Commonsense Inference in Dynamic Spatial Systems

Mehul Bhatt

SFB/TR 8 Spatial Cognition
Universität Bremen, Germany
bhatt@informatik.uni-bremen.de

June 22, 2009
Overview

1. Commonsense Reasoning about the World
2. Commonsense and Space
3. Application Framework
4. Outlook
Outline

1. Commonsense Reasoning about the World
   - An Example
   - Vision statement

2. Commonsense and Space
   - Reasoning about space, actions and change
   - Default and non-monotonic aspects of spatial reasoning

3. Application Framework

4. Outlook
A grasper, and a table on which lie two glasses, one empty and one filled with a liquid...
A grasper, and a table on which lie two glasses, one empty and one filled with a liquid...
High-level Reasoning + Low-level Control

1. Perceive this scene and connect ‘blobs’ to (known) domain specific symbolic categories

2. Generate a qualitative scene description backed by a formal spatial ontology
   - *i.e., with topological, orientational, directional and size information*

3. Use (known) common-sense notions of space, change and affordances to reason about the grounded material world
   - rigidity, containment, deformity, surface information, stability, graspability, ...

4. Given an ‘action description logic’ and a ‘domain theory’:
   - apply ‘what if...’ scenarios – projection / simulation
   - achieve ‘transfer of liquid’ – planning
   - explain ‘broken glass’ – causal explanation

5. Low-level motion control
High-level Reasoning + Low-level Control

1. Perceive this scene and connect ‘blobs’ to (known) domain specific symbolic categories

2. Generate a qualitative scene description backed by a formal spatial ontology
   - *i.e., with topological, orientational, directional and size information*

3. Use (known) common-sense notions of space, change and affordances to reason about the grounded material world
   - *rigidity, containment, deformity, surface information, stability, graspability, ...*

4. Given an ‘action description logic’ and a ‘domain theory’:
   - apply ‘what if...’ scenarios – projection / simulation
   - achieve ‘transfer of liquid’ – planning
   - explain ‘broken glass’ – causal explanation

5. Low-level motion control
High-level Reasoning + Low-level Control

1. Perceive this scene and connect ‘blobs’ to (known) domain specific symbolic categories

2. Generate a qualitative scene description backed by a formal spatial ontology
   - *i.e., with topological, orientational, directional and size information*

3. Use (known) common-sense notions of space, change and affordances to reason about the grounded material world
   - *rigidity, containment, deformity, surface information, stability, graspability, ...*

4. Given an ‘action description logic’ and a ‘domain theory’:
   - apply ‘what if...’ scenarios – projection / simulation
   - achieve ‘transfer of liquid’ – planning
   - explain ‘broken glass’ – causal explanation

5. Low-level motion control
High-level Reasoning + Low-level Control

1. Perceive this scene and connect ‘blobs’ to (known) domain specific symbolic categories

2. Generate a qualitative scene description backed by a formal spatial ontology
   - *i.e., with topological, orientational, directional and size information*

3. Use (known) common-sense notions of space, change and affordances to reason about the grounded material world
   - *rigidity, containment, deformity, surface information, stability, graspability, ...*

4. Given an ‘action description logic’ and a ‘domain theory’:
   - apply ‘what if...’ scenarios – projection / simulation
   - achieve ‘transfer of liquid’ – planning
   - explain ‘broken glass’ – causal explanation

5. Low-level motion control
High-level Reasoning + Low-level Control

1. Perceive this scene and connect ‘blobs’ to (known) domain specific symbolic categories

2. Generate a qualitative scene description backed by a formal spatial ontology
   - \textit{i.e., with topological, orientational, directional and size information}

3. Use (known) common-sense notions of space, change and affordances to reason about the grounded material world
   - rigidity, containment, deformity, surface information, stability, graspability, ...

4. Given an ‘action description logic’ and a ‘domain theory’:
   - apply ‘what if...’ scenarios – projection / simulation
   - achieve ‘transfer of liquid’ – planning
   - explain ‘broken glass’ – causal explanation

5. Low-level motion control

M. Bhatt (SFB/TR 8 Spatial Cognition)
Universität Bremen
High-level Reasoning + Low-level Control

1. Perceive this scene and connect ‘blobs’ to (known) domain specific symbolic categories

2. Generate a qualitative scene description backed by a formal spatial ontology
   - *i.e.*, with topological, orientational, directional and size information

3. Use (known) common-sense notions of space, change and affordances to reason about the grounded material world
   - rigidity, containment, deformity, surface information, stability, graspability, ...

4. Given an ‘action description logic’ and a ‘domain theory’:
   - apply ‘what if...’ scenarios – projection / simulation
   - achieve ‘transfer of liquid’ – planning
   - explain ‘broken glass’ – causal explanation

5. Low-level motion control
Integrating Grounding, Action and Control

1. Generate an ontological view or categorisation of environmental and perceptual data

2. Derive qualitative scene descriptions backed by formal spatial ontologies that are grounded in adequate spatial calculi (i.e., connect the concrete with the general)

3. Use common-sense notions of space and spatial change for high-level integrated reasoning about ‘space, actions and change’

   - spatial planning or re-configuration (e.g., cognitive robotics, design)
   - causal explanation – retrospective analyses of observed/recorded spatial and temporal data (e.g., event-based GIS, cognitive vision: scene analyses, surveillance, behaviour monitoring)
Integrating Grounding, Action and Control

1. Generate an ontological view or categorisation of environmental and perceptual data

2. Derive qualitative scene descriptions backed by formal spatial ontologies that are grounded in adequate spatial calculi (i.e., connect the concrete with the general)

3. Use common-sense notions of space and spatial change for high-level integrated reasoning about ‘space, actions and change’
   - spatial planning or re-configuration (e.g., cognitive robotics, design)
   - causal explanation – retrospective analyses of observed/recorded spatial and temporal data (e.g., event-based GIS, cognitive vision: scene analyses, surveillance, behaviour monitoring)
Integrating Grounding, Action and Control

1. Generate an ontological view or categorisation of environmental and perceptual data

2. Derive qualitative scene descriptions backed by formal spatial ontologies that are grounded in adequate spatial calculi (i.e., connect the concrete with the general)

3. Use common-sense notions of space and spatial change for high-level integrated reasoning about ‘space, actions and change’
   - spatial planning or re-configuration (e.g., cognitive robotics, design)
   - causal explanation – retrospective analyses of observed/recorded spatial and temporal data (e.g., event-based GIS, cognitive vision: scene analyses, surveillance, behaviour monitoring)
Outline

1 Commonsense Reasoning about the World
   • An Example
   • Vision statement

2 Commonsense and Space
   • Reasoning about space, actions and change
   • Default and non-monotonic aspects of spatial reasoning

3 Application Framework

4 Outlook
Motivation

Shanahan puts it eloquently:

‘If we are to develop a formal theory of commonsense, we need a precisely defined language for talking about shape, spatial location and change. The theory will include axioms, expressed in that language, that capture domain-independent truths about shape, location and change, and will also incorporate a formal account of any non-deductive forms of commonsense inference that arise in reasoning about the spatial properties of objects and how they vary over time’

(Shanahan 1995)
Some key tasks (‘the problem’):

Integration at ontological, representational and computational levels:

1. Qualitative physics
   *integration of domain-independent qual. physics in a logical framework*

2. Causal and teleological aspects of (spatial) change
   *i.e., an integration of the ‘how’ and the ‘why’ aspects of change*

3. Epistemological issues
   *investigate implications of frame, ramification, qualification problems*

4. Incorporate default and non-monotonic inference patterns
   *e.g., to account for (3)*

5. Concurrency in the spatial domain
   *(i.e., in the context of existing calculi)*
Some key tasks (‘the problem’):

Integration at ontological, representational and computational levels:

1. Qualitative physics
   *integration of domain-independent qual. physics in a logical framework*

2. Causal and teleological aspects of (spatial) change
   *i.e., an integration of the ‘how’ and the ‘why’ aspects of change*

3. Epistemological issues
   *investigate implications of frame, ramification, qualification problems*

4. Incorporate default and non-monotonic inference patterns
   *e.g., to account for (3)*

5. Concurrency in the spatial domain
   *(i.e., in the context of existing calculi)*
Some key tasks (‘the problem’):

Integration at ontological, representational and computational levels:

1. Qualitative physics
   *integration of domain-independent qual. physics in a logical framework*

2. Causal and teleological aspects of (spatial) change
   *i.e., an integration of the ‘how’ and the ‘why’ aspects of change*

3. Epistemological issues
   *investigate implications of frame, ramification, qualification problems*

4. Incorporate default and non-monotonic inference patterns
   *e.g., to account for (3)*

5. Concurrency in the spatial domain
   *(i.e., in the context of existing calculi)*
Commonsense and Space
Reasoning about space, actions and change

Some key tasks (‘the problem’):

Integration at ontological, representational and computational levels:

1. Qualitative physics
   *integration of domain-independent qual. physics in a logical framework*

2. Causal and teleological aspects of (spatial) change
   *i.e., an integration of the ‘how’ and the ‘why’ aspects of change*

3. Epistemological issues
   *investigate implications of frame, ramification, qualification problems*

4. Incorporate default and non-monotonic inference patterns
   *e.g., to account for (3)*

5. Concurrency in the spatial domain
   *(i.e., in the context of existing calculi)*
Some key tasks (‘the problem’):

Integration at ontological, representational and computational levels:

1. Qualitative physics
   *integration of domain-independent qual. physics in a logical framework*

2. Causal and teleological aspects of (spatial) change
   *i.e., an integration of the ‘how’ and the ‘why’ aspects of change*

3. Epistemological issues
   *investigate implications of frame, ramification, qualification problems*

4. Incorporate default and non-monotonic inference patterns
   *e.g., to account for (3)*

5. Concurrency in the spatial domain
   *(i.e., in the context of existing calculi)*
Some key tasks (‘the problem’):

Integration at ontological, representational and computational levels:

1. Qualitative physics
   *integration of domain-independent qual. physics in a logical framework*

2. Causal and teleological aspects of (spatial) change
   *i.e., an integration of the ‘how’ and the ‘why’ aspects of change*

3. Epistemological issues
   *investigate implications of frame, ramification, qualification problems*

4. Incorporate default and non-monotonic inference patterns
   *e.g., to account for (3)*

5. Concurrency in the spatial domain
   *(i.e., in the context of existing calculi)*
Basic Level:

E.g., a naive ‘scene description ontology’ for room-space

Depending on richness of the spatial theory / degree of formalization:

- Primarily consist of qualitative spatial relationships relevant to one or more spatial dimensions:
  - *topology*
  - *orientation*
Basic Level:

E.g., a naive ‘scene description ontology’ for room-space

Depending on richness of the spatial theory / degree of formalization:

- Primarily consist of qualitative spatial relationships relevant to one or more spatial dimensions:
  - topology
  - orientation

E.g., using \( \text{RCC, OPRA}_m \) primitives for scene description

\[ \text{RCC – 8 Primitives} \quad \text{The } \text{OPRA}_2 \text{ relation } \hat{A} \ 2 \angle \frac{1}{7} \hat{B} \]
Scenario: Static Scene Description in Room Space

A partial scene description matrix:

<table>
<thead>
<tr>
<th>$\phi_{top}/\phi_{ort}$</th>
<th>$S_1$</th>
<th>$S_2$</th>
<th>$T$</th>
<th>TV</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>x</td>
<td>x</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>DC $\preceq 0$</td>
<td>DC $\preceq 0$</td>
</tr>
<tr>
<td>$S_2$</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>x</td>
<td>x</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>DC $\preceq \frac{1}{2}$</td>
</tr>
<tr>
<td>$T$</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>x</td>
<td>x</td>
<td>DC $\preceq \frac{1}{2}$</td>
</tr>
<tr>
<td>TV</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>DC $\preceq 0$</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>C</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>DC $\preceq \frac{1}{2}$</td>
<td>x</td>
</tr>
</tbody>
</table>
Ontological Extensions for a Dynamic Setup

But why do configurations change?

There is interaction within an environment! ∴ we need more than a temporal logic!!

- actions, events, causality, ...!?
- more importantly, we need other modes of reasoning:

  - projection, explanation, planning, simulation within the context of a general, high-level, logic-based framework
Ontological Extensions for a Dynamic Setup

But why do configurations change?

There is interaction within an environment! \(\therefore\) we need more than a temporal logic!!

- actions, events, causality, . . . !?
- more importantly, we need other modes of reasoning:
  - projection, explanation, planning, simulation within the context of a general, high-level, logic-based framework

To re-iterate key reasoning tasks:

- Spatial re-configuration:
  What are the spatial transformations (actions?) that achieve a certain goal-directed objective?

- Causal explanation
  What are the actions and/or events that may have caused a certain observed state of affairs?
Need a Dynamic Spatial Systems Perspective . . .

What is a Dynamic Spatial System?

‘A specialisation of the dynamic systems (Sandewall 1994) concept for the case where spatial configurations undergo change as a result of named occurrences, whatever be the ontological status of such occurrences (typically events and actions)’

A ‘domain-independent spatial theory’ that operationalizes this perspective is necessary...

Key requirements for a theory that builds up on ‘spatial calculi’:

R1. Interdependent spatial knowledge components
R2. Globally consistent relational scene descriptions
   i.e., compositional constraints respected wrt. change
R3. Continuity constraints preserved
R4. Dynamically appearing and disappearing objects
   i.e., incompletely known domain of discourse
R5. Physical properties of objects explicitly modelled
   e.g., containment, deformation, full-rigidity, semi-rigidity, ...
Need a Dynamic Spatial Systems Perspective...

What is a Dynamic Spatial System?

‘A specialisation of the dynamic systems (Sandewall 1994) concept for the case where spatial configurations undergo change as a result of named occurrences, whatever be the ontological status of such occurrences (typically events and actions)’

A ‘domain-independent spatial theory’ that operationalizes this perspective is necessary...

Key requirements for a theory that builds up on ‘spatial calculi’:

R1. Interdependent spatial knowledge components
R2. Globally consistent relational scene descriptions
   i.e., compositional constraints respected wrt. change
R3. Continuity constraints preserved
R4. Dynamically appearing and disappearing objects
   i.e., incompletely known domain of discourse
R5. Physical properties of objects explicitly modelled
   e.g., containment, deformation, full-rigidity, semi-rigidity, ...
Need a Dynamic Spatial Systems Perspective...

What is a Dynamic Spatial System?

‘A specialisation of the dynamic systems (Sandewall 1994) concept for the case where spatial configurations undergo change as a result of named occurrences, whatever be the ontological status of such occurrences (typically events and actions)’

A ‘domain-independent spatial theory’ that operationalizes this perspective is necessary...

Key requirements for a theory that builds up on ‘spatial calculi’:

R1. Interdependent spatial knowledge components
R2. Globally consistent relational scene descriptions
   i.e., compositional constraints respected wrt. change
R3. Continuity constraints preserved
R4. Dynamically appearing and disappearing objects
   i.e., incompletely known domain of discourse
R5. Physical properties of objects explicitly modelled
   e.g., containment, deformation, full-rigidity, semi-rigidity, ...
Need a Dynamic Spatial Systems Perspective...

What is a Dynamic Spatial System?
‘A specialisation of the dynamic systems (Sandewall 1994) concept for the case where spatial configurations undergo change as a result of named occurrences, whatever be the ontological status of such occurrences (typically events and actions)’

A ‘domain-independent spatial theory’ that operationalizes this perspective is necessary...

Key requirements for a theory that builds up on ‘spatial calculi’:

R1. Interdependent spatial knowledge components
R2. Globally consistent relational scene descriptions
   *i.e., compositional constraints respected wrt. change*
R3. Continuity constraints preserved
R4. Dynamically appearing and disappearing objects
   *i.e., incompletely known domain of discourse*
R5. Physical properties of objects explicitly modelled
   *e.g., containment, deformation, full-rigidity, semi-rigidity, ...*
Need a Dynamic Spatial Systems Perspective...

What is a Dynamic Spatial System?

‘A specialisation of the dynamic systems (Sandewall 1994) concept for the case where spatial configurations undergo change as a result of named occurrences, whatever be the ontological status of such occurrences (typically events and actions)’

A ‘domain-independent spatial theory’ that operationalizes this perspective is necessary...

Key requirements for a theory that builds up on ‘spatial calculi’:

R1. Interdependent spatial knowledge components
R2. Globally consistent relational scene descriptions
   i.e., compositional constraints respected wrt. change
R3. Continuity constraints preserved
R4. Dynamically appearing and disappearing objects
   i.e., incompletely known domain of discourse
R5. Physical properties of objects explicitly modelled
   e.g., containment, deformation, full-rigidity, semi-rigidity, ...
Need a Dynamic Spatial Systems Perspective...

What is a Dynamic Spatial System?

‘A specialisation of the dynamic systems (Sandewall 1994) concept for the case where spatial configurations undergo change as a result of named occurrences, whatever be the ontological status of such occurrences (typically events and actions)’

A ‘domain-independent spatial theory’ that operationalizes this perspective is necessary...

Key requirements for a theory that builds up on ‘spatial calculi’:

R1. Interdependent spatial knowledge components

R2. Globally consistent relational scene descriptions
   i.e., compositional constraints respected wrt. change

R3. Continuity constraints preserved

R4. Dynamically appearing and disappearing objects
   i.e., incompletely known domain of discourse

R5. Physical properties of objects explicitly modelled
   e.g., containment, deformation, full-rigidity, semi-rigidity, ...
Need a Dynamic Spatial Systems Perspective...

What is a Dynamic Spatial System?

‘A specialisation of the dynamic systems (Sandewall 1994) concept for the case where spatial configurations undergo change as a result of named occurrences, whatever be the ontological status of such occurrences (typically events and actions)’

A ‘domain-independent spatial theory’ that operationalizes this perspective is necessary...

Key requirements for a theory that builds up on ‘spatial calculi’:

R1. Interdependent spatial knowledge components
R2. Globally consistent relational scene descriptions
    *i.e., compositional constraints respected wrt. change*
R3. Continuity constraints preserved
R4. Dynamically appearing and disappearing objects
    *i.e., incompletely known domain of discourse*
R5. Physical properties of objects explicitly modelled
    *e.g., containment, deformation, full-rigidity, semi-rigidity, ...*
Need a Dynamic Spatial Systems Perspective...

What is a Dynamic Spatial System?

‘A specialisation of the dynamic systems (Sandewall 1994) concept for the case where spatial configurations undergo change as a result of named occurrences, whatever be the ontological status of such occurrences (typically events and actions)’

A ‘domain-independent spatial theory’ that operationalizes this perspective is necessary...

Key requirements for a theory that builds up on ‘spatial calculi’:

R1. Interdependent spatial knowledge components
R2. Globally consistent relational scene descriptions
   *i.e.*, compositional constraints respected wrt. change
R3. Continuity constraints preserved
R4. Dynamically appearing and disappearing objects
   *i.e.*, incompletely known domain of discourse
R5. Physical properties of objects explicitly modelled
   *e.g.*, containment, deformation, full-rigidity, semi-rigidity, ...
Operationalising the Dynamic Spatial Systems Perspective

Action description logic (\(ADL\))
\{actions, events, causation, fluents, \ldots\}

\+

Domain-Independent Qualitative Spatial Theory (\(QST\))
\{JEPD’ness, composition theorems, conceptual neighbourhood, basic properties of relations, axioms of interaction, appearance and disappearance phenomena, physical properties of objects, \ldots\}

(i.e., requirements (R1 – R5))

\[\downarrow\]

Reasoning Tasks
\{\(ADL \cup QST\) \(\models\) projection, planning and explanation\}
Operationalising the Dynamic Spatial Systems Perspective

Action description logic ($ADL$)

$$\{actions, events, causation, fluents, \ldots \}$$

$$+$$

Domain-Independent Qualitative Spatial Theory ($QST$)

$$\{JEPD’ness, composition theorems, conceptual neighbourhood, basic properties of relations, axioms of interaction, appearance and disappearance phenomena, physical properties of objects, \ldots\}$$

(i.e., requirements ($R1 – R5$))

Reasoning Tasks

$$\{ADL \cup QST \models \text{projection, planning and explanation}\}$$
Operationalising the Dynamic Spatial Systems Perspective

Action description logic ($\mathcal{ADL}$)

\{actions, events, causation, fluents, \ldots \}

+ 

Domain-Independent Qualitative Spatial Theory ($\mathcal{QST}$)

\{JEPD’ness, composition theorems, conceptual neighbourhood, basic properties of relations, axioms of interaction, appearance and disappearance phenomena, physical properties of objects, \ldots \}

(i.e., requirements (R1 – R5))

\[\downarrow\]

Reasoning Tasks

\{\mathcal{ADL} \cup \mathcal{QST} \models \text{projection, planning and explanation}\}
Operationalising the Dynamic Spatial Systems Perspective

Action description logic \( (ADL) \)
\[
\{ \text{actions, events, causation, fluents, \ldots} \}
\]

+ 

Domain-Independent Qualitative Spatial Theory \( (QST) \)
\[
\{ \text{JEPD’ness, composition theorems, conceptual neighbourhood, basic properties of relations, axioms of interaction, appearance and disappearance phenomena, physical properties of objects, \ldots} \}
\]

(i.e., requirements \( (R1 - R5) \))

\[ \downarrow \]

Reasoning Tasks
\[
\{ ADL \cup QST = \text{projection, planning and explanation} \}
Operationalising the Dynamic Spatial Systems Perspective

Action description logic ($ADL$)

\{ \textit{actions, events, causation, fluents,} \ldots \} 

+ 

Domain-Independent Qualitative Spatial Theory ($QST$)

\{ \textit{JEPD’ness, composition theorems, conceptual neighbourhood, basic properties of relations, axioms of interaction, appearance and disappearance phenomena, physical properties of objects,} \ldots \} 

(i.e., requirements ($R1 – R5$))

\{ ADL \cup QST = \text{projection, planning and explanation} \}
Operationalising the Dynamic Spatial Systems Perspective

Action description logic (\(ADL\))

\{actions, events, causation, fluents, \ldots\}

+ 

Domain-Independent Qualitative Spatial Theory (\(QST\))

\{JEPD’ness, composition theorems, conceptual neighbourhood, basic properties of relations, axioms of interaction, appearance and disappearance phenomena, physical properties of objects, \ldots\}

(i.e., requirements (\(R1 - R5\))

\(\Downarrow\)

Reasoning Tasks

\(\{ADL \cup QST \Rightarrow projection, planning and explanation\}\)
Dynamic Spatial Systems in the Situation Calculus

Realizing \([\mathcal{ADL} + \mathcal{QST}]\)

\[ [\Sigma_{\text{sit}} \cup \Sigma_{\text{space}}] \cup [\Sigma_{\text{ini}}] \implies \{\text{projection, planning and explanation}\} \]

- Meta-theory of the \(\mathcal{ADL}\) (\(\Sigma_{\text{sit}}\))
- Domain-independent spatial theory or \(\mathcal{QST}\) (\(\Sigma_{\text{space}}\))
- Initial situation (\(\Sigma_{\text{ini}}\))

Default and Non-Monotonic Aspects of Spatial Reasoning

Some instances in the context of: $[ADL + QST] / [\Sigma_{sit} \cup \Sigma_{space}]$

1. Global compositional consistency of spatial information
   ‘connected to the ramification problem’

2. Spatial property persistence
   ‘connected to the frame problem’

3. Phenomenal aspect – Appearance and disappearance of objects
   ‘incompletely known domain’

4. Reasoning requirements
   ‘explanation as abduction’ (Shanahan 1993)
Assume binary fluents with reified spatial relationships:

\[ \phi_{sp}(o_1, o_2) = \{\gamma_1, \gamma_2, \ldots, \gamma_n\} \]
\[ \phi_{top}(o_1, o_2) = \{dc, ec, \ldots, ntpp^{-1}\} \]
Some notation...

- Assume binary fluents with reified spatial relationships:
  \[ \phi_{sp}(o_1, o_2) = \{\gamma_1, \gamma_2, \ldots, \gamma_n\} \]
  \[ \phi_{top}(o_1, o_2) = \{dc, ec, \ldots, ntpp^{-1}\} \]

- Ternary relationship of property exemplification (i.e., fluents)
  \[ Holds(\phi_{sp}(o_1, o_2), \gamma, s) \]
Some notation...

Assume binary fluents with reified spatial relationships:

\[ \phi_{sp}(o_1, o_2) = \{\gamma_1, \gamma_2, \ldots, \gamma_n\} \]

\[ \phi_{top}(o_1, o_2) = \{dc, ec, \ldots, ntpp^{-1}\} \]

Ternary relationship of property exemplification (i.e., fluents)

\[ \text{Holds}(\phi_{sp}(o_1, o_2), \gamma, s) \]

Ternary causal relationship

\[ \text{Caused}(\phi(o_1, o_2), \gamma, s) \]
Some notation...

- Assume binary fluents with reified spatial relationships:
  \[ \phi_{sp}(o_1, o_2) = \{\gamma_1, \gamma_2, \ldots, \gamma_n\} \]
  \[ \phi_{top}(o_1, o_2) = \{dc, ec, \ldots, ntpp^{-1}\} \]

- Ternary relationship of property exemplification (i.e., fluents)
  \[ Holds(\phi_{sp}(o_1, o_2), \gamma, s) \]

- Ternary causal relationship
  \[ Caused(\phi(o_1, o_2), \gamma, s) \]

- The usual set...
  \{¬, ∧, ∨, ∀, ∃, ⊃, ≡\}
Global Consistency and Ramifications - I

Need Complete N-Clique Descriptions

\[ \text{OPRA}_2 \quad \text{RCC} - 8 \]

Given \( n \) domain objects and \( k \) spatial domains being modelled:

- Static configurations consist of \((k \times [n(n - 1)/2])\) spatial relationships
- (\( \because \) of UNA): \([\phi_{sp}(o_i, o_j) \neq \phi_{sp}(o_j, o_i)]\)

\( \because (k \times [n(n - 1)/2]) \times 2 \) unique fluents
Global Consistency and Ramifications - II

Compositional constraints contain ramifications / indirect effects

\[(\forall s) \big[ \text{Holds}(\phi(o_1, o_2), \gamma_1, s) \land \text{Holds}(\phi(o_2, o_3), \gamma_2, s) \implies \text{Holds}(\phi(o_1, o_3), \gamma_3, s) \big] \]
Global Consistency and Ramifications - II

Compositional constraints contain ramifications / indirect effects

\[(\forall s) \ [\text{Holds}(\phi(o_1, o_2), \gamma_1, s) \land \text{Holds}(\phi(o_2, o_3), \gamma_2, s) \supset \text{Holds}(\phi(o_1, o_3), \gamma_3, s)]\]
Global compositional consistency:

One solution:
Global compositional consistency:

One solution:

1. Property causation axiom

\[ \text{Caused}(\phi(\tilde{x}), \gamma, s) \supset \text{Holds}(\phi(\tilde{x}), \gamma, s) \]

(i.e., keep extensionality of ‘\text{Holds}(\ldots)’ open-ended)
Global compositional consistency:

One solution:

1. Property causation axiom

\[\text{Caused}(\phi(\bar{x}), \gamma, s) \Rightarrow \text{Holds}(\phi(\bar{x}), \gamma, s)\]

(i.e., keep extensionality of ‘\text{Holds}(\ldots)’ open-ended)

2. Ramification constraints

Appeal to causality for modelling ramification-yielding state constraints [Lin and Reiter 1994]:

\[(\forall s). [\text{Holds}(\phi_{sp}(o_1, o_2), \gamma_1, s) \land \text{Holds}(\phi_{sp}(o_2, o_3), \gamma_2, s) \Rightarrow \text{Caused}(\phi_{sp}(o_1, o_3), \gamma_3, s)]\]
Global compositional consistency:

One solution:

1. Property causation axiom

\[ \text{Caused}(\phi(\bar{x}), \gamma, s) \supset \text{Holds}(\phi(\bar{x}), \gamma, s) \]

(i.e., keep extensionality of ‘\text{Holds}(\ldots)’ open-ended)

2. Ramification constraints

Appeal to causality for modelling ramification-yielding state constraints [Lin and Reiter 1994]:

\[ (\forall s). \left[ \text{Holds}(\phi_{sp}(o_1, o_2), \gamma_1, s) \land \text{Holds}(\phi_{sp}(o_2, o_3), \gamma_2, s) \right. \]

\[ \left. \supset \text{Caused}(\phi_{sp}(o_1, o_3), \gamma_3, s) \right] \]

For a spatial calculus with ‘\(n\)’ JEPD relationships, \([n \times n]\) theorems like above necessary
Global compositional consistency: Final step

3. Minimize change (effects).

Minimize ‘Caused’ by circumscribing (CIRC) it in the foundational theory:

\[
\text{CIRC}\left[\Sigma_{\text{sit}} \cup \Sigma_{\text{space}} ; \text{Caused}\right]
\]
Global compositional consistency: Final step

3. Minimize change (effects).

Minimize ‘Caused’ by circumscribing (CIRC) it in the foundational theory:

\[
\text{CIRC}[\Sigma_{sit} \cup \Sigma_{space} ; \text{Caused}]
\]

\[
[\text{Caused}(\phi_{sp}(o_i, o_j), \gamma, s) \equiv \{ (A) \lor (B) \} ]
\]

\[\Downarrow\]
Global compositional consistency: Final step

3. Minimize change (effects).

Minimize ‘Caused’ by circumscribing (CIRC) it in the foundational theory:

\[ CIRC[\Sigma_{sit} \cup \Sigma_{space} ; Caused] \]

\[ [Caused(\phi_{sp}(o_i, o_j), \gamma, s) \equiv \{(A) \lor (B)\} ] \]

\[ \Downarrow \]

1. (A) → ‘Direct effects’ (of actions and events)
2. (B) → ‘Indirect effects’ (compositional and others)
Global compositional consistency: Final step

3. Minimize change (effects).

Minimize ‘Caused’ by circumscribing (\(CIRC\)) it in the foundational theory:

\[
CIRC[\Sigma_{sit} \cup \Sigma_{space} ; \ Caused] \\
[Caused(\phi_{sp}(o_i, o_j), \gamma, s) \equiv \{(A) \lor (B)\}] 
\]

\[\downarrow\]

1. (A) → ‘Direct effects’ (of actions and events)
2. (B) → ‘Indirect effects’ (compositional and others)

(i.e., close the extensionality of what is ‘Caused’, and hence what ‘Holds(…)’, in a given situation ‘s’)

\(\Sigma_{sit}\): Situation terms, \(\Sigma_{space}\): Space terms.
Global compositional consistency: Final step

3. Minimize change (effects).

Minimize ‘Caused’ by circumscribing (CIRC) it in the foundational theory:

\[ CIRC[\Sigma_{sit} \cup \Sigma_{space} ; Caused] \]

\[ Caused(\phi_{sp}(o_i, o_j), \gamma, s) \equiv \{(A) \lor (B)\} \]

\[ \downarrow \]

1. (A) → ‘Direct effects’ (of actions and events)
2. (B) → ‘Indirect effects’ (compositional and others)

(i.e., close the extensionality of what is ‘Caused’, and hence what ‘Holds(… )’, in a given situation ‘s’)

However, what happens when there are no indirect effects or ramifications?
2. Spatial property persistence – (‘the frame Problem’)

Spatial relationships ‘*typically*’ persist

‘*Formalise the intuition that spatial relationships between domain objects typically persist*’
2. Spatial property persistence – (‘the frame Problem’)

Spatial relationships ‘*typically*’ persist

‘*Formalise the intuition that spatial relationships between domain objects typically persist*’

This is trivial: given that $\theta(\bar{v})$ is a parameterized event or action:

$$\text{Poss}(\theta(\bar{v}), s) \lor \text{Occurs}(\theta(\bar{v}), s) \supset$$

$$[\neg (\exists \gamma') \text{Caused}(\phi(\bar{x}), \gamma', \text{Result}(\theta(\bar{v}), s)) \supset$$

$$\text{Holds}(\phi(\bar{x}), \gamma, \text{Result}(\theta(\bar{v}), s)) \equiv \text{Holds}(\phi(\bar{x}), \gamma, s)]$$
2. Spatial property persistence – (‘the frame Problem’)

Spatial relationships ‘*typically*’ persist

‘Formalise the intuition that spatial relationships between domain objects typically persist’

This is trivial: given that $\theta(\bar{v})$ is a parameterized event or action:

$$\text{Poss}(\theta(\bar{v}), s) \lor \text{Occurs}(\theta(\bar{v}), s) \supset$$

$$\neg(\exists \gamma') \text{ Caused}(\phi(\bar{x}), \gamma', \text{Result}(\theta(\bar{v}), s)) \supset$$

$$\text{Holds}(\phi(\bar{x}), \gamma, \text{Result}(\theta(\bar{v}), s)) \equiv \text{Holds}(\phi(\bar{x}), \gamma, s)$$

And how do we know what is ‘Caused’?
2. Spatial property persistence – (‘the frame Problem’)

Spatial relationships ‘typically’ persist

‘Formalise the intuition that spatial relationships between domain objects typically persist’

This is trivial: given that $\theta(\tilde{v})$ is a parameterized event or action:

$$\text{Poss}(\theta(\tilde{v}), s) \lor \text{Occurs}(\theta(\tilde{v}), s) \Rightarrow$$

$$[\neg(\exists \gamma') \text{Caused}(\phi(\tilde{x}), \gamma', \text{Result}(\theta(\tilde{v}), s)) \Rightarrow$$

$$\text{Holds}(\phi(\tilde{x}), \gamma, \text{Result}(\theta(\tilde{v}), s)) \equiv \text{Holds}(\phi(\tilde{x}), \gamma, s)]$$

And how do we know what is ‘Caused’?

Recall that ‘$\text{Caused}(...)$’ (i.e., the effects) is minimised in order to obtain the causation axioms of the following form:

$$\text{Caused}(\phi_{sp}(o_i, o_j), \gamma, s) \equiv \left[ \{(A) \lor (B)\} \right]$$
3. Phenomenal aspects – Appearance and disappearance of objects

Incompletely known domain

A Delivery System Scenario

Object Change History (Source: [Worboys 05])
Appearance and Disappearance of Objects

Branching Time Situation-Based History

For the new object:

1. what is it’s spatial relationship with other existing objects?
2. how to make it ‘not exist’ in the past?
   - note that the object is ‘unknown’ in the past
3. how to make past/present/future n-clique situation descriptions ‘compositionally consistent’?

Recall that:
- ramification constraints range over the entire (hypothetical) situation space
- potential axioms of interaction between inter-dependent spatial domains
Appearance and Disappearance of Objects

Branching Time Situation-Based History

For the new object:

1. what is it’s spatial relationship with other existing objects?

2. how to make it ‘not exist’ in the past?
   - note that the object is ‘unknown’ in the past

3. how to make past/present/future n-clique situation descriptions ‘compositionally consistent’?

Recall that:

- *ramification constraints* range over the entire (hypothetical) situation space
- potential *axioms of interaction* between inter-dependent spatial domains
Commonsense and Space

Default and non-monotonic aspects of spatial reasoning

Appearance and Disappearance of Objects

exists(c, s_0)

(a, s_0)

exists(c, s_0)

(a, s_0)

exists(c, s_1)

(a, s_1)

exists(c, s_1)

(a, s_1)

unknown

(--)

(--)

(a, s_0)

exists(c, s_0)

(a, s_0)

exists(b, s_0)

exists(b, s_0)

exists(c, s_0)

(a, s_0)

exists(c, s_0)

(a, s_0)

exists(b, s_0)

exists(b, s_0)

exists(c, s_2)

(a, s_2)

exists(c, s_2)

(a, s_2)

exists(b, s_2)

exists(b, s_2)

unknown

(--)

(--)

M. Bhatt (SFB/TR 8 Spatial Cognition)

Universität Bremen
Need default reasoning about ‘non-existence’

Solution sketch (presuming ‘identity’ for the case of re-appearance)

1. Maintain existential facts/fluents about objects $\text{exists}(b, s_2)$
   - *(i.e., unlike a state-based approach, no propagation required!)*

2. Add special ‘appearance’ and ‘disappearance’ events
   - *these act on the ‘existential’ fluent*

3. Maintain ‘null’ spatial relationships for non-existing objects
   - *these acquire a special status in the calculus!*

4. Add constraint that newly appearing objects must participate in at least one ‘non-null’ spatial relationship

5. Finally, either apply predicate completion for ‘$\text{exists}(\ldots)$’ or minimise its on a situation-by-situation basis
**Need default reasoning about ‘non-existence’**

<table>
<thead>
<tr>
<th>Solution sketch (presuming ‘identity’ for the case of re-appearance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maintain existential facts/fluents about objects $\text{exists}(b, s_2)$</td>
</tr>
<tr>
<td>- (i.e., unlike a state-based approach, no propagation required!)</td>
</tr>
<tr>
<td>2. add special ‘appearance’ and ‘disappearance events’</td>
</tr>
<tr>
<td>- these act on the ‘existential’ fluent</td>
</tr>
<tr>
<td>3. Maintain ‘null’ spatial relationships for non-existing objects</td>
</tr>
<tr>
<td>- these acquire a special status in the calculus!</td>
</tr>
<tr>
<td>4. Add constraint that newly appearing objects must participate in at least one ‘non-null’ spatial relationship</td>
</tr>
<tr>
<td>5. Finally, either apply predicate completion for ‘$\text{exists}(...)$’ or minimise its on a situation-by-situation basis</td>
</tr>
</tbody>
</table>
Need default reasoning about ‘non-existence’

Solution sketch (presuming ‘identity’ for the case of re-appearance)

1. Maintain existential facts/fluents about objects $\text{exists}(b, s_2)$
   - *(i.e., unlike a state-based approach, no propagation required!)*

2. Add special ‘appearance’ and ‘disappearance events’
   - *these act on the ‘existential’ fluent*

3. Maintain ‘null’ spatial relationships for non-existing objects
   - *these acquire a special status in the calculus!*

4. Add constraint that newly appearing objects must participate in at least one ‘non-null’ spatial relationship

5. Finally, either apply predicate completion for ‘$\text{exists}(\ldots)$’ or minimise its on a situation-by-situation basis
Need default reasoning about ‘non-existence’

Solution sketch (presuming ‘identity’ for the case of re-appearance)

1. Maintain existential facts/fluents about objects \( \text{exists}(b, s_2) \)
   - \( i.e., \text{unlike a state-based approach, no propagation required!} \)

2. add special ‘appearance’ and ‘disappearance events’
   - \( \text{these act on the ‘existential’ fluent} \)

3. Maintain ‘null’ spatial relationships for non-existing objects
   - \( \text{these acquire a special status in the calculus!} \)

4. Add constraint that newly appearing objects must participate in at least one ‘non-null’ spatial relationship

5. Finally, either apply predicate completion for ‘\( \text{exists}(\ldots) \)’ or minimise its on a situation-by-situation basis
Need default reasoning about ‘non-existence’

Solution sketch (presuming ‘identity’ for the case of re-appearance)

1. Maintain existential facts/fluents about objects $exists(b, s_2)$
   - (i.e., unlike a state-based approach, no propagation required!)

2. Add special ‘appearance’ and ‘disappearance’ events
   - these act on the ‘existential’ fluent

3. Maintain ‘null’ spatial relationships for non-existing objects
   - these acquire a special status in the calculus!

4. Add constraint that newly appearing objects must participate in at least one ‘non-null’ spatial relationship

5. Finally, either apply predicate completion for ‘$exists(\ldots)$’ or minimise its on a situation-by-situation basis
4. Reasoning requirement – Explanation tasks

Causal explanation

Given a set of time-stamped observations or snapshots (e.g., observation of a mobile-robot or time-stamped GIS data), the objective is to explain which domain specific (spatial?) events and actions may have caused the observed state-of-affairs.

- In essence, all problems resembling the classic ‘stolen-car scenario’
4. Reasoning requirement – Explanation tasks

Causal explanation

Given a set of time-stamped observations or snapshots (e.g., observation of a mobile-robot or time-stamped GIS data), the objective is to explain which domain specific (spatial?) events and actions may have caused the observed state-of-affairs.

- In essence, all problems resembling the classic ‘stolen-car scenario’

Explanation by Abduction (in the situation calculus)

Formula $\Delta$ is an explanation of $\Phi$ in terms of the abduction policy $\eta^*$ given a background theory $\Sigma$ and a circumscription policy that minimizes $\rho^*$ iff [Shanahan 93,97]:

- $\text{CIRC}[\Sigma \land \Delta ; \rho^*]$ is consistent,
- $\Delta$ mentions only predicates in $\eta^*$, and
- $\text{CIRC}[\Sigma \land \Delta ; \rho^*] \models \Phi$

Point of above dogma is: it’s a non-monotonic setup!
Structure of Abductive Explanation
Structure of Abductive Explanation
Structure of Abductive Explanation

Abduction policy:

\[ \eta = [\text{Happens}, <, \leq] \]

Circumscription policy:

\[ \rho^* = [\text{Happens}] \]

\[ \Psi \equiv \text{Holds} (\phi_{top}(a, c), po, S_0) \land \text{Holds} (\exists (a), true, S_0) \land \text{Holds} (\exists (c), true, S_0) \]

\[ \Phi_1 \equiv \text{HoldsAt} (\phi_{top}(a, c), ec, t_1) \land \text{HoldsAt} (\exists (b), true, t_1) \land \text{HoldsAt} (\phi_{top}(b, a), ntpp, t_1) \]

\[ \Delta \equiv (\exists t_i, t_j, t_k) \]

\[ t_1 \leq t_i < t_1 \land \text{Happens} (\text{appearance} (b), t_i) \land t_i < t_j < t_1 \land \text{Happens} (\text{tran} (b, a, tpp), t_j) \land t_k < t_1 \land \text{Happens} (\text{tran} (a, c, ec), t_k) \land t_k \neq t_i \land t_k \neq t_j \]
Structure of Abductive Explanation

\[\sum_{s \in t_0} \land \sum_{\text{space}} \land \Psi \land \Delta / \equiv \Phi_1 \]

\[\text{Abduction policy: } \eta = \left[ \text{Happens}, \prec, \leq \right] \text{ and Circumscription policy: } \rho^* = \left[ \text{Happens} \right] \]

\[\Psi \equiv \text{Holds}(\phi_{\text{top}}(a, c), p_0, S_0) \land \text{Holds}(\text{exists}(a), \text{true}, S_0) \land \text{Holds}(\text{exists}(c), \text{true}, S_0) / \equiv \]

\[\Phi_1 \equiv \text{HoldsAt}(\phi_{\text{top}}(a, c), \text{ec}, t_1) \land \text{HoldsAt}(\text{exists}(b), \text{true}, t_1) \land \text{HoldsAt}(\phi_{\text{top}}(b, a), \text{ntpp}, t_1) / \equiv \]

\[\Delta \equiv (\exists t_i, t_j, t_k). \]

\[t_1 \leq t_i < t_1 \land \text{Happens}(\text{appearance}(b), t_i) \land t_i < t_j < t_1 \land \text{Happens}(\text{tran}(b, a, \text{tpp}), t_j) \land t_k < t_1 \land \text{Happens}(\text{tran}(a, c, \text{ec}), t_k) \land t_k \neq t_i \land t_k \neq t_j / \equiv \]
Structure of Abductive Explanation

Abduction policy: $\eta = [\text{Happens}, <, \leq]$ and Circumscription policy: $\rho^* = [\text{Happens}]

$\Psi \equiv \text{Holds}(\phi_{top}(a, c), po, S_0) \land \text{Holds}(\exists(a), true, S_0) \land \text{Holds}(\exists(c), true, S_0)$

$\Phi_1 \equiv \text{HoldsAt}(\phi_{top}(a, c), ec, t_1) \land \text{HoldsAt}(\exists(b), true, t_1) \land \text{HoldsAt}(\phi_{top}(b, a), ntpp, t_1)$
Structure of Abductive Explanation

\[ \sum_{sit} \wedge \sum_{space} \]
Structure of Abductive Explanation

\[ \sum_{sit} \land \sum_{space} \land \Psi \]
Structure of Abductive Explanation

\[ \sum_{sit} \land \sum_{space} \land \Psi \land \Delta \]
Structure of Abductive Explanation

\[
\left[ \sum_{sit} \land \sum_{space} \right] \land \Psi \land \Delta \models \Phi_1
\]
Structure of Abductive Explanation

\[
\left[ \Sigma_{sit} \land \Sigma_{space} \right] \land \Psi \land \Delta \models \Phi_1
\]

Abduction policy: \( \eta = [\text{Happens}, <, \leq] \) and Circumscription policy: \( \rho^* = [\text{Happens}] \)
Structure of Abductive Explanation

\[
[\Sigma_{sit} \land \Sigma_{space}] \land \Psi \land \Delta \models \Phi_1
\]

Abduction policy: \( \eta = [Happens, <, \leq] \) and Circumscription policy: \( \rho^* = [Happens] \)

\[
\Psi \equiv Holds(\phi_{top}(a, c), po, S_0) \land Holds(exists(a), true, S_0) \land Holds(exists(c), true, S_0)
\]
Structure of Abductive Explanation

\[ [\Sigma_{sit} \land \Sigma_{space}] \land \Psi \land \Delta \models \Phi_1 \]

Abduction policy: \( \eta = [\text{Happens}, <, \leq] \) and Circumscription policy: \( \rho^* = [\text{Happens}] \)

\[
\Psi \equiv \text{Holds}(\phi_{\text{top}}(a, c), \text{po}, S_0) \land \text{Holds}(\text{exists}(a), \text{true}, S_0) \land \text{Holds}(\text{exists}(c), \text{true}, S_0)
\]

\[
\Phi_1 \equiv \text{HoldsAt}(\phi_{\text{top}}(a, c), \text{ec}, t_1) \land \text{HoldsAt}(\text{exists}(b), \text{true}, t_1) \land \text{HoldsAt}(\phi_{\text{top}}(b, a), \text{ntpp}, t_1)
\]
Structure of Abductive Explanation

\[
\text{Abduction policy: } \eta = [\text{Happens}, <, \leq] \text{ and Circumscription policy: } \rho^* = [\text{Happens}]
\]

\[
\Psi \equiv \text{Holds}(\phi_{top}(a, c), \text{po}, S_0) \land \text{Holds}(\text{exists}(a), \text{true}, S_0) \land \text{Holds}(\text{exists}(c), \text{true}, S_0)
\]

\[
\Phi_1 \equiv \text{HoldsAt}(\phi_{top}(a, c), \text{ec}, t_1) \land \text{HoldsAt}(\text{exists}(b), \text{true}, t_1) \land \text{HoldsAt}(\phi_{top}(b, a), \text{ntpp}, t_1)
\]

\[
[\Sigma_{sit} \land \Sigma_{space} \land \Psi \land \Delta] \models \Phi_1, \text{ where }
\]

\[
\Delta \equiv (\exists t_i, t_j, t_k). [t_1 \leq t_i < t_1 \land \text{Happens}(\text{appearance}(b), t_i)] \land [t_i < t_j < t_1 \land \text{Happens}(\text{tran}(b, a, \text{tpp}), t_j)] \land [t_k < t_1 \land \text{Happens}(\text{tran}(a, c, \text{ec}), t_k)] \land [t_k \neq t_i \land t_k \neq t_j]
\]
Modelling explanation abductively in the situation calculus

High-level / Domain-specific Abducible

E.g. task: domain-specific pattern identification / mining in object-level GIS:

\[
\begin{align*}
activity\_pattern(entering\_office, t, t') & \leftarrow \\
& \left[ (\exists t_i). \text{Between}(t_i, t, t') \land \text{Happens}(\theta_i, t_i) \equiv \Delta_1 \right] \\
\vdots
\end{align*}
\]

\[
\begin{align*}
activity\_pattern(saw\_alien, t, t') & \leftarrow \\
& \left[ (\exists t_i, t_j). \text{Between}(t_i, t, t') \land \text{Between}(t_j, t, t') \land t_1 < t_j \land \\
& \text{Happens}(\theta_j, t_i) \land \text{Happens}(\theta_k, t_j) \equiv \Delta_n \right]
\end{align*}
\]
Outline

1 Commonsense Reasoning about the World
   - An Example
   - Vision statement

2 Commonsense and Space
   - Reasoning about space, actions and change
   - Default and non-monotonic aspects of spatial reasoning

3 Application Framework

4 Outlook
An Experimental Cognitive Robotics Framework

An Exemplar: Indigolog and Gazebo

Laser Guided Mobile Humanoid Gripper

- Low-level control implemented within the open-source Player+Gazebo simulation framework

Demo: High-level reasoning + low-level motion control
Integration of Robotcub (YARP & iCub) Ongoing

Humanoid Simulator (Tikhanoff, V., et al., 2008)
Outline

1. Commonsense Reasoning about the World
   - An Example
   - Vision statement

2. Commonsense and Space
   - Reasoning about space, actions and change
   - Default and non-monotonic aspects of spatial reasoning

3. Application Framework

4. Outlook
Action and Control

- advance theoretical work on ‘reasoning about space, action and change’
  - identify other default reasoning scenarios
  - spatial reasoning with other action calculi (e.g., fluent and event calculi)

Other application domains

- spatial and temporal reasoning for AMI systems (e.g., smart offices/homes)
  - applying spatial calculi for representation and reasoning with dynamic scenes / configurations
  - identifying motion / activity patterns
    - e.g., for trigger generation, energy saving, surveillance, ...
Action and Control

- advance theoretical work on ‘reasoning about space, action and change’
  - identify other default reasoning scenarios
  - spatial reasoning with other action calculi (e.g., fluent and event calculi)

Other application domains

- spatial and temporal reasoning for AMI systems (e.g., smart offices/homes)
  - applying spatial calculi for representation and reasoning with dynamic scenes / configurations
  - identifying motion / activity patterns
    - e.g., for trigger generation, energy saving, surveillance, ...
Call for Papers:
Journal of Spatial Cognition and Computation

Special Issue: *Emerging Applications of Spatial and Temporal Reasoning*
Editors: Mehul Bhatt, Hans Guesgen, Shyamanta Hazarika, Stefan Woelfl

Consider Attending:

- **IJCAI 2009 - Workshop on Spatial and Temporal Reasoning**
  - Where: Pasadena, California, USA
  - When: July 11, 2009

- **COSIT 2009 - Spatial and Temporal Reasoning for Ambient Intelligence Systems**
  - Where: Aber Wrac’h, France
  - When: September 21, 2009