From Conceptual Blending to Computational Concept Invention

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Concept Invention:
A highly interdisciplinary endeavour

- **From Conceptual Blending**
  - Cognitive Linguistics / Embodied Cognition
  - Metaphor Theory / Analogies
  - Image Schema Theory
- **to Computational Concept Invention**
  - Computational Creativity (CC)
  - Knowledge Engineering / Ontologies
  - category theory / non-classical logic / computational logic

Concept Invention:
A highly interdisciplinary endeavour

- **Part 1:**
  - what is conceptual blending?
- **Part 2:**
  - an abstract framework and representation language
- **Part 3:**
  - cognitive modelling and computational problems
    - image schemas as generic spaces
    - computing generic spaces via generalisation

Part 1:

Conceptual Blending

Conceptual Blending

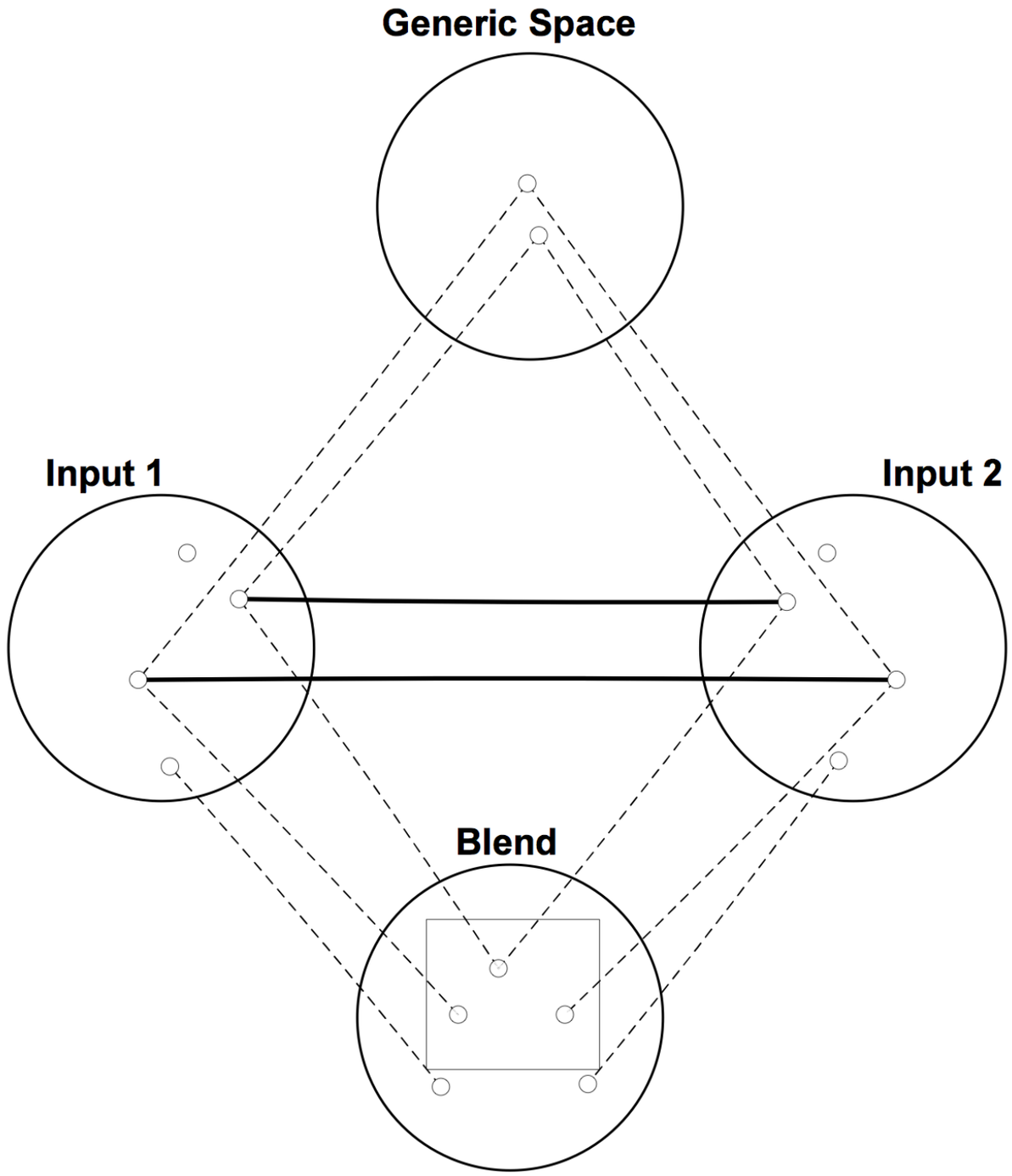
- **Mark Turner (2014):** a hypothetical explanation for the '**human spark**':
- The 'lionman', approximately 32.000 years old, blends the concepts of 'human' and 'lion'.
- The period of its creation marks the end of an apparent deadlock of human cultural development,
- and the beginning of rapid cultural evolution (hypothesis: expansion of working memory).

Conceptual Blending

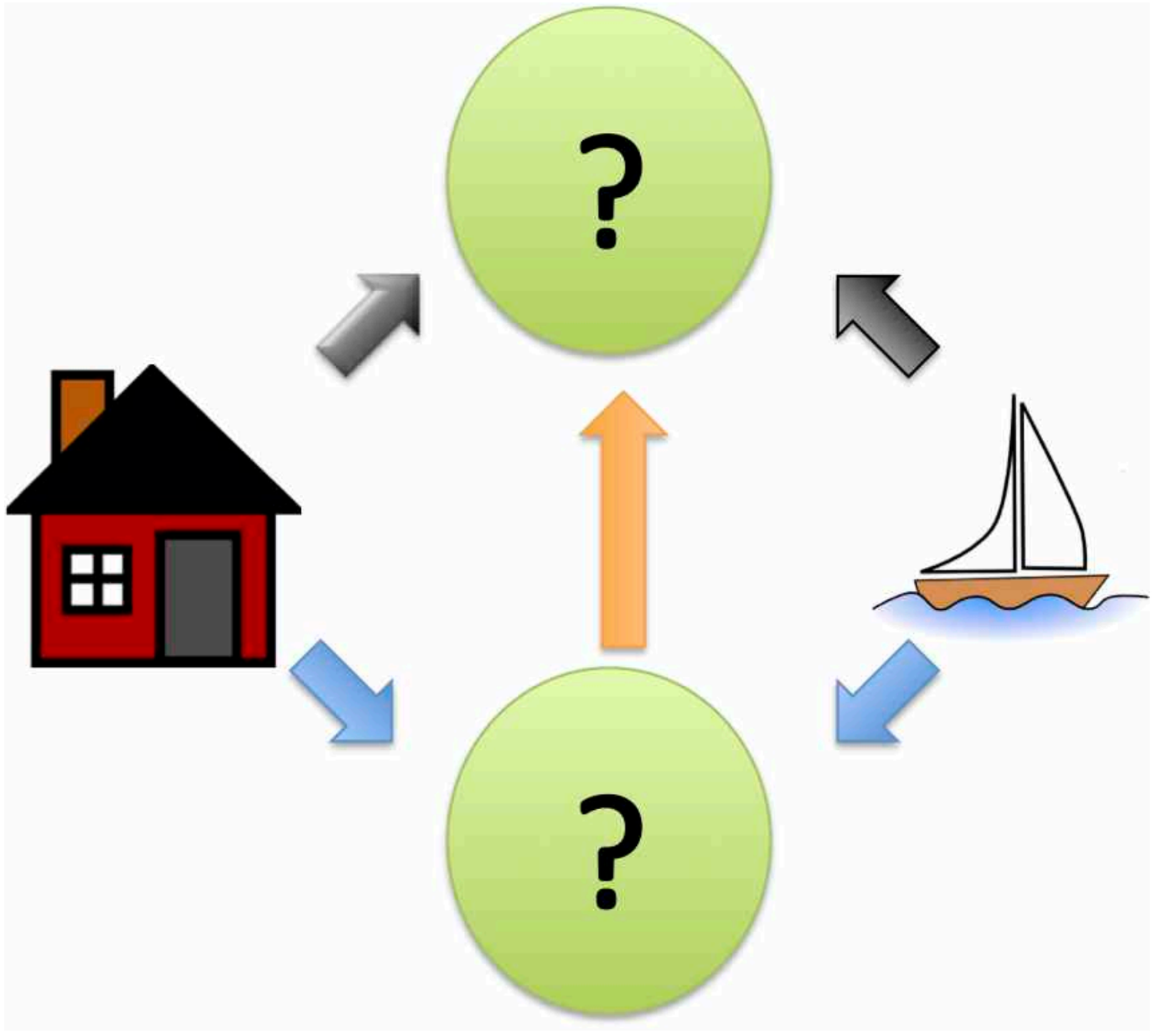
- developed in the early 1990s by Gilles Fauconnier and Mark Turner
- intended to understand and model the process of concept invention
- much studied within cognitive psychology and linguistics
- Conceptual Blending concerns blending of two thematically rather different conceptual spaces yielding a new conceptual space with
  - emergent structure, selectively combining parts of the given spaces
  - whilst respecting common structural properties.

Summarised by Fauconnier & Turner (2003):

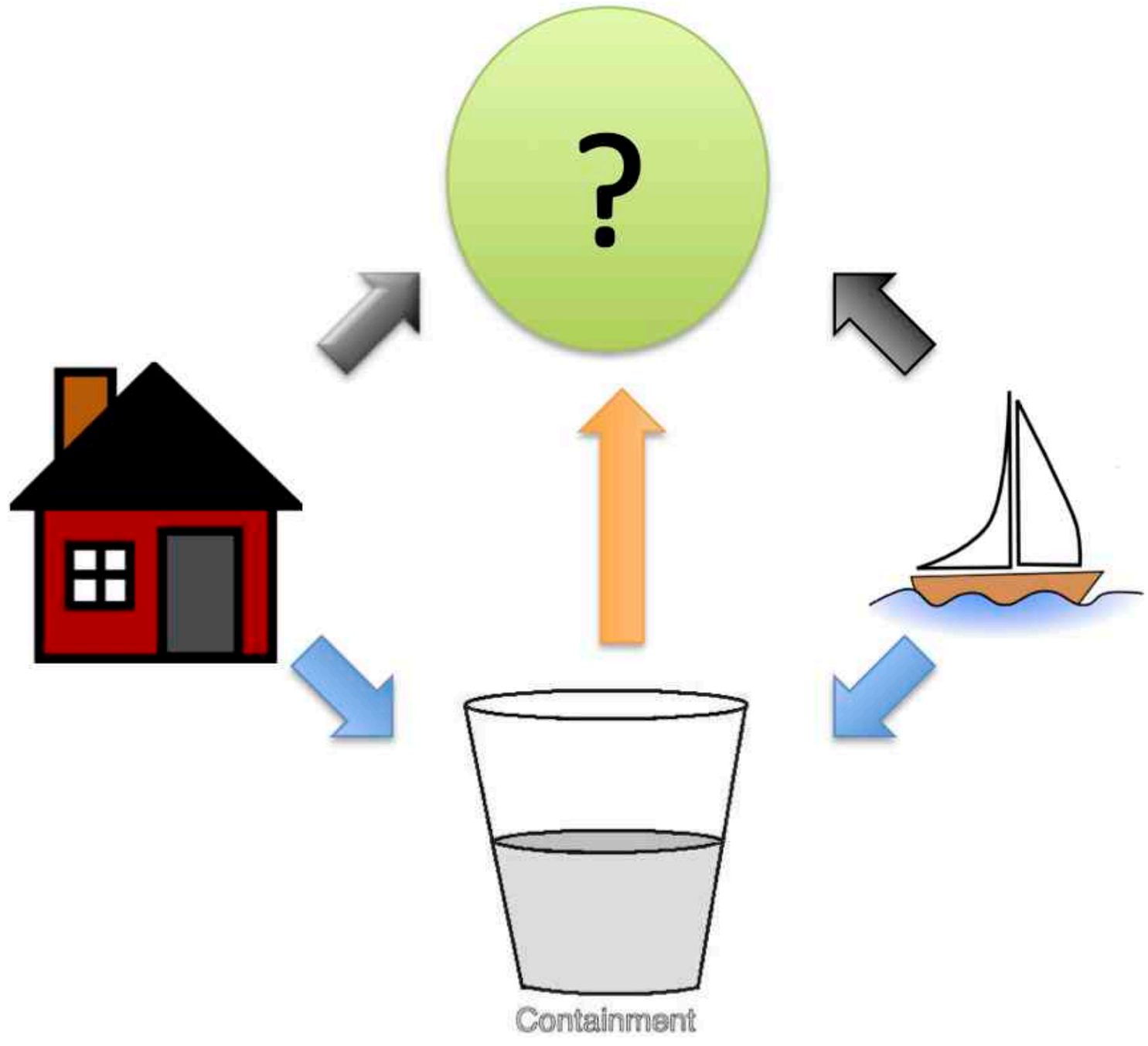
- inputs have different organising frames
- blend has an organising frame that receives projections
- blend has emergent structure on its own
- inputs offer the possibility of rich clashes
- offer challenges to the imagination
- resulting blends can turn out to be highly imaginative



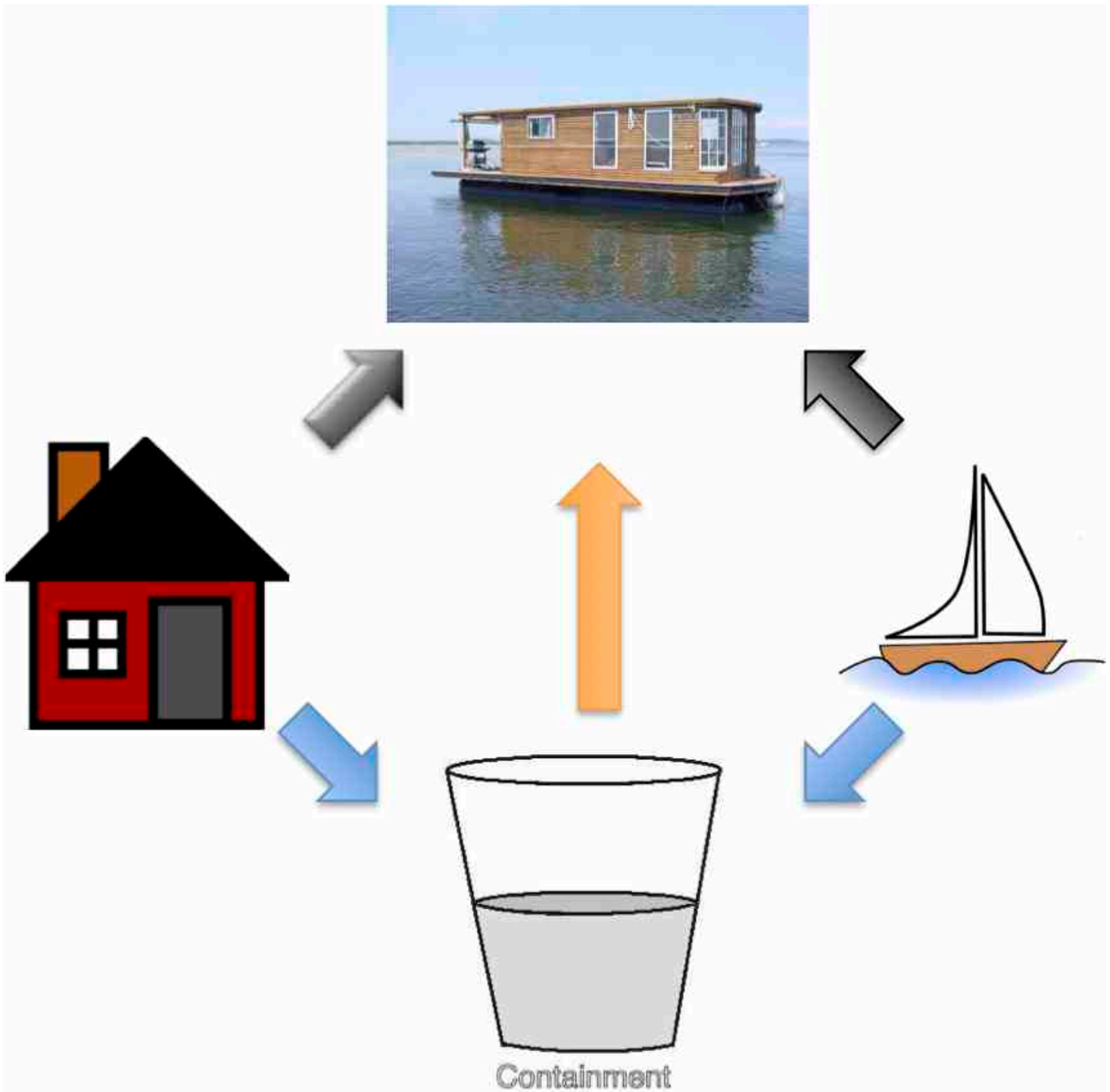
Conceptual Blending: Example



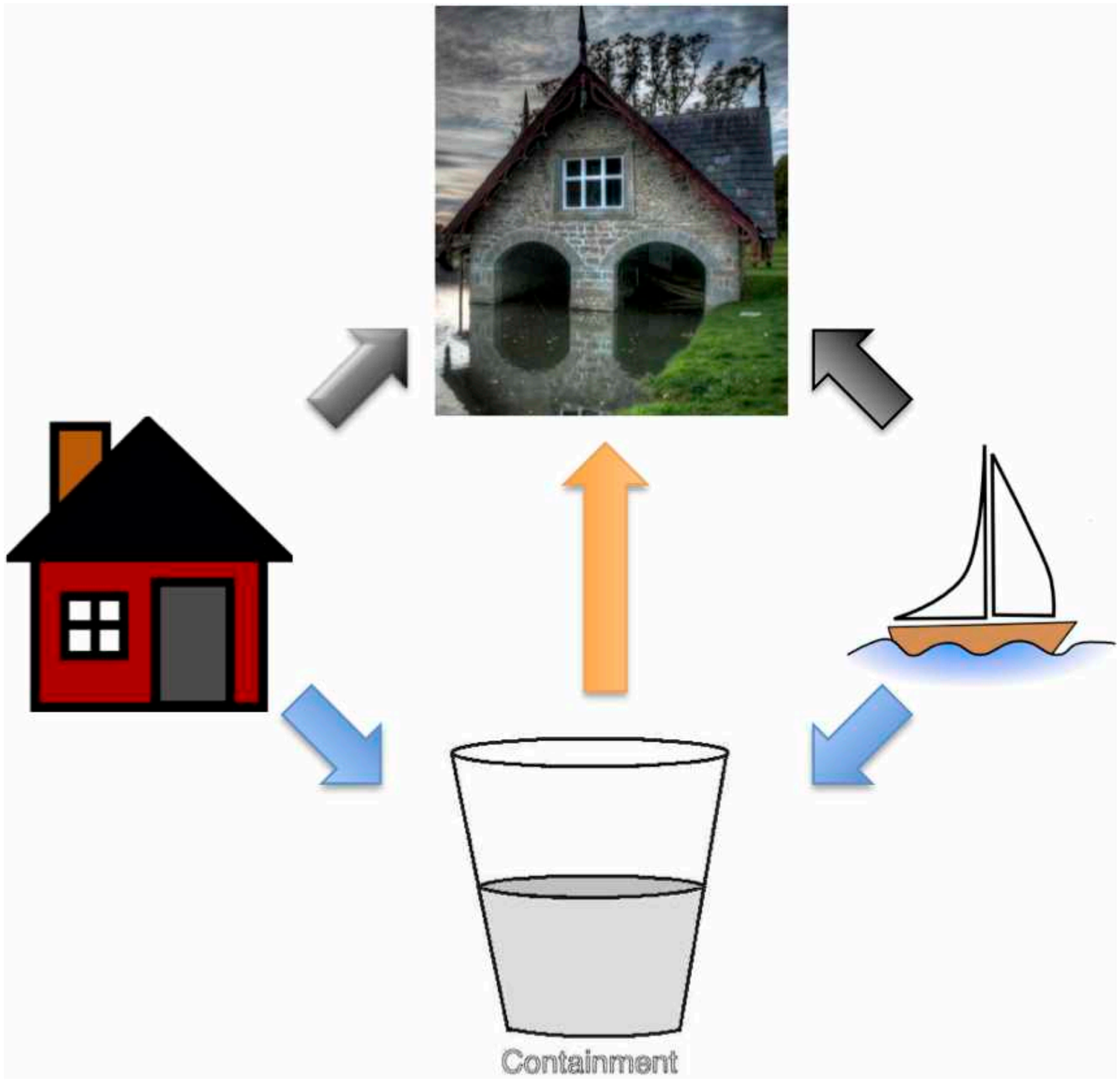
Conceptual Blending: Example



Conceptual Blending: Example



Conceptual Blending: Example



Blending Signs and Forests: Input 1

- **Signs:**

  a piece of paper, wood or metal that has writing or a picture on it that gives you information, instructions, a warning

  (Oxford Advanced Learner's Dictionary)

Blending Signs and Forests: Input 2

- **Forests**

  complex eco-logical systems in which trees are the dominant life form

  (Encyclopaedia Britannica)

Blending Signs and Forests: Blend 1

Signs in Forests

Blending Signs and Forests: Blend 2

Forestsigns

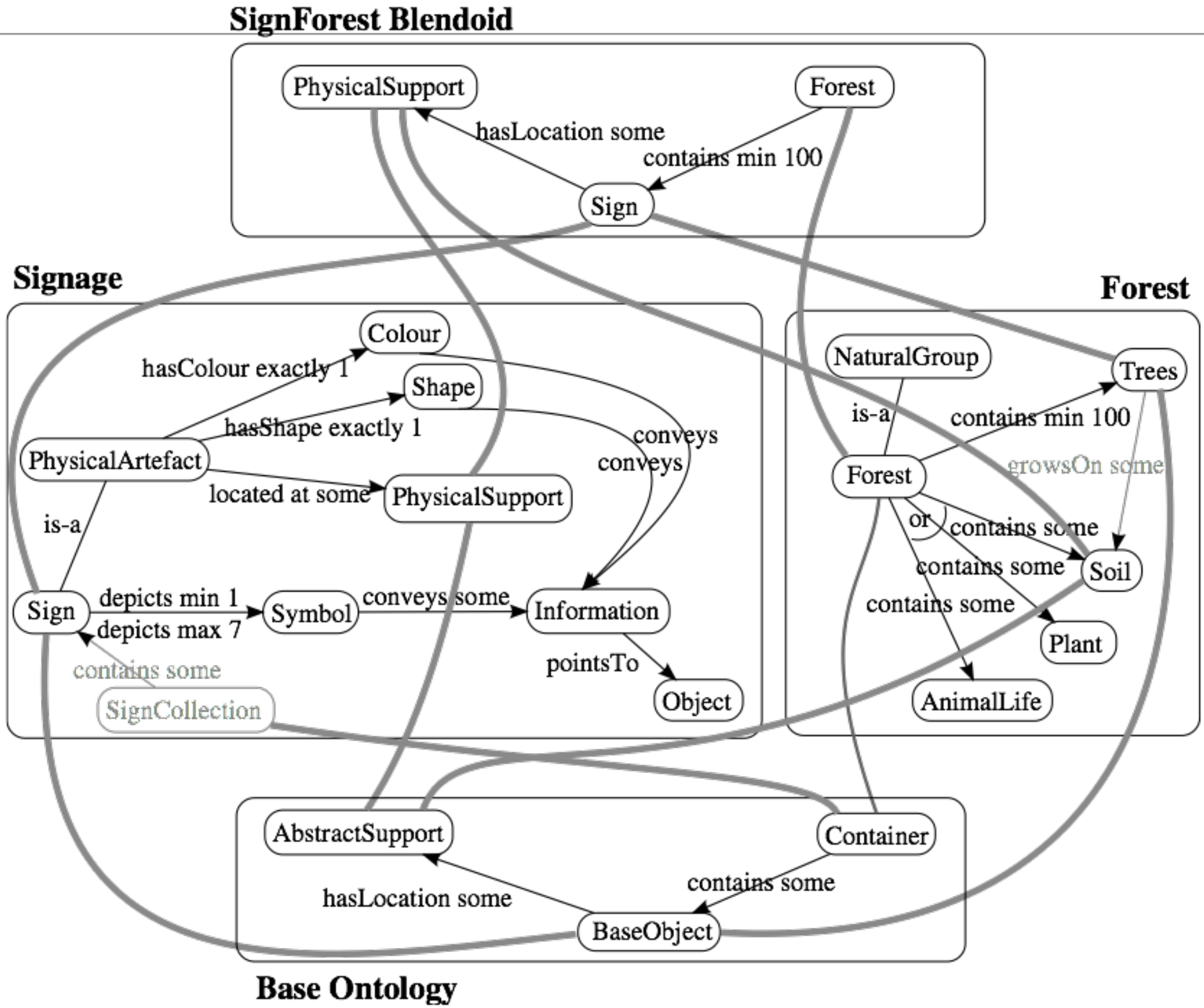
Blending Signs and Forests: Blend 3

Signforests

Optimality Principles:
What makes a good blend?

- **Integration:** The blend must constitute a tightly integrated scene that can be manipulated as a unit.
- **Pattern Completion:** complete elements in the blend . . .
- **Maximization of Vital Relations:** change, identity, time, space, cause-effect, part-whole, . . .
- **Unpacking:** The blend alone must enable the perceiver to unpack the blend to reconstruct the inputs, the cross-space mapping, the generic space, and the network of connections between all these spaces
- **Relevance:** ... **Web:** ...

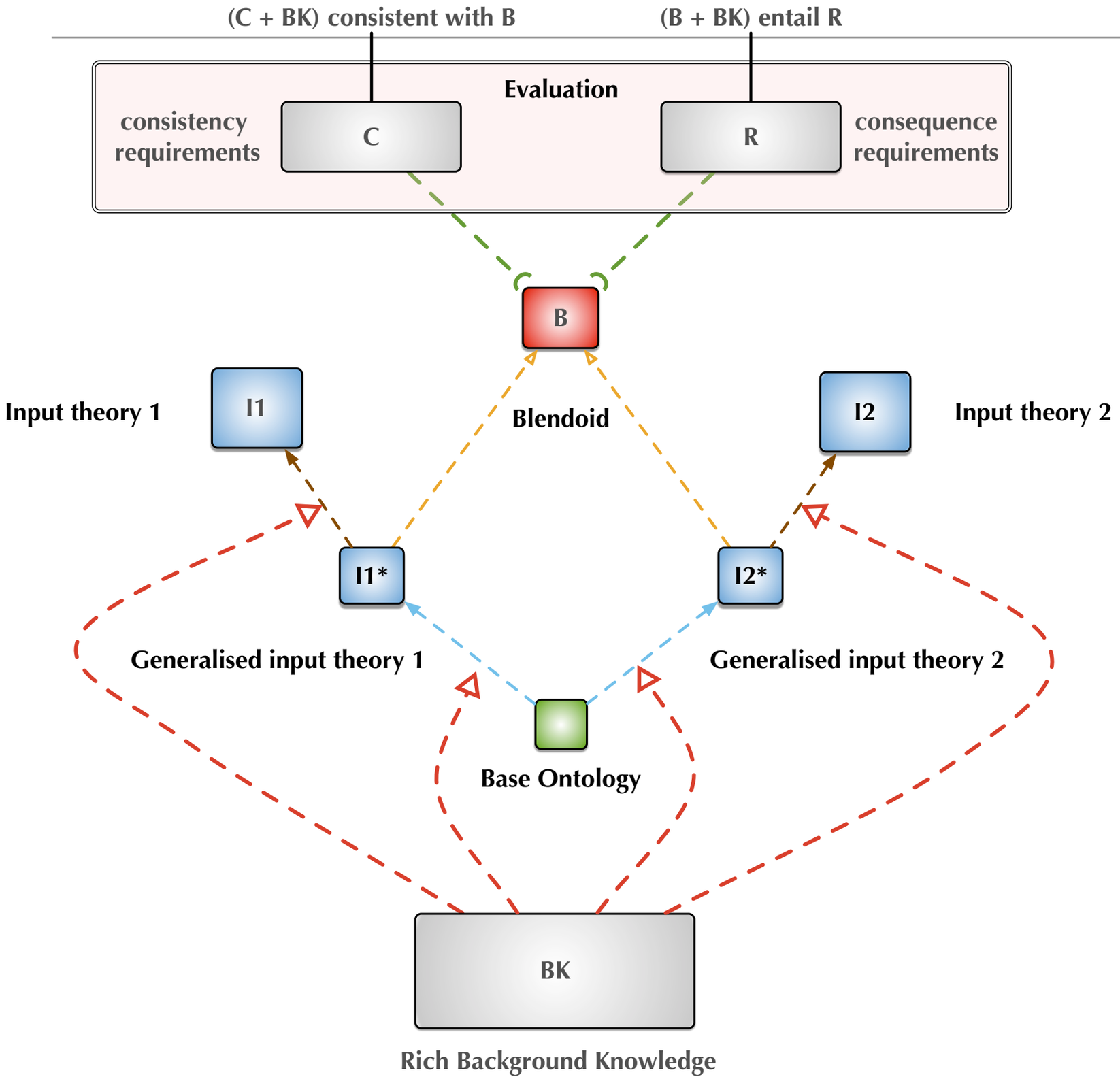
Graphical representation of a formal DOL specification



Part 2:

Abstract Framework and Representation Language

Blending: Formal Model

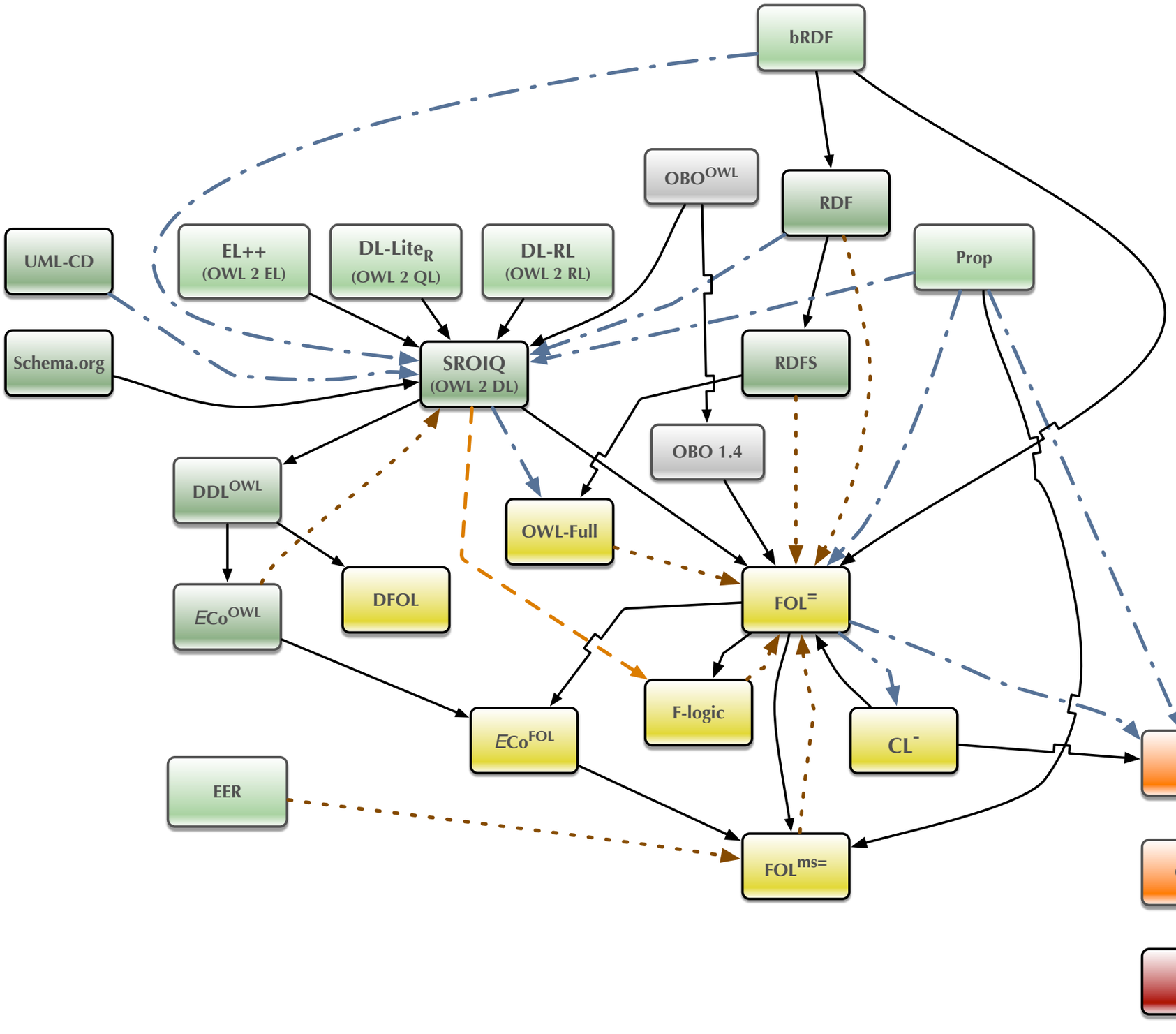


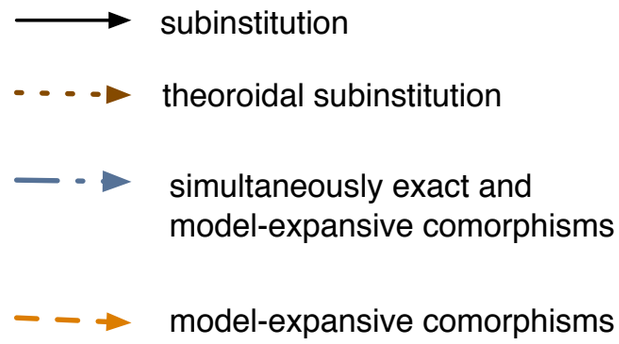
- Creating blends in Ontohub/DOL
- usage of background ontologies
- image schemas as base ontologies
- evaluation features
  - constraints
  - requirements

Blending with DOL, Hets, Ontohub

- Formal (meta)-language: **DOL**
  - describe structured ontologies/models/specifications
  - support specification of blending diagrams
  - specify requirements for evaluation
- Heterogenous reasoning: **Hets**
  - proof support for structured ontologies/theories
  - computation of colimits
- Repository for heterogeneous theories: **Ontohub**
  - support a variety of logical languages for ontology, mathematics, music
  - support for ontology evaluation techniques

Logic Graph supported by DOL





grey: no fixed expressivity

green: decidable ontology languages

yellow: semi-decidable

orange: some second-order constructs

red: full second-order logic

DEMO of ontohub/conceptportal

Ontohub | Repositories | Ontologies | Categories | Logics | Mappings | Help

Conceptportal

Overview | Ontologies | File browser | Url catalog | History | Errors

House+boat DOL

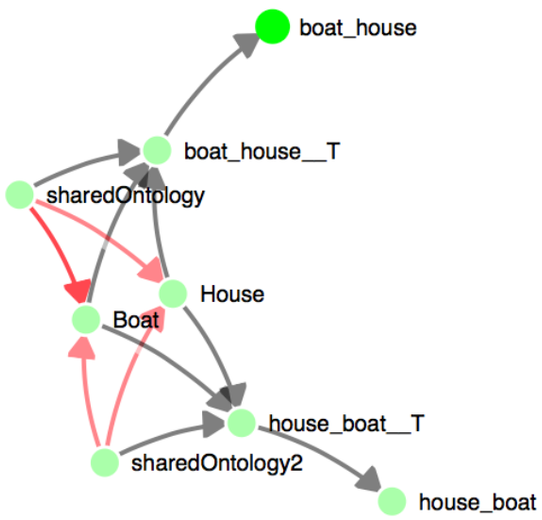
Ontology defined in the file /conceptportal/Blending_Experiments/house+boat.dol

http://ontohub.org/conceptportal/Blending_Experiments/house+boat

Content | Comments | Metadata | Versions | Graphs | Mappings

Graphical Visualization of Ontology-Links

House+boat



Ontology: boat_house

IRI: http://ontohub.org/conceptportal/Blending_Experiments/house+boat?boat_house

Description:

Symbols:

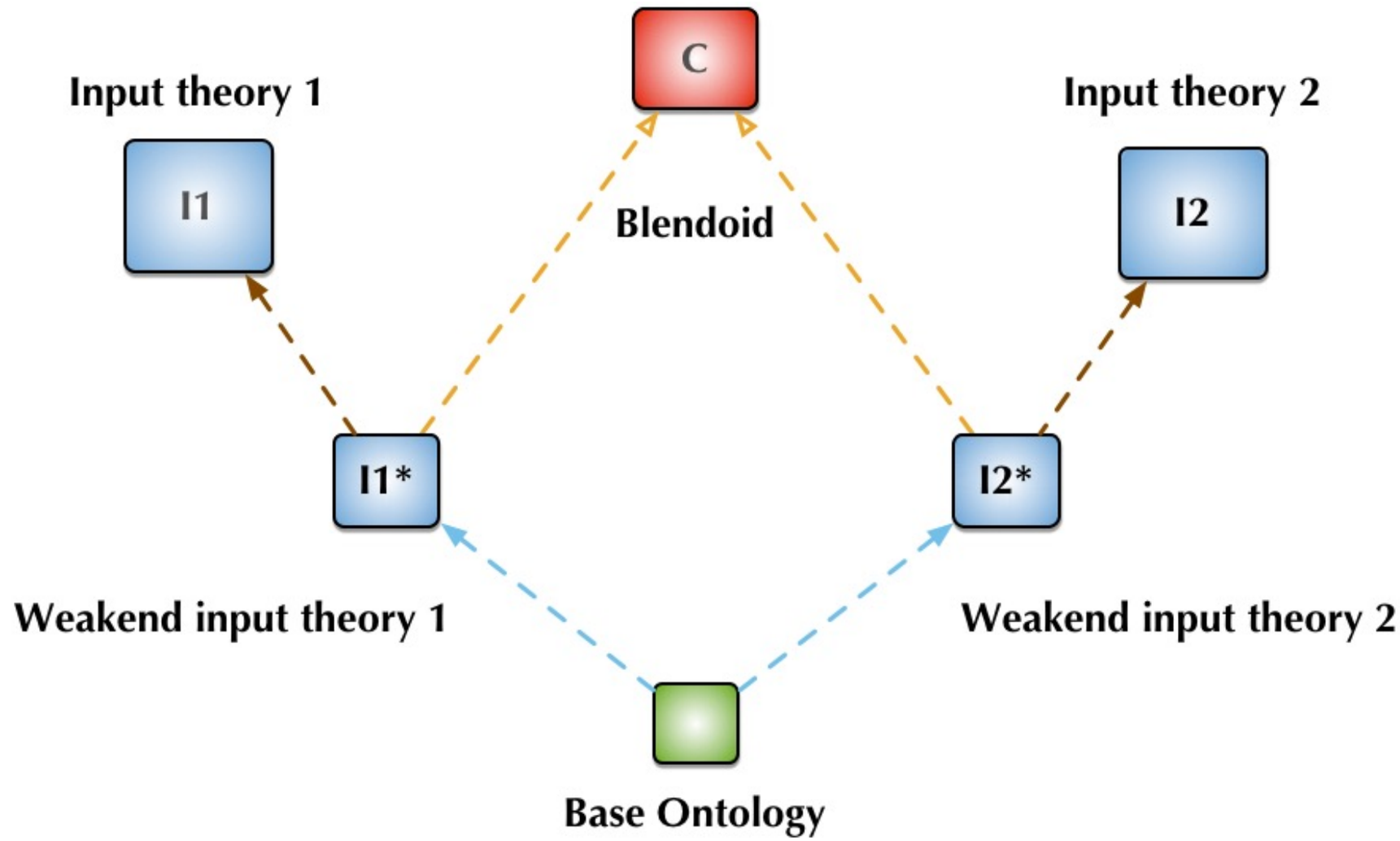
Class: 12

ObjectProperty: 6

Part 3:
Cognitive Modelling and Computational Approaches

Goal: Computationally Generate Concepts

COINVENT's Model for CCB



Challenges:

- How to represent the blending process?
- What do we keep from the input spaces?
- How to find the right base space + morphisms?

Hypothesis

How to find the right base ontology for blending?

Hypothesis

- **Image schemas** may form a conceptual skeleton of bases spaces

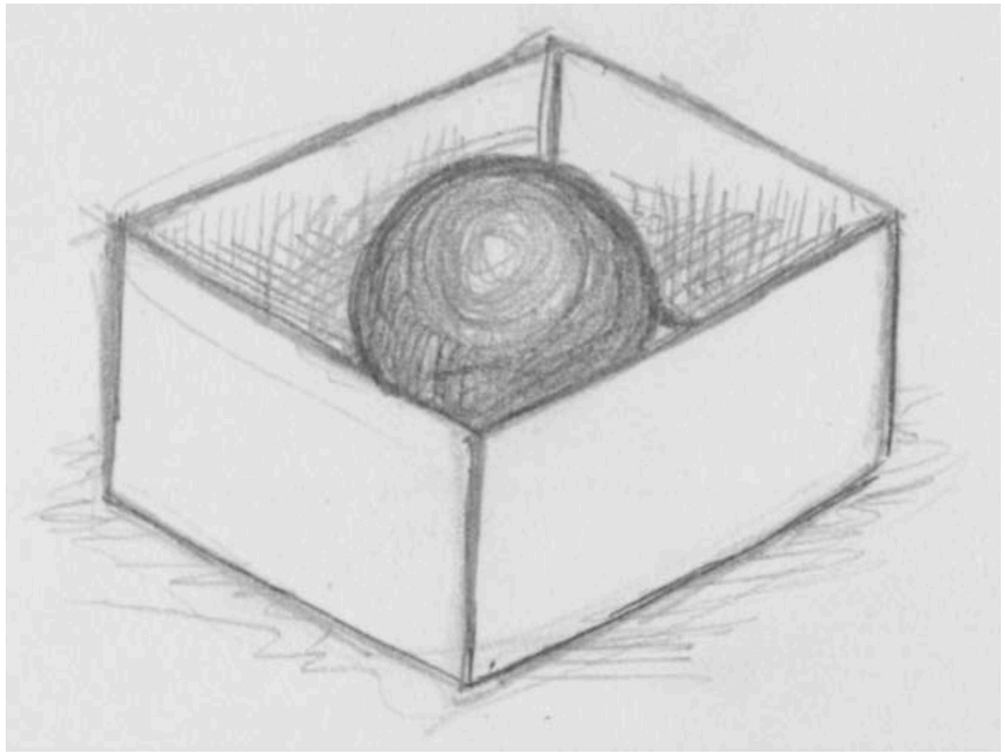
Image schemas?

- **Mark Johnson (1987)** describes them as
  - ". . .a recurring, dynamic pattern of our perceptual interactions and motor programs that gives coherence and structure to our experience"

- **Todd Oakley (2007)** defines an image schema as
  - "...a condensed re-description of perceptual experience for the purpose of mapping spatial structure onto conceptual structure"

Image schemas: Lakoff & Johnson 1987

- **Spatial motion group**
  - Containment
  - Path
  - Source-Path-Goal
  - Blockage
- **Force Group**
  - Counterforce
  - Link
- **Balance Group**
  - Axis Balance
  - Point Balance …



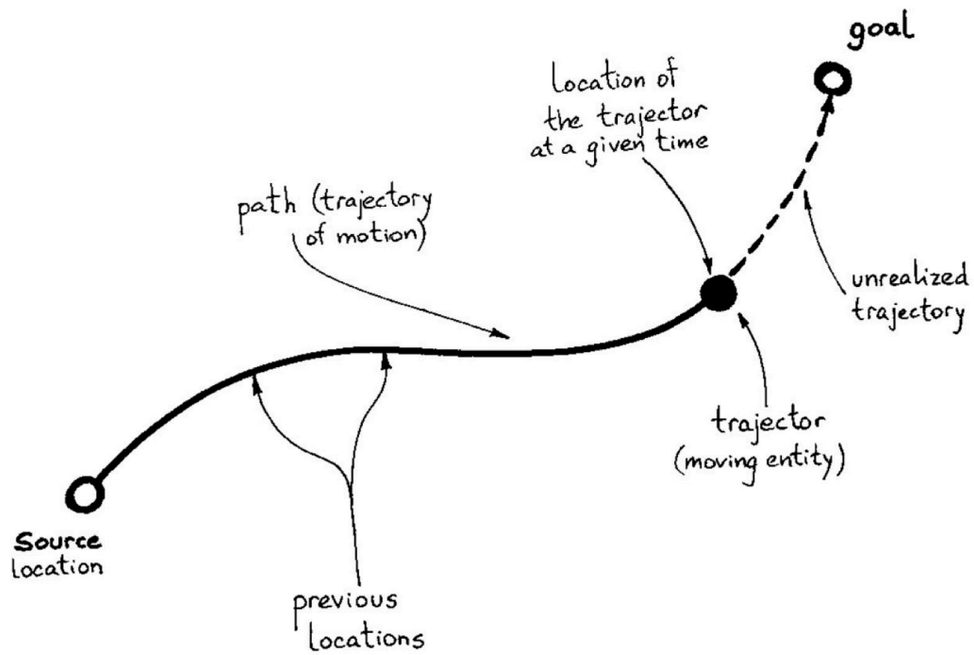


Image Schema Days

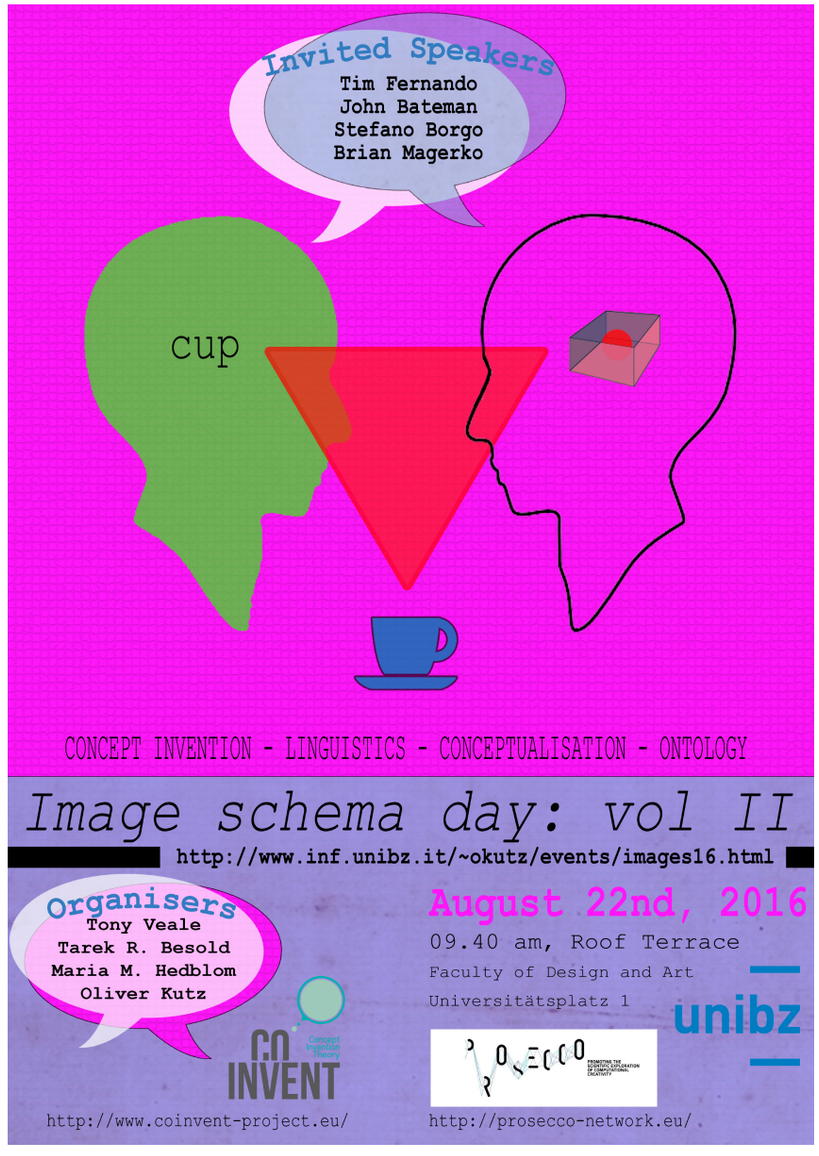


Image schemas, blending, ontologies, and symbol grounding

- **Motivation:** image schemas ground the search for meaningful concepts in human cognition and embodiment
- Image schemas provide candidates (the conceptual **skeleton**) for (parts of) the **generic space** in blending
- Image schema formalisations provide an approach to **generalisation** and **abstraction** in blending

- **Core problem:**
  - What are appropriate formal/logical approaches to representing and reasoning with image schemas?

What have these things in common?

- Space ship
- North Korea
- The universe
- Marriage
- Bank account

Simile

- This space ship
- North Korea
- The universe
- Their marriage
- My bank account

is like a

- prison
- leaky pot
- treasure chest
- bottomless pit
- balloon

Simile ('Objects')

- This space ship
- North Korea
- The universe
- Their marriage
- My bank account

is like a

- prison
- leaky pot
- treasure chest
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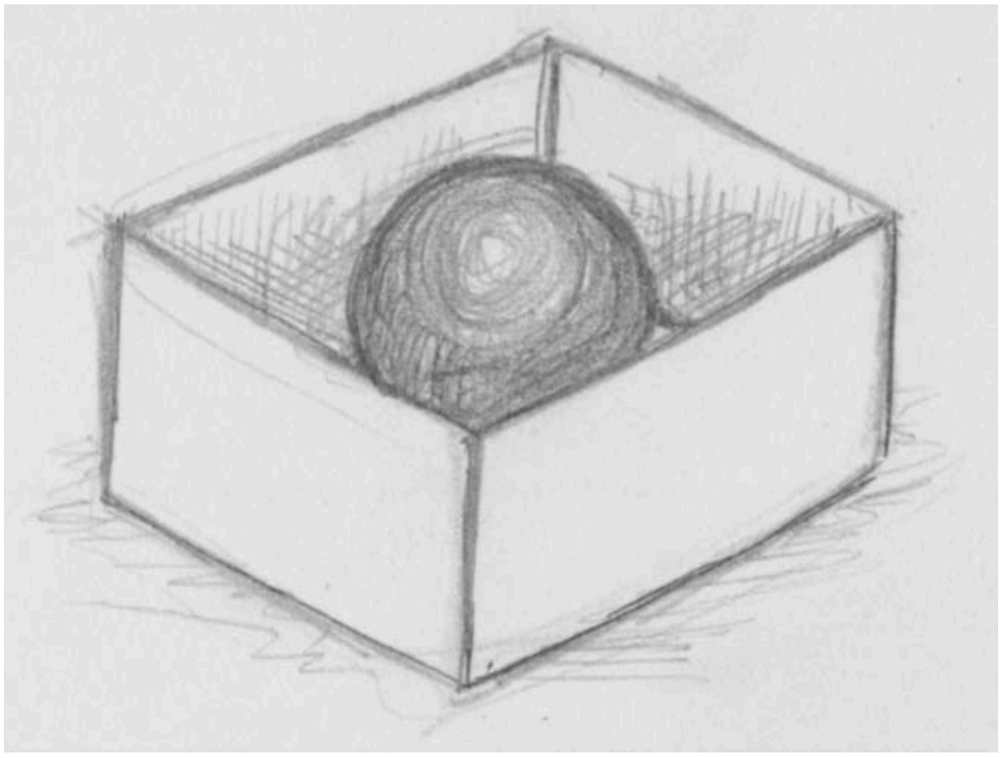
- balloon

If the concepts on the left are so dissimilar, why can they be meaningfully compared to the same things?

Simile ('Objects')



Container

is like a

- prison
- leaky pot
- treasure chest
- bottomless pit
- balloon

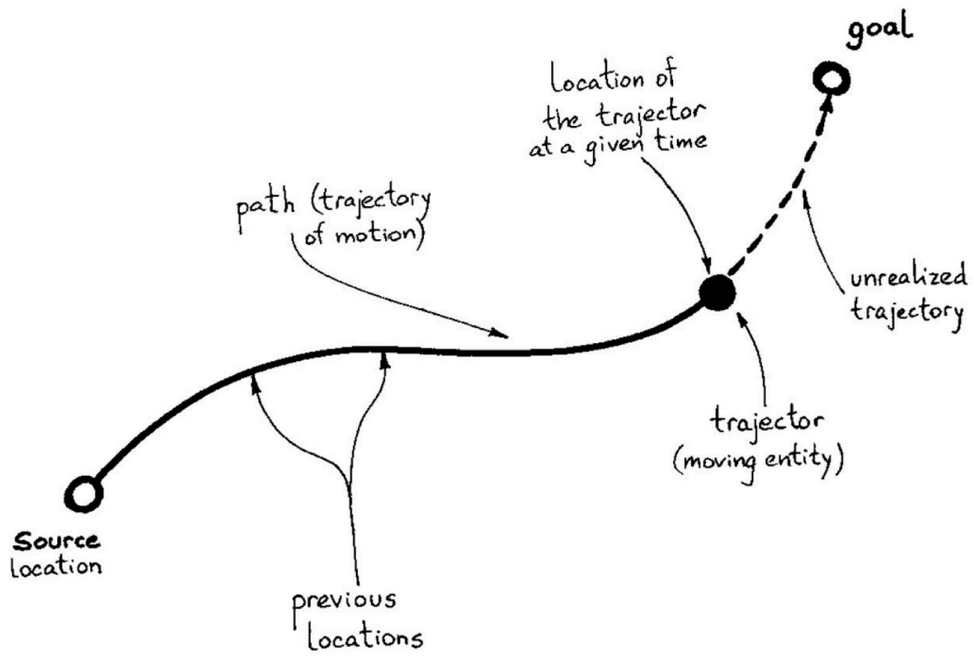
Simile ('Events')

- The story
- Watching the football game
- Their marriage
- Bob’s career
- Democracy in Italy

is like

- a roller coaster ride
- a Prussian military parade
- a marathon
- escaping a maze
- stroll in the park

Simile ('Events')



Source-Path-Goal

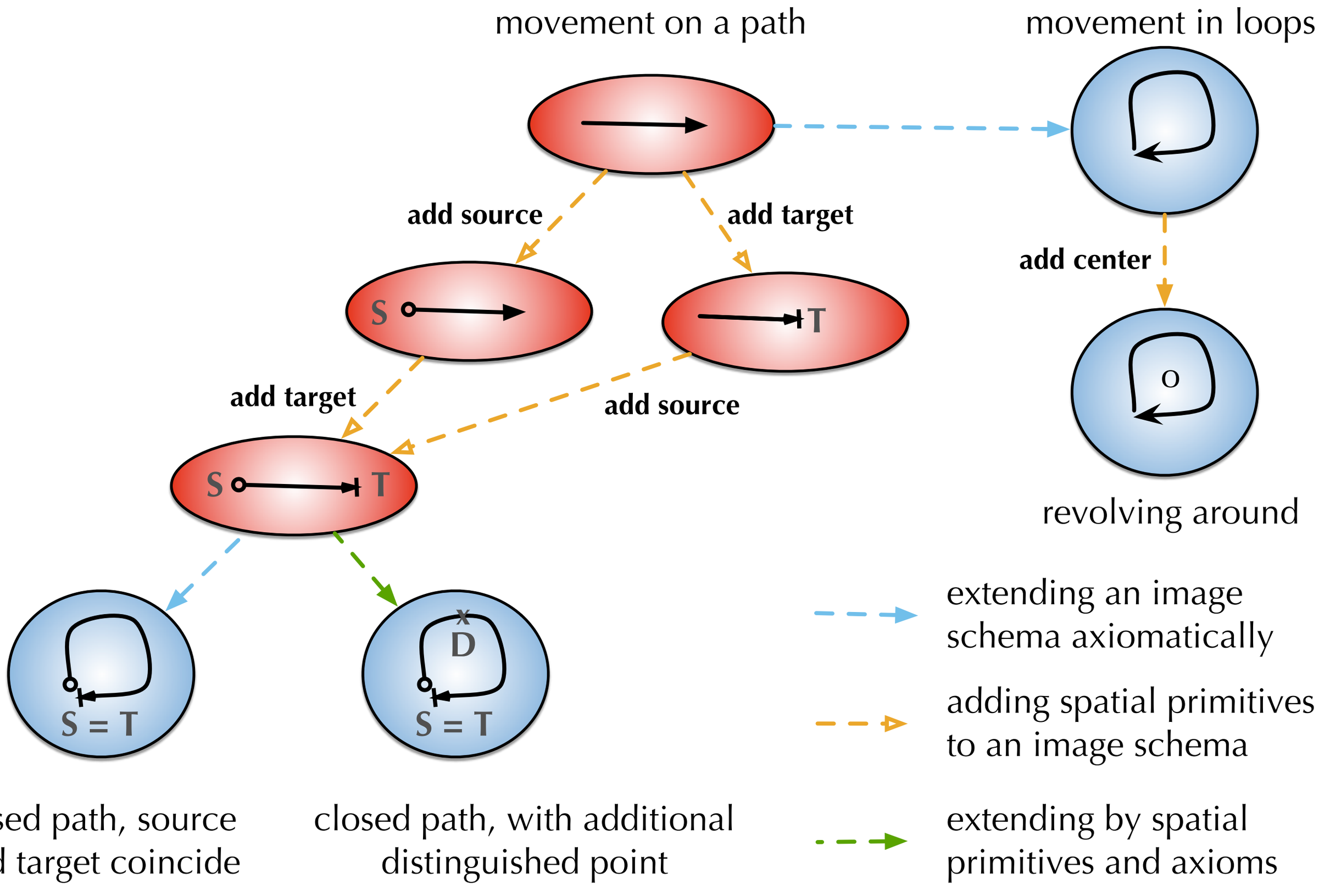
is like

- a roller coaster ride
- a Prussian military parade
- a marathon
- escaping a maze
- stroll in the park

What are Image Schemas (Logically)?

- What is the ontology of image schemas
- What are the primitive notions
  - spatial primitives
  - spatial schemas
  - time / simulation
  - physics / forces?
- Understanding time and/or space led to specialised logics of time and space, and of spatio-temporal combined reasoning
- Is the logic of image schemas a particular kind of spatio-temporal logic?
- Or do we require a new kind of logic?

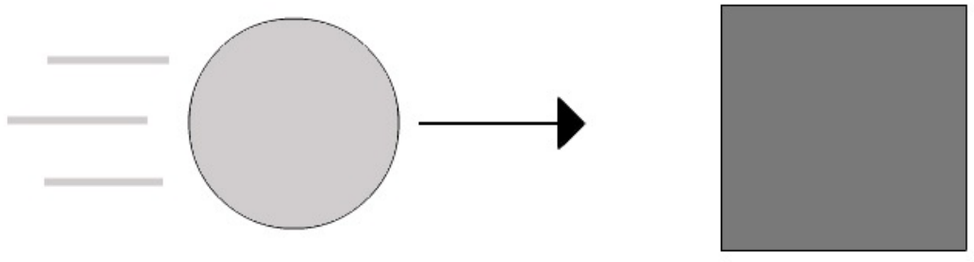
The image schema family of path, loop, and revolving



Event structure / patterns:
Image schema of caused movement

Time 1

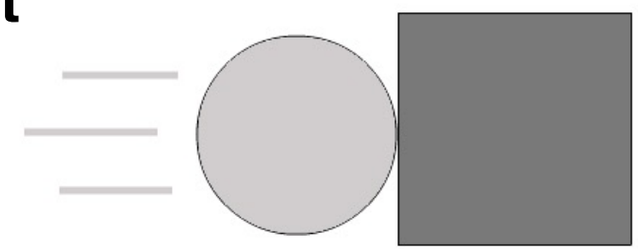
Path



Path schema

Time 2

Contact



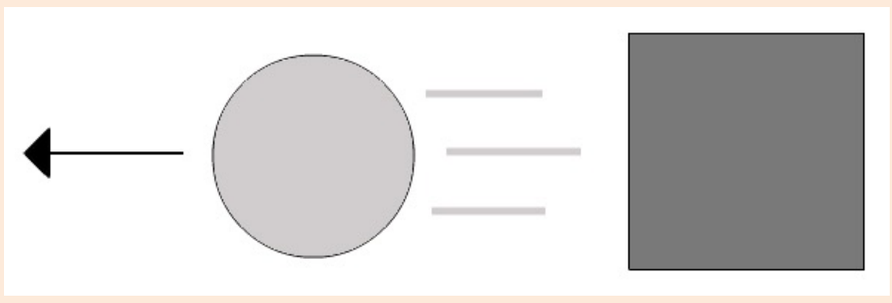
Contact schema

Time 3A

Caused_movement

Time 3B

Bouncing



Open problems for us

- Analyse the ontology of image schemas further
- Identify different levels of logical expressivity, cognitively adequate for various phenomena
- Develop the computational side of using image schema families for generalisation / base space discovery in blending
- Develop the logical and computational side of combination and multi-modality for image schemas
- Many spatio-temporal logics have been devised. Do image schemas necessitate a novel combination, i.e.:

  Do we need a new Logic of Image Schemas?

Image Schema Logic ISL

- The image schema logic ISL combines
  - The Region Connection Calculus RCC8
  - Cardinal directions
  - A simple modelling of 'force'
  - Qualitative trajectory calculus QTC
  - Linear temporal logic

THE TWO-OBJECT FAMILY: an excerpt from the extended image schema family of relationships between two objects

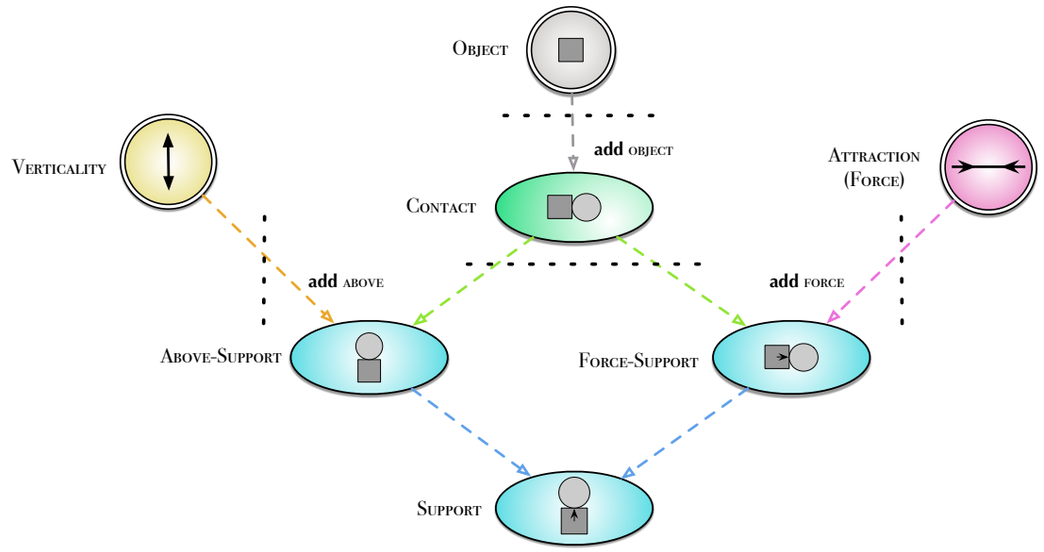
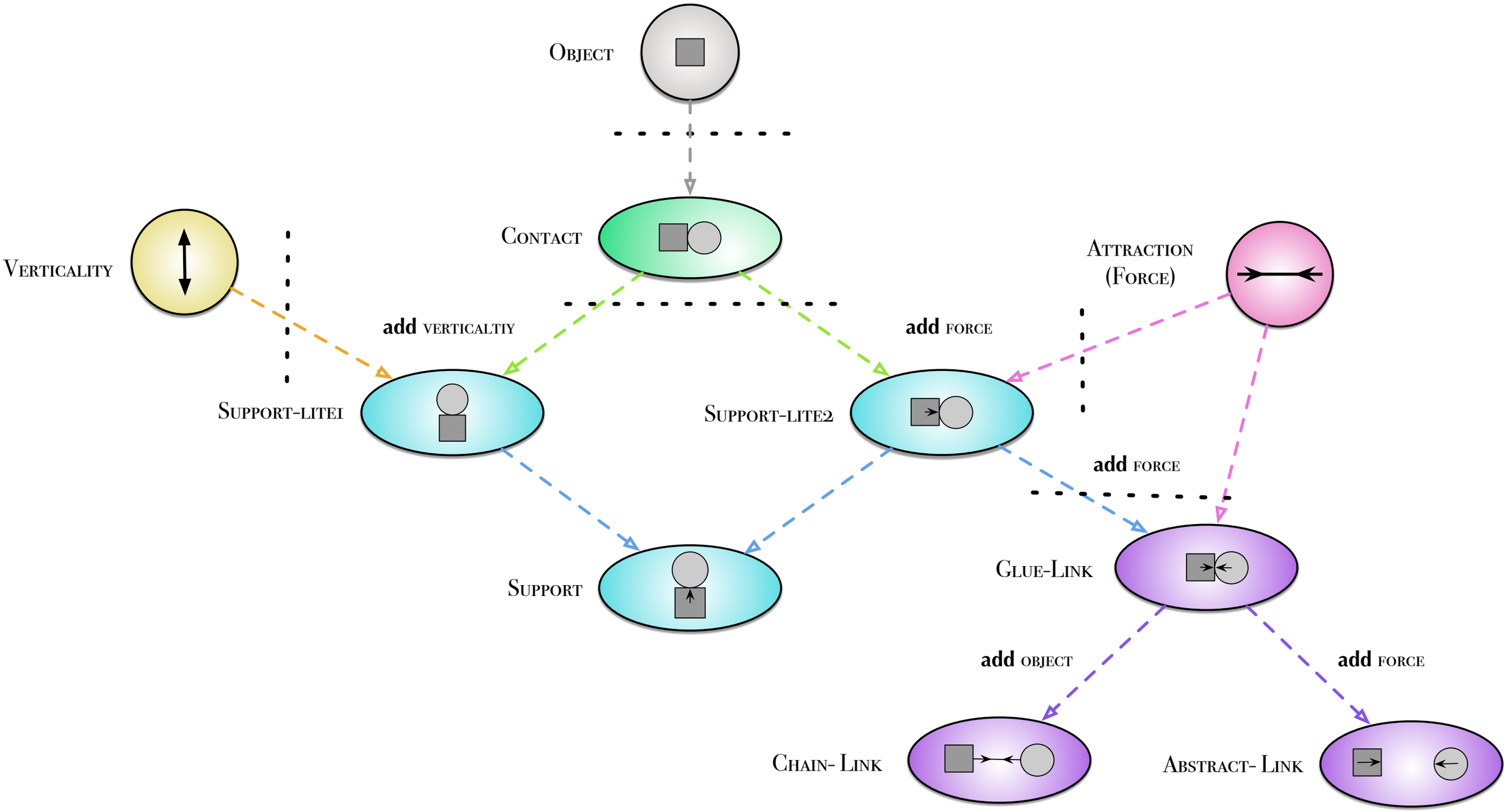


Image Schema Logic ISL

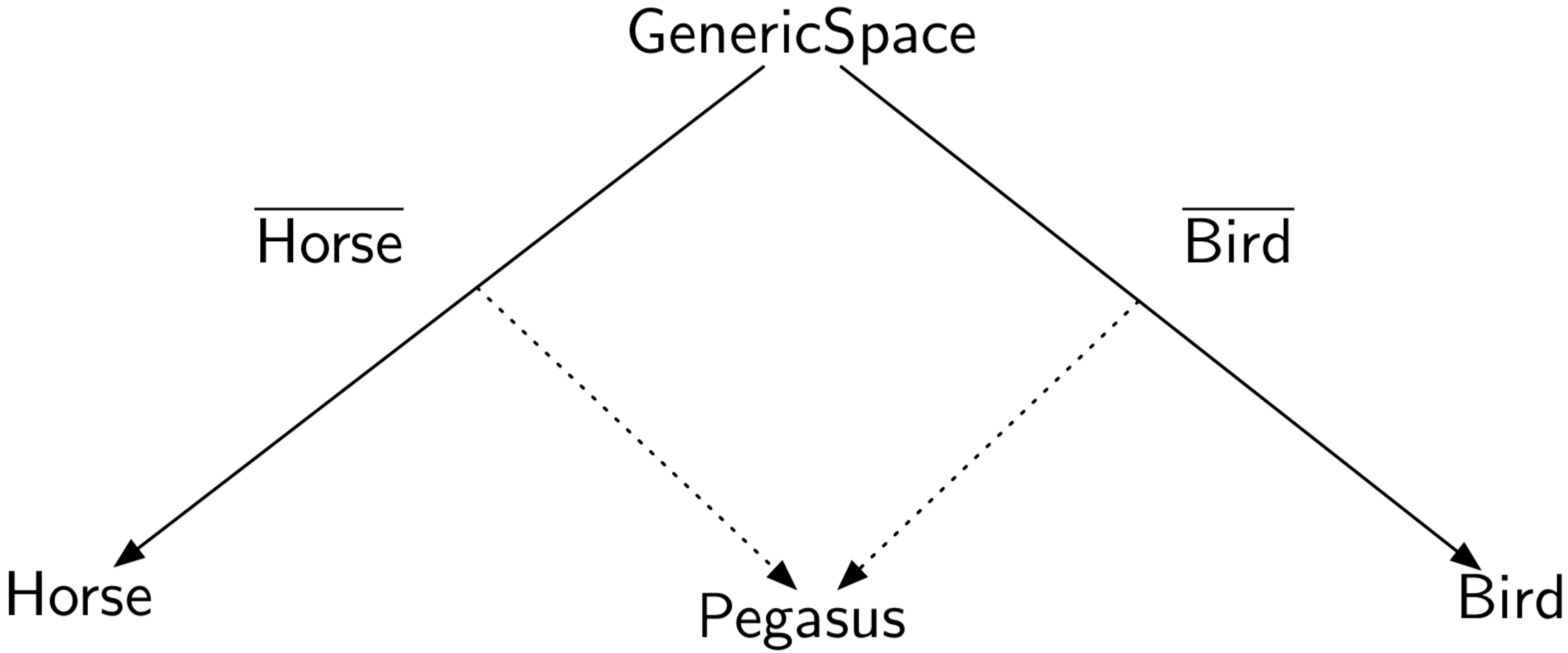
CONTACT: the image schema family of relationships between several objects



Computing Generic Spaces

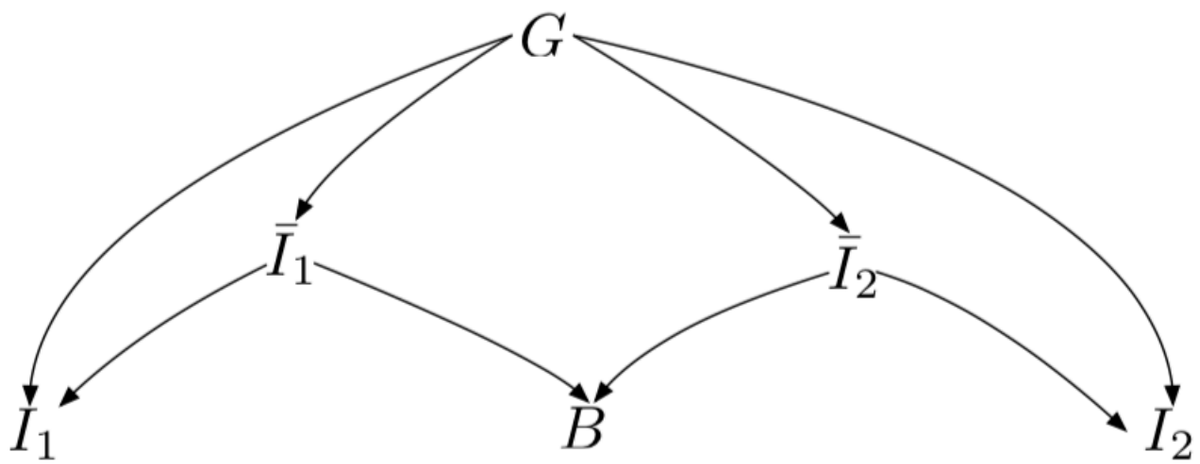
- Two basic approaches:
  - **Identification approach**: use the idea of formalised image schema families to identify them in an input space via theory interpretation
  - **Generalisation approach:** generalise the input spaces to a common core via generalisation operators, and prioritise image-schematic structure.

Creating $\mathcal{EL}^{++}$ Concepts via Conceptual Blending



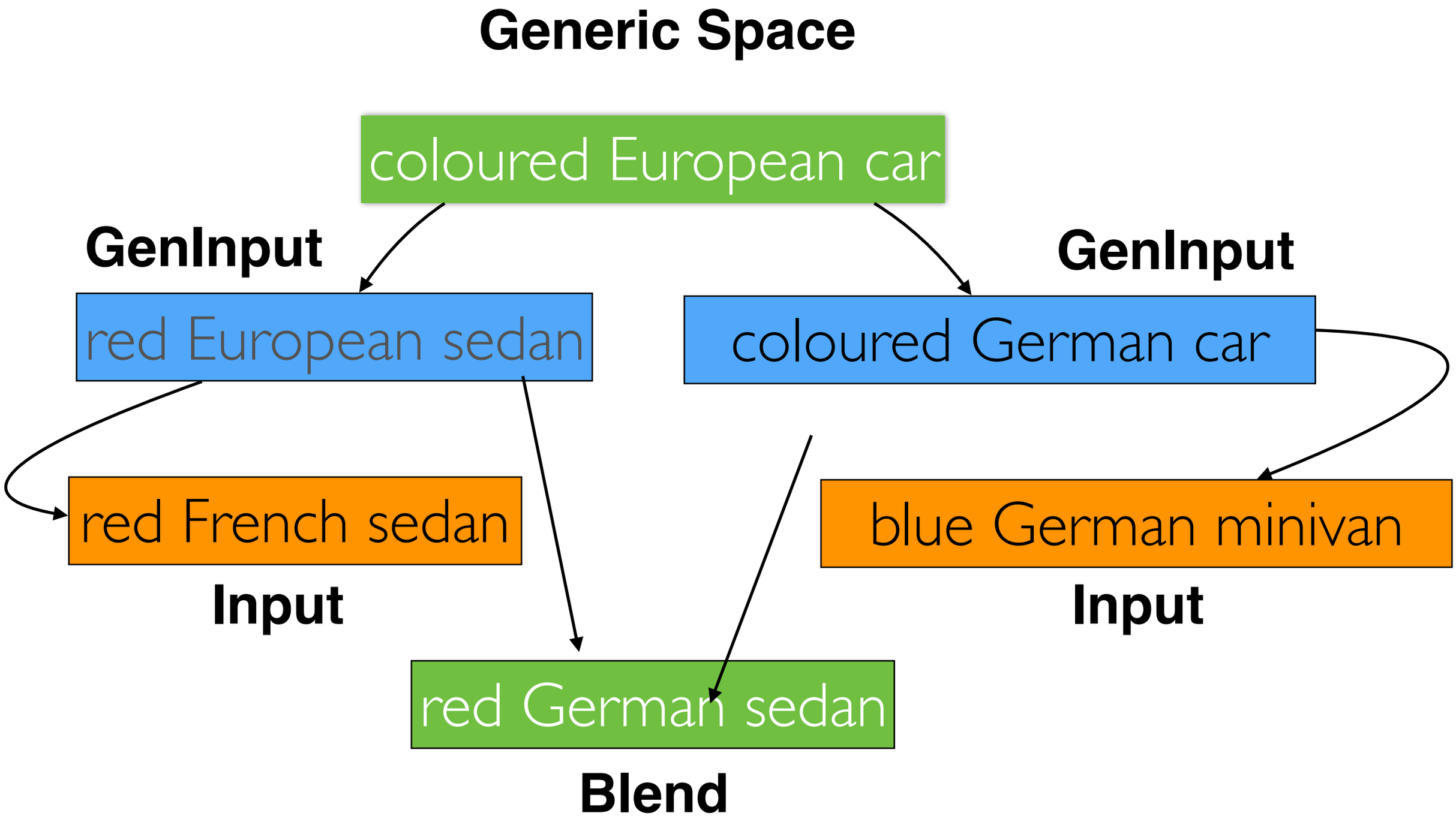
Computational Model of Conceptual Blending - Amalgamation

- Amalgamation originates from the notion of *amalgam* Ontañón and Plaza [2010] in case-based reasoning
- It applies to any language $\mathcal{L}$ such that $\langle \mathcal{L}, \sqsubseteq \rangle$ is a poset



- An *amalgam* of two input concepts is a new concept that combines parts from the original descriptions
  - Find *Generic Space* (G) of input concepts (commonalities) and try to combine non-common elements in I_1 and I_2
  - Often, input concepts I_1 and I_2 cannot be combined directly (inconsistency or insatisfaction of some properties)
  - Input concepts have to be first *generalised* into I_1' and I_2'
  - I_1' and I_2' can be finally blended to obtain a 'good' B

AMALGAMS as Blends



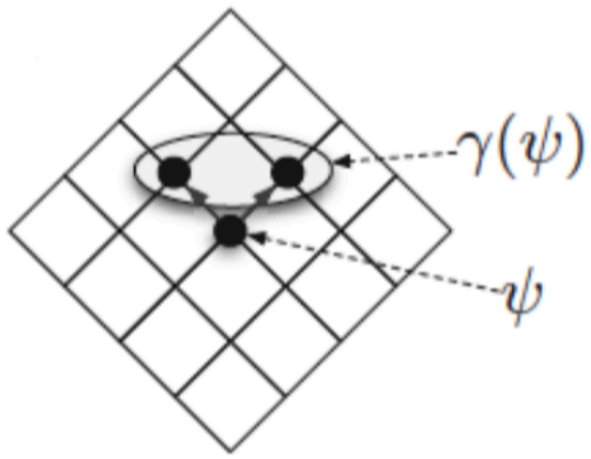
Generalising $\mathcal{EL}^{++}$ Concepts — Why?

$$\begin{aligned}
\text{Horse} \equiv \quad & \text{Mammal} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs} \sqcap \\
& \exists \text{hasAbility.Walk} \sqcap \exists \text{hasAbility.Trot} \\
\text{Bird} \equiv \quad & \text{Avialae} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs} \sqcap \\
& \exists \text{hasBodyPart.Wings} \sqcap \exists \text{hasAbility.LayEggs} \sqcap \exists \text{hasAbility.Fly}
\end{aligned}$$

- The 'direct' combination of Horse and Bird violates the common sense (or background knowledge) that:
  - Mammals do not generally lay eggs ($\text{Mammals} \sqcap \exists \text{hasAbility.LayEggs} \sqsubseteq \bot$)
  - Avialae do not trot ($\text{Avialae} \sqcap \exists \text{hasAbility.Trot} \sqsubseteq \bot$)

Generalisation operators

- The generalisation in the amalgamation algorithm is based on a search in the poset $\langle \mathcal{L}(\mathcal{T}), \sqsubseteq_{\mathcal{T}} \rangle$
- The generalisation of an $\mathcal{EL}^{++}$ concept can be done through a *generalisation refinement operator* γ



Refinement operator properties

- Local finiteness
- Properness
- Completeness

Generalising an $\mathcal{EL}^{++}$ concept

- The upward refinement operator generalises an $\mathcal{EL}^{++}$ concept by:
  - generalising a concept
  - generalising the concept filling the range of a role
  - generalising a role
  - 'removing' a role/concept

Properties

- Trade-off between completeness and finiteness
  - The operator is finite, proper but not complete
  - It is possible that the generic space is not a *least general generalisation* (or least common subsumer)
  - Not a big issue for conceptual blending, the important thing is to find the commonalities between the concepts

Generalising an $\mathcal{EL}^{++}$ concept (cont'd)

Generalisation operator:

$$
\begin{array}{rcl}
\gamma(A) & = & \mathsf{UpCov}(A) \\
\gamma(\top) & = & \mathsf{UpCov}(\top) = \emptyset \\
\gamma(\bot) & = & \mathsf{UpCov}(\bot) \\
\gamma(C \sqcap D) & = & \{C' \sqcap D \mid C' \in \gamma(C)\} \cup \{C \sqcap D' \mid D' \in \gamma(D)\} \cup \{C, D\} \\
\gamma(\exists r.C) & = & \begin{cases} \gamma_r(\exists r.C) \cup \gamma_C(\exists r.C) & \text{whenever } \mathsf{UpCov}(r) \neq \emptyset \text{ or } \gamma(C) \neq \emptyset \\ \{\top\} & \text{otherwise} \end{cases} \\
\gamma_r(\exists r.C) & = & \{\exists s.C \mid s \in \mathsf{UpCov}(r)\} \\
\gamma_C(\exists r.C) & = & \{\exists r.C' \mid C' \in \gamma(C)\}
\end{array}
$$

Where UpCov:

$$
\begin{array}{rl}
\mathsf{UpCov(A)} = & \{C \in \mathsf{sub}(\mathcal{T}) \mid A \sqsubseteq_{\mathcal{T}} C \text{ and } \nexists C' \in \mathsf{sub}(\mathcal{T}) \\
& \quad \text{such that } A \sqsubset_{\mathcal{T}} C' \sqsubset_{\mathcal{T}} C\} \\
\mathsf{UpCov(r)} = & \{r \in N_R \mid r \sqsubseteq_{\mathcal{T}} s \text{ and } \nexists s' \in N_R \\
& \quad \text{such that } r \sqsubset_{\mathcal{T}} s' \sqsubset_{\mathcal{T}} s\}
\end{array}
$$

Generalisations and generic space

Generalising Horse

$$\begin{aligned}
&\mathsf{Mammal} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Torso} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Legs} \sqcap \\
&\quad \exists \mathsf{hasAbility}.\mathsf{Walk} \sqcap \exists \mathsf{hasAbility}.\mathsf{Trot} \\
&\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Torso} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Legs} \sqcap \\
&\quad \exists \mathsf{hasAbility}.\mathsf{Walk} \sqcap \exists \mathsf{hasAbility}.\mathsf{Trot} \\
&\ldots \quad \ldots \\
&\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Torso} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Legs} \sqcap \exists \mathsf{hasAbility}.\mathsf{Walk} \\
&\ldots \quad \ldots \\
&\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Torso} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Legs}
\end{aligned}$$

Generalisations and generic space (cont'd)

Generalising Bird

$$\begin{aligned}
&\text{Avialae} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs} \sqcap \\
&\quad \exists \text{hasBodyPart.Wings} \sqcap \exists \text{hasAbility.LayEggs} \sqcap \exists \text{hasAbility.Fly} \\
&\text{Clade} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs} \sqcap \\
&\quad \exists \text{hasBodyPart.Wings} \sqcap \exists \text{hasAbility.LayEggs} \sqcap \exists \text{hasAbility.Fly} \\
&\ldots \quad \ldots \\
&\text{Clade} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs} \sqcap \\
&\quad \exists \text{hasBodyPart.Wings} \sqcap \exists \text{hasAbility.LayEggs} \\
&\ldots \quad \ldots \\
&\text{Clade} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs} \sqcap \\
&\quad \exists \text{hasBodyPart.Wings} \\
&\ldots \quad \ldots \\
&\text{Clade} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs}
\end{aligned}$$

Implementation of Generalisation in ASP - Overview

- The search for generalisations is modeled as an ASP search problem where the 'goal' is to find a generic space for two input $\mathcal{EL}^{++}$ concepts:
  1. $\mathcal{EL}^{++}$ concepts in background and domain knowledge are translated to ASP facts (base part)
  2. Generalisation operators are implemented as a step-wise process to generalise $\mathcal{EL}^{++}$ concepts in the domain knowledge until they are equal (cumulative part)
  3. Each ASP stable model returns a generalisation path from the input specifications to a generic space

Blends in $\mathcal{EL}^{++}$

- Blends are computed as most general specialisations (MGS) of pairs of generalised concepts
- In $\mathcal{EL}^{++}$, the MGS is defined by $\sqcap$

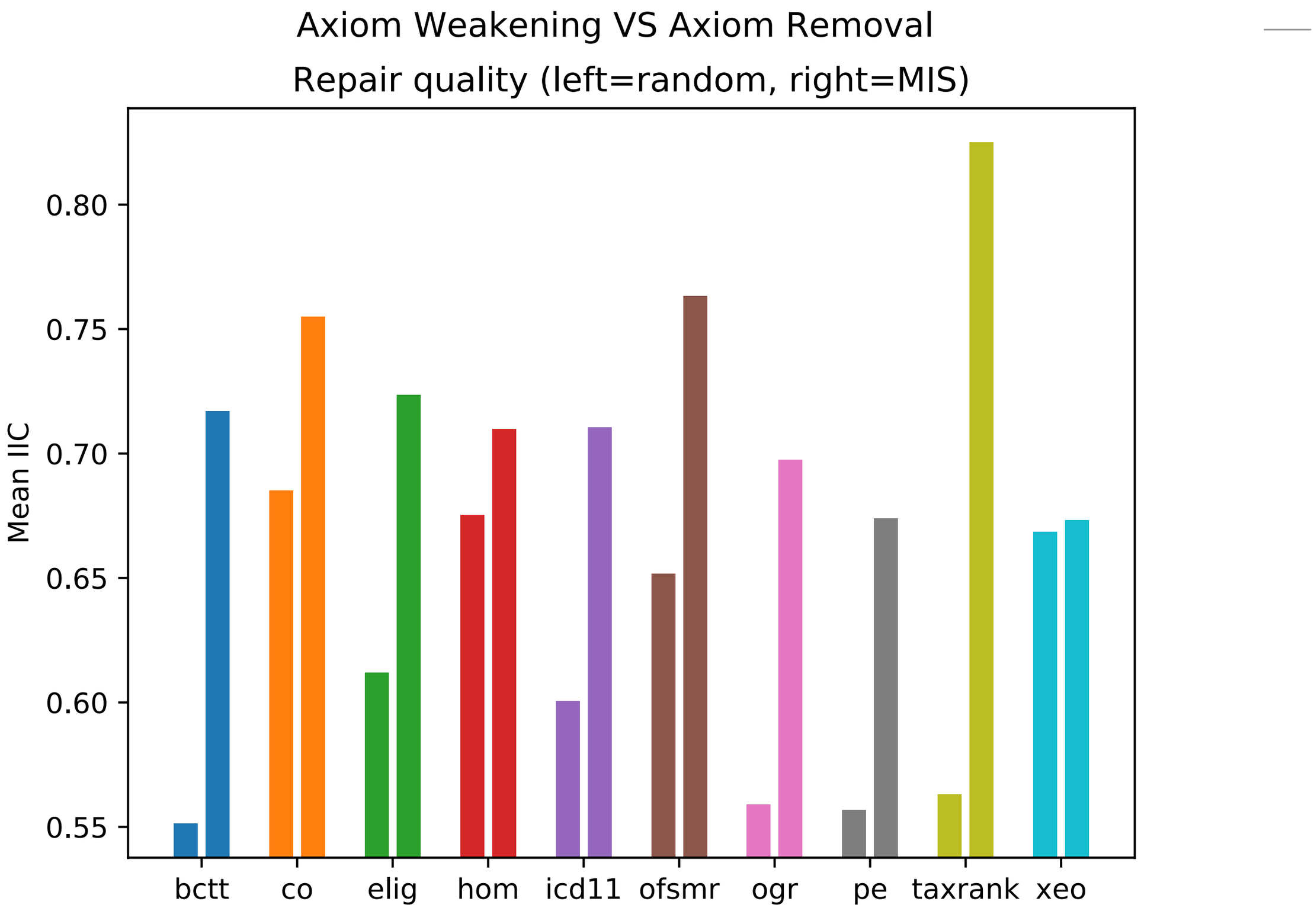
$$\overline{\text{Bird}} \equiv \text{Clade} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs} \sqcap \exists \text{hasBodyPart.Wings} \sqcap \exists \text{hasAbility.Fly}$$

$$\overline{\text{Horse}} \equiv \text{Mammal} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs} \sqcap \exists \text{hasAbility.Walk} \sqcap \exists \text{hasAbility.Trot}$$

Blend

$$\text{Pegasus} \equiv \text{Mammal} \sqcap \exists \text{hasBodyPart.Torso} \sqcap \exists \text{hasBodyPart.Legs} \sqcap \exists \text{hasBodyPart.Wings} \sqcap \exists \text{hasAbility.Walk} \sqcap \exists \text{hasAbility.Trot} \sqcap \exists \text{hasAbility.Fly}$$

Generalisation vs. Deletion of Axioms



Summary

- Conceptual blending provides a rich cognitively motivated theory for computational concept invention
- Image Schema Theory is essential for understanding the dynamics of concept invention
- Current and future work includes:
  - Rich spatial-temporal logics for image schemas
  - Refinement of the generalisation approach to richer logics and to be guided by common-sense knowledge
  - Integrating social choice theory and argumentation

Some Relevant Papers (Blending)

- M M Hedblom, O Kutz, F Neuhaus: "**Choosing the Right Path: Image Schema Theory as a Foundation for Concept Invention**", Journal of Artificial General Intelligence 6 (1): 22-54, De Gruyter, 2015.
- O Kutz, J Bateman, T Mossakowski, F Neuhaus, M Bhatt: "**E pluribus unum: Formalisation, Use-Cases, and Computational Support for Conceptual Blending**", in T. R. Besold et al., editors, Computational Creativity Research: Towards Creative Machines, Atlantis/Springer, Thinking Machines, 2015.
- M M Hedblom, O Kutz, F Neuhaus: "**Image schemas in computational conceptual blending**", Cognitive Systems Research 39, 42-57, Elsevier, 2016.
- T R Besold, M M Hedblom, O Kutz: "**A narrative in three acts: Using combinations of image schemas to model events**", Biologically Inspired Cognitive Architectures, Elsevier, 2016.
- M M Hedblom, O Kutz, T Mossakowski, F Neuhaus: "**Between Contact and Support: Introducing a logic for image schemas and directed movement**", 16th International Conference of the Italian Association for Artificial Intelligence (AI*IA 2017)}, Bari, Italy, Springer, 2017.
- M Eppe, E Maclean, R Confalonieri, O Kutz, M Schorlemmer, E Plaza, K-U Kühnberger: "**A Computational Framework for Concept Blending**", Artificial Intelligence, 2017.

Some Relevant Papers (DOL and Weakening)

- T. Mossakowski, M. Codescu, F. Neuhaus and O. Kutz: "**The Distributed Ontology, Modeling and Specification Language - DOL**", in: A. Koslow and A. Buchsbaum, editors, *The Road to Universal Logic*, pages 489-520. Birkhäuser, 2015.
- Mihai Codescu, Till Mossakowski and Oliver Kutz: "**A categorical approach to networks of aligned ontologies**", *Journal on data semantics* 6(4):155-197, 2017.
- R Confalonieri, M Eppe, M Schorlemmer, O Kutz, R Penaloza, E. Plaza: "**Upward Refinement Operators for Conceptual Blending in the Description Logic EL++**", Annals of Mathematics and Artificial Intelligence (AMAI), Springer, 2016.
- M Codescu, E Kuksa, O Kutz, T Mossakowski, and F Neuhaus: "**Ontohub: A semantic repository for heterogeneous ontologies"**, Journal of Applied Ontology, IOS Press, 2017
- D Porello, N Troquard, R Confalonieri, P Galliani, O Kutz, R Peñaloza: "**Repairing Socially Aggregated Ontologies Using Axiom Weakening**", 20th International Conference on Principles and Practice of Multi-Agent Systems (PRIMA 2017)}, Nice, France, Springer, 2017.
- O. Kutz, T. Mossakowski, D. Lücke: "**Carnap, Goguen, and the Hyperontologies: Logical Pluralism and Heterogeneous Structuring in Ontology Design**", Logica Universalis 4(2): 255-333, 2010.