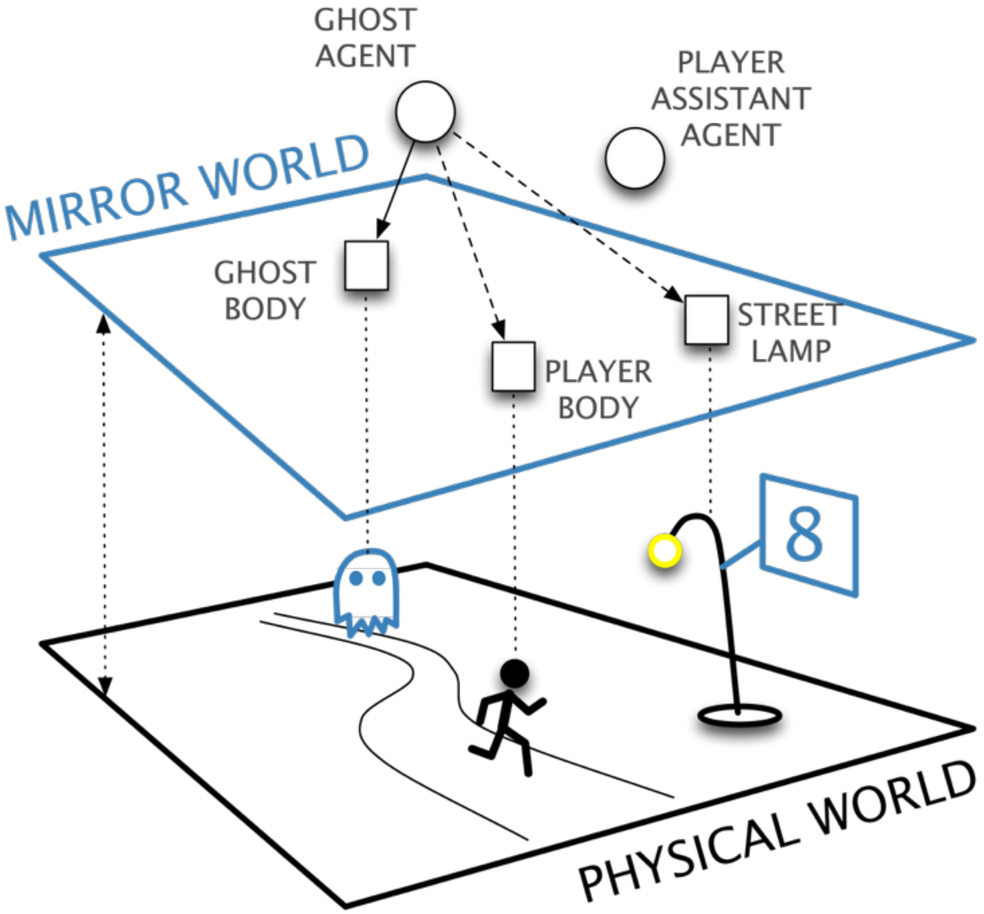
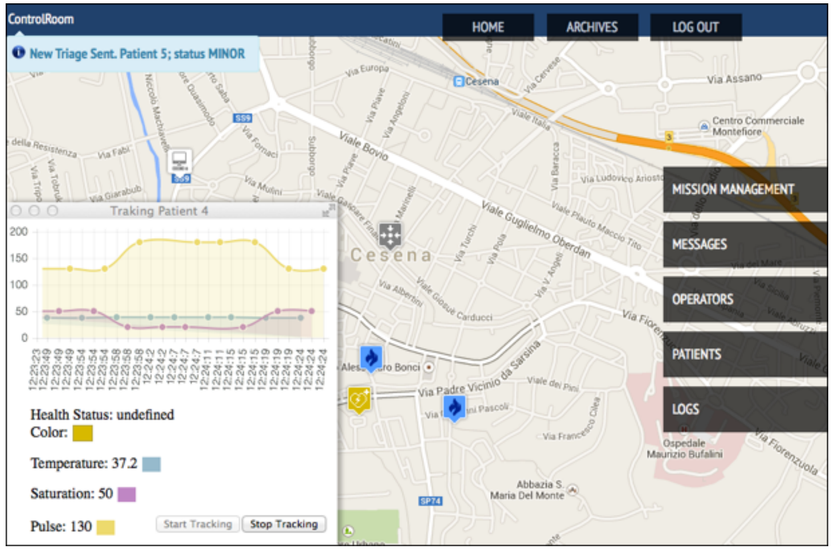
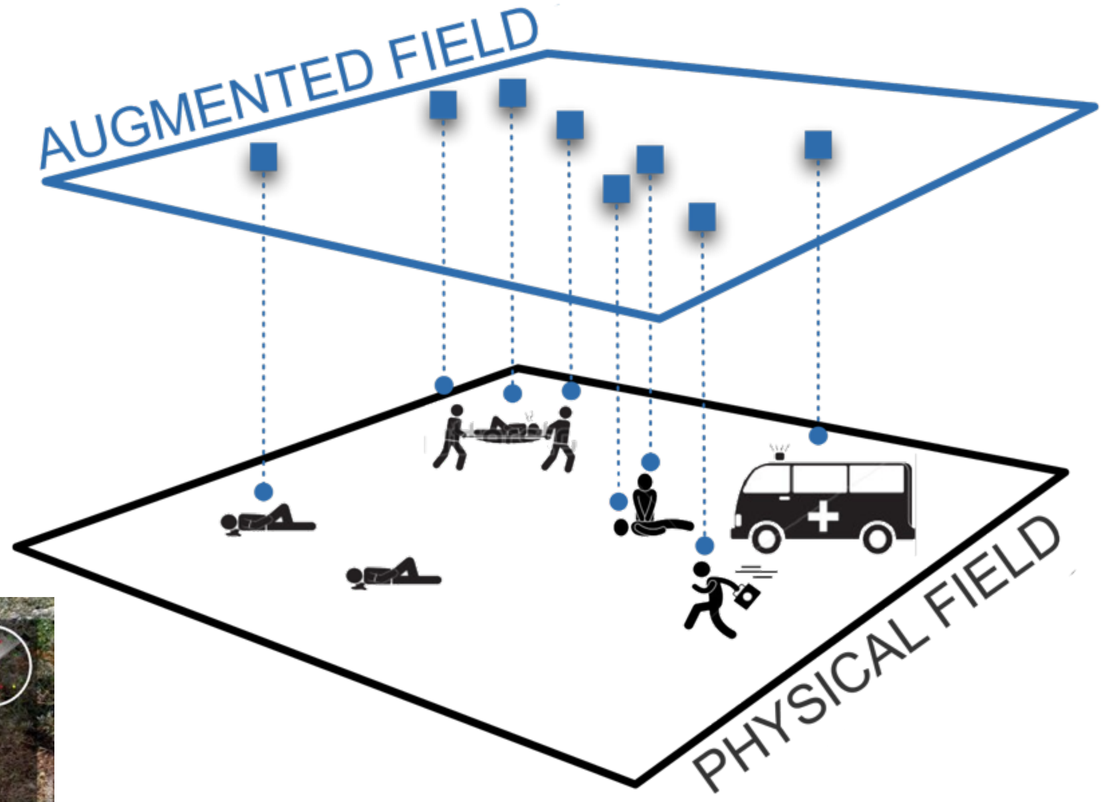


MOTIVATING SCENARIO

- **Smart Rescue Systems**
  - augmented world based technology to help rescuers in their job





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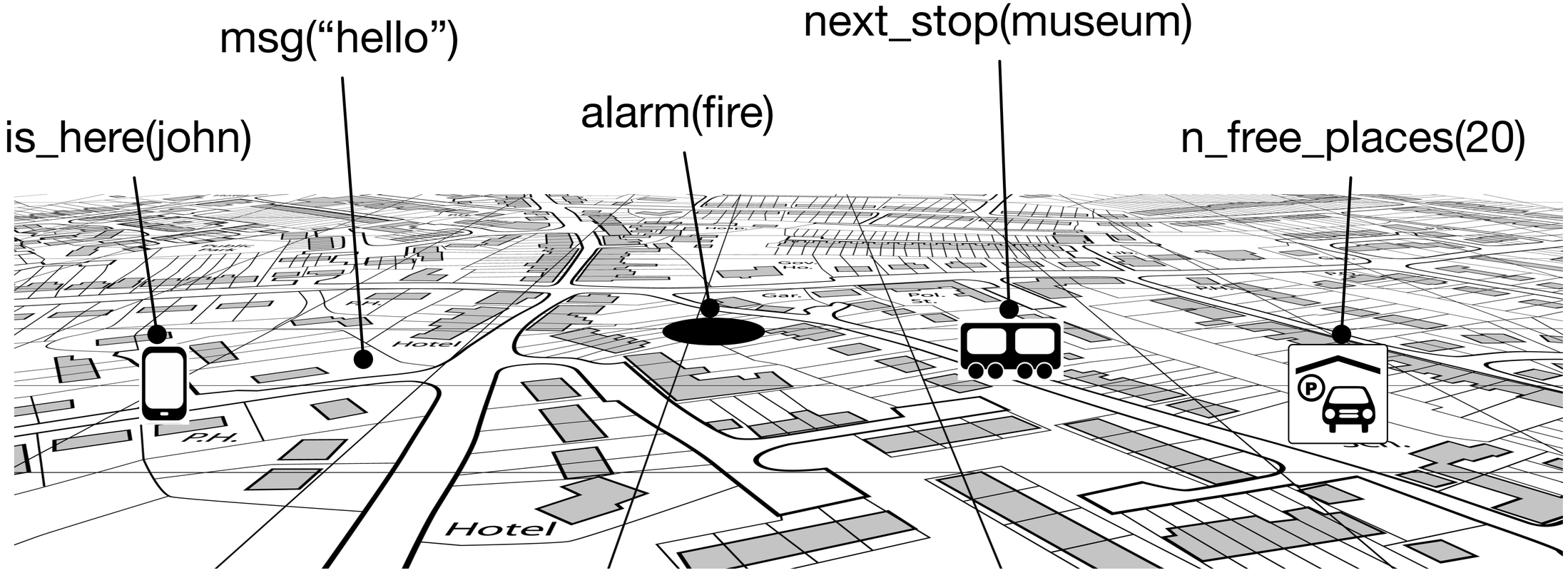

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- Tuples with a physical location and extension
  - *augmenting* the physical reality with information of any sort
- Can be
  - inserted in the space by agents either situated or not
  - associatively observed by agents
    - possibly depending on their location

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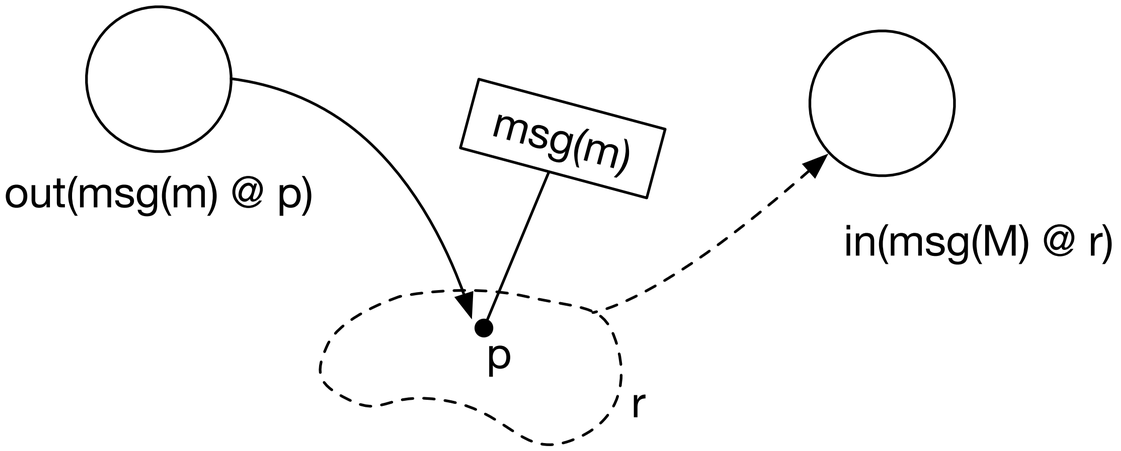

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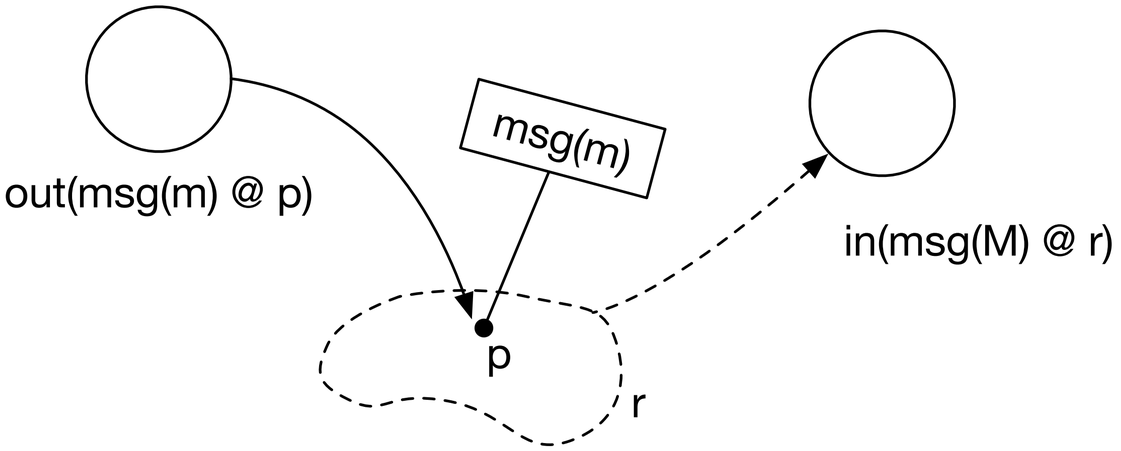

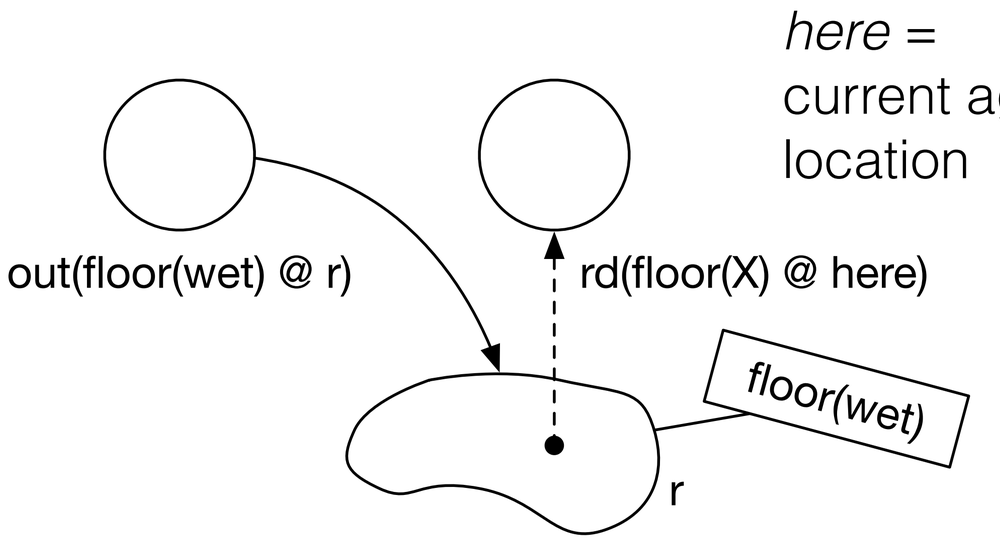

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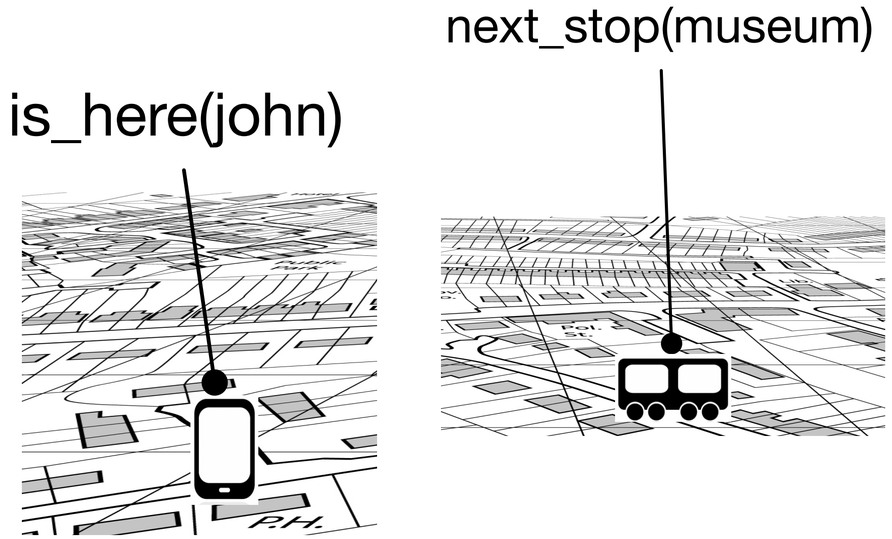
- **Mobility**
  - out(t @ **id**), rd(tt @ **id**), in(tt @ **id**)
    - id = logical identifier of some (mobile) component of the system
- Examples
  - out(nextStop(“UPMC”)@autobus(12))
  - rd(nextStop(X)@autobus(12))
  - out(is_here(john)@me)
    - *me* = implicit reference to thecomponent where the agent is deployed



SIMPLE COORDINATION PATTERNS AND EXAMPLES

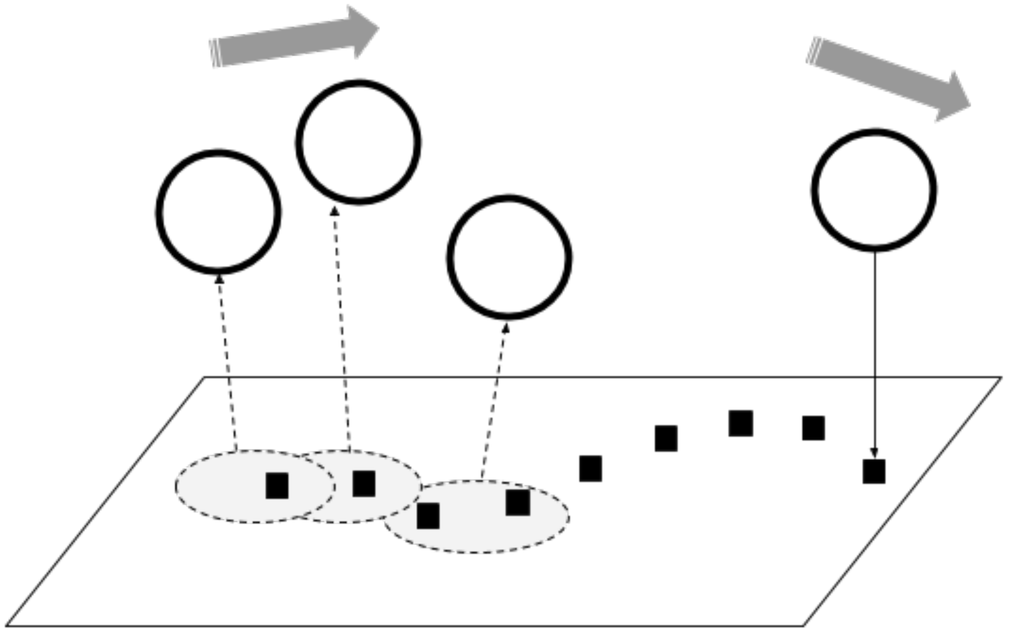
- Breadcrumbs
- Awareness
- Situated knowledge sharing
- Spatial sync & mutex
- Spatial Dining Philosophers

BREADCRUMBS

- (Physically) moving agents leaving **traces**:

  out(wasHere(hansel, C) **@ here**)

  - e.g. agent running on a mobile/wearable devices
- Basic elements for enabling ***stigmergic*** forms of coordination
  - BIC & *follow me* *(Castelfranchi et al.)*



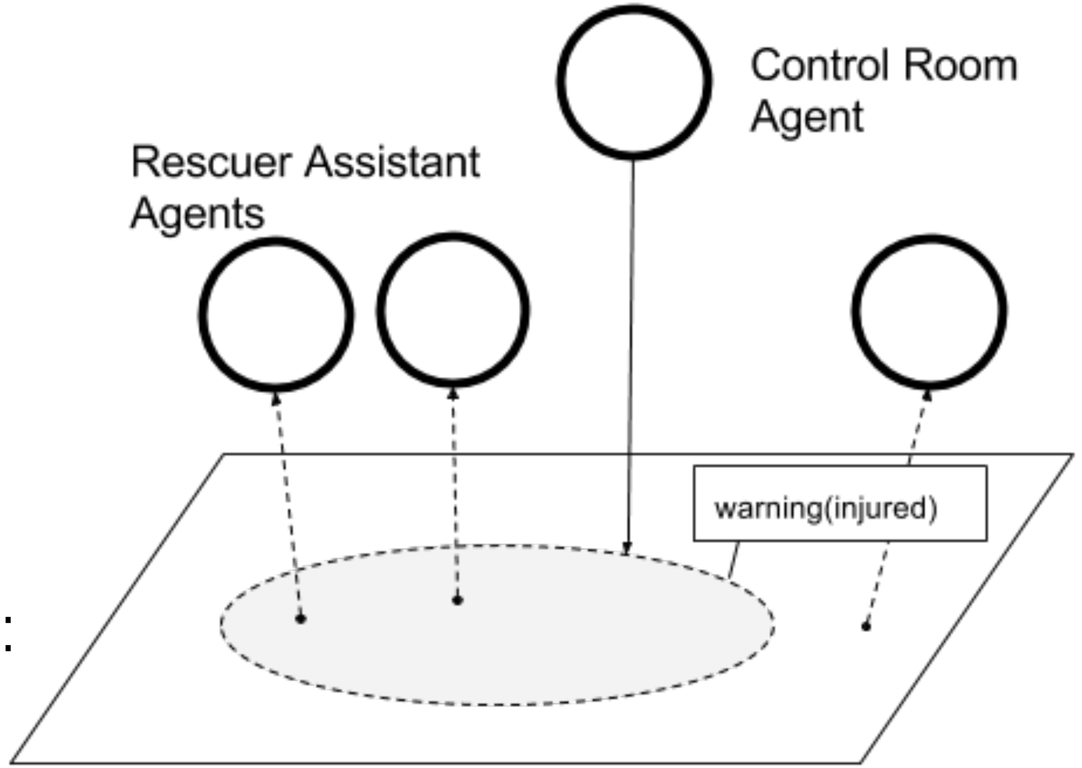
SITUATED KNOWLEDGE SHARING

- Informing all agents that are or enters in a specific region about some info:

  out(warning(injured) **@ region**)

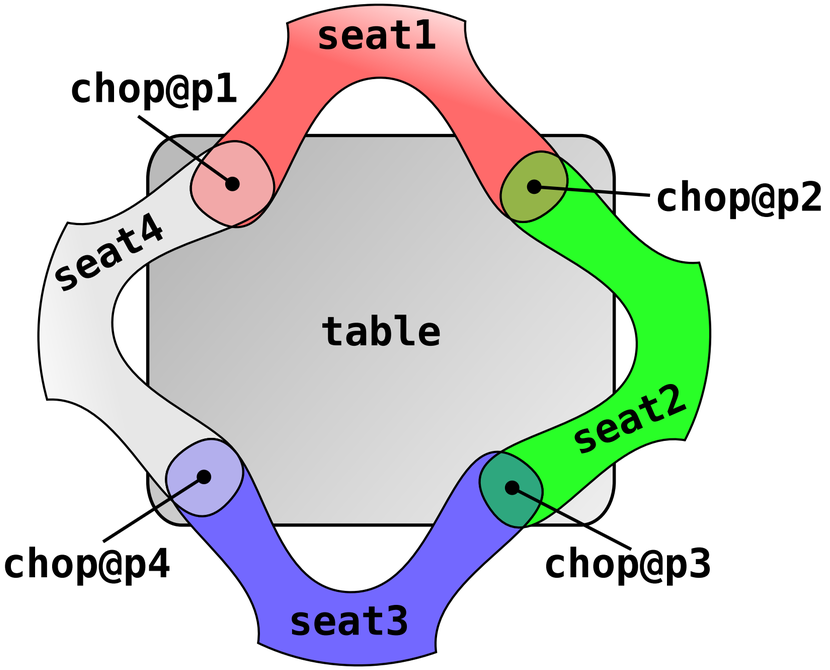
  - *situated communication*
- Situated agent that wants to be aware:

  rd(warning(W) **@ here**)



SPATIAL DINING PHILOSOPHERS

- Spatial tuples **chop** situated in **p1**…**p4**
- Philosophers sitting in regions **seat1**…**seat4**
- Pre-protocol, issuing:
  in(chop @ seat*N*)
  twice.
- Post-protocol:
  out(chop @ p_i)
  out(chop @ $p_{(i+1)\%4}$)



FORMALISATION (SKETCH)

- Extension of the standard process algebraic description of Linda
  - available in an extended version of the paper
- Syntax

$$
\begin{array}{rcll}
l & ::= & p \mid id & \text{Location} \\
r & ::= & \mathtt{region}(l, ext) & \text{Region} \\
\tau & ::= & t@l & \text{Situated tuple} \\
a & ::= & \mathtt{out}(\tau) \mid \mathtt{in}(\tau) \triangleright \tau' \mid \mathtt{rd}(\tau) \triangleright \tau' & \text{Action} \\
A & ::= & 0 \mid a.A & \text{Agent behaviour} \\
S & ::= & 0 \mid \tau \mid id \rightsquigarrow p \mid id[A] \mid (S \mid S) & \text{System}
\end{array}
$$

FORMALISATION (SKETCH)

- Matching

$$t@r \bowtie_S t'@r' \;\; \text{iff} \;\; \{t/t'\} \neq \bot \;\; \text{and} \; overlap(\epsilon_S(r), \epsilon_S(r'))$$
$$\epsilon_S(\texttt{region}(p, ext)) = \texttt{region}(p, ext)$$
$$\epsilon_{S \mid id \rightsquigarrow p}(\texttt{region}(id, ext)) = \texttt{region}(p, ext)$$

FORMALISATION (SKETCH)

- Operational semantics
  - transition system $\langle \boldsymbol{S}, \longrightarrow, \mathit{Lab} \rangle$
  - $\lambda \in \mathit{Lab}$ (coordination action or agent movement)

$$S \xrightarrow{\lambda} S' \quad \text{if} \quad S \equiv S_1, S' \equiv S'_1, S_1 \xrightarrow{\lambda} S'_1$$

$$S \mid id \rightsquigarrow p \xrightarrow{id \rightsquigarrow p'} id \rightsquigarrow p' \mid S \quad \text{if } S \mid id \rightsquigarrow p \not\xrightarrow{\cdot}$$

$$S \mid id[\mathtt{out}(\tau).A] \xrightarrow{\cdot} id[A] \mid k_S^{id}(\tau) \mid S \quad \text{if } ground(k_S^{id}(\tau))$$

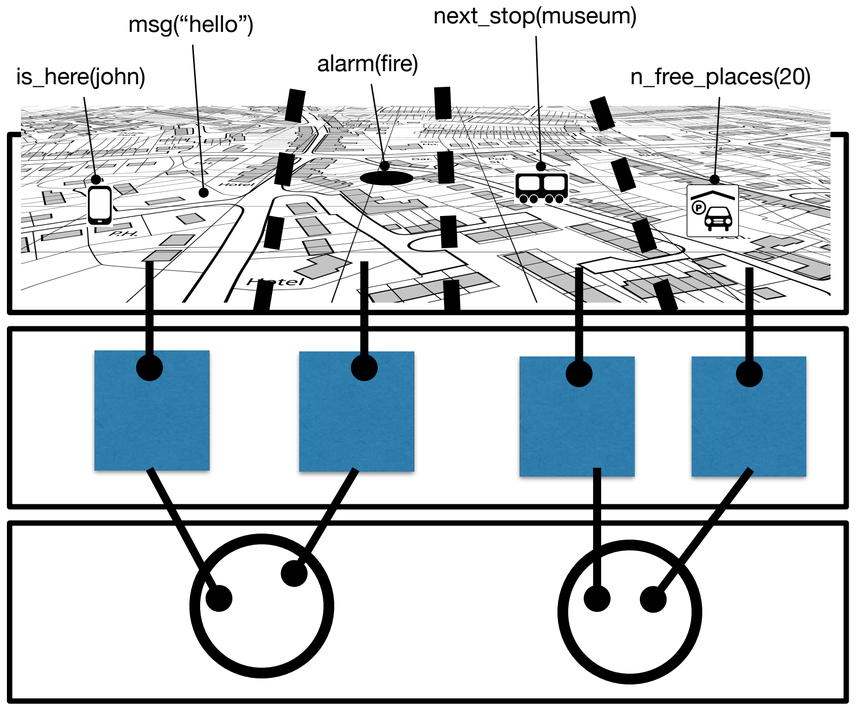
$$S \mid \tau \mid id[\mathtt{in}(\tau') \triangleright \tau''.A] \xrightarrow{\cdot} id[A\{\tau''/\tau\}] \mid S \quad \text{if } k_S^{id}(\tau') \bowtie_S \tau$$

$$S \mid \tau \mid id[\mathtt{rd}(\tau') \triangleright \tau''.A] \xrightarrow{\cdot} id[A\{\tau''/\tau\}] \mid \tau \mid S \quad \text{if } k_S^{id}(\tau') \bowtie_S \tau$$

$$k^{id}_{S \mid id \rightsquigarrow p}(\tau) = \tau\{\mathtt{here}/p\}\{\mathtt{me}/id\}$$

INFRASTRUCTURE DESIGN & IMPLEMENTATION

- Proof-of-concept Java-based implementation
  - based on TuCSoN technology
- Orthogonal to the agent model & technology adopted



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- Precision and accuracy of location information
  - localisation techniques and devices
    - e.g. GPS devices
- Space description language matching function
  - complexity, efficiency, scalability

RELATED APPROACHES

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- **Spatial Computing** literature
  - Tuple space & Linda spatial extensions
  - TOTA, Lime, στ-Linda, Spatial ReSpecT,…
- Common point
  - enriching tuple spaces with an explicit physical location *given by the mobile hardware device on which they are meant to run*

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spatial properties are at the *tuple* level

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- more similar to **Mirror Worlds** and mobile AR

FUTURE WORK

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- Exploring the usefulness and applicability to heterogeneous application domains and real-world scenarios
  - smart rescue scenario

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- Refining and extending the basic model
  - more investigation about spatial languages
  - spatial reactions?

END.