From Conceptual Blending to Computational Concept Invention

Oliver Kutz

CORE Conceptual and Cognitive Modelling Group
KRDB Research Centre for Knowledge and Data
Free University of Bozen-Bolzano, Italy

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
    - computing generic spaces via generalisation
    - image schemas as generic spaces

Part 1:

Conceptual Blending

Conceptual Blending ...

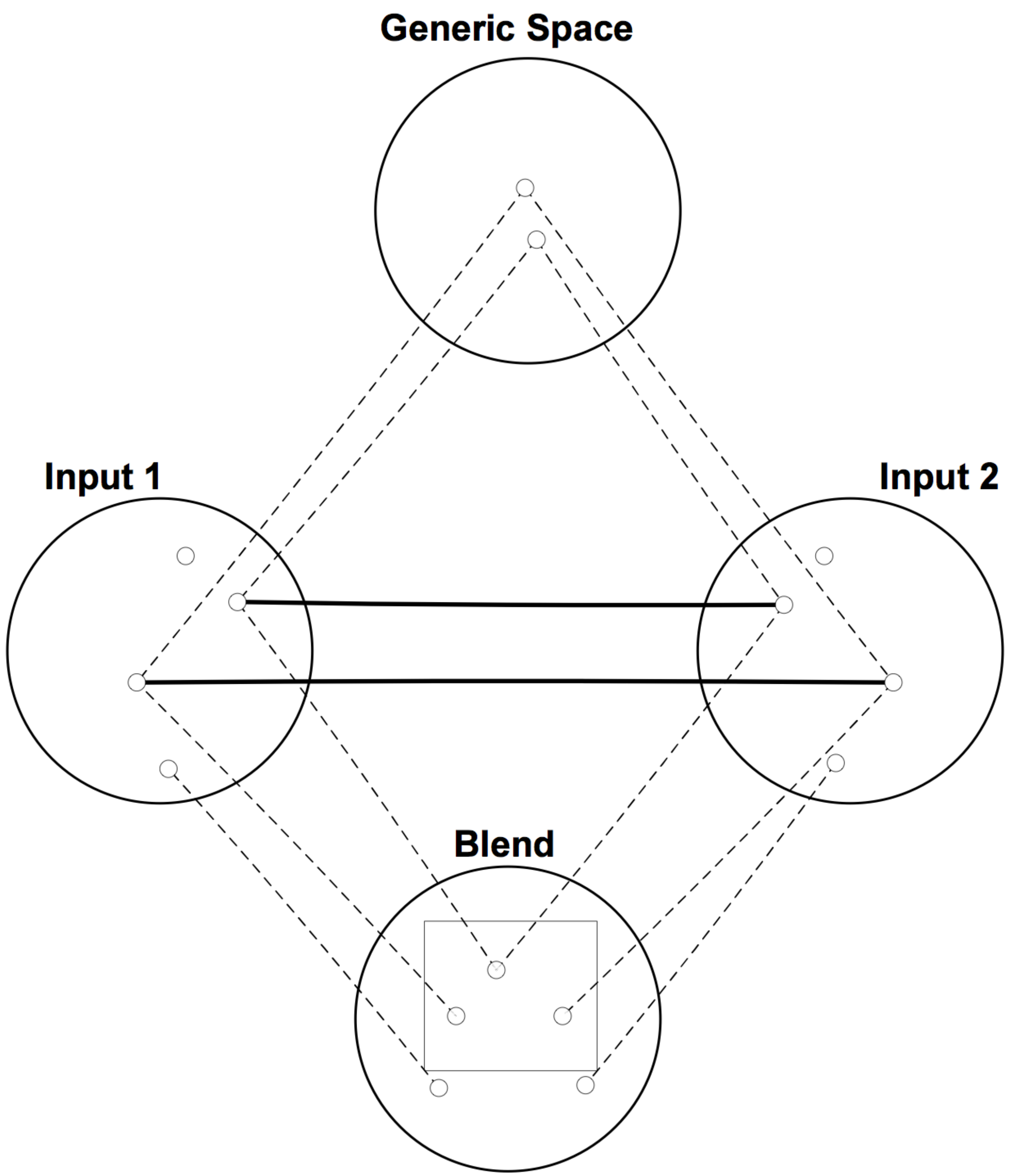
- **Mark Turner (2014):** a hypothetical explanation for the ‘**human spark**’:
- The ‘lionman’, approximately 32.000 years old, blends the concepts of ‘human’ and ‘lion’.
- The period of its creation marks the end of an apparent ***deadlock of human cultural development***, ...
- and the beginning of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

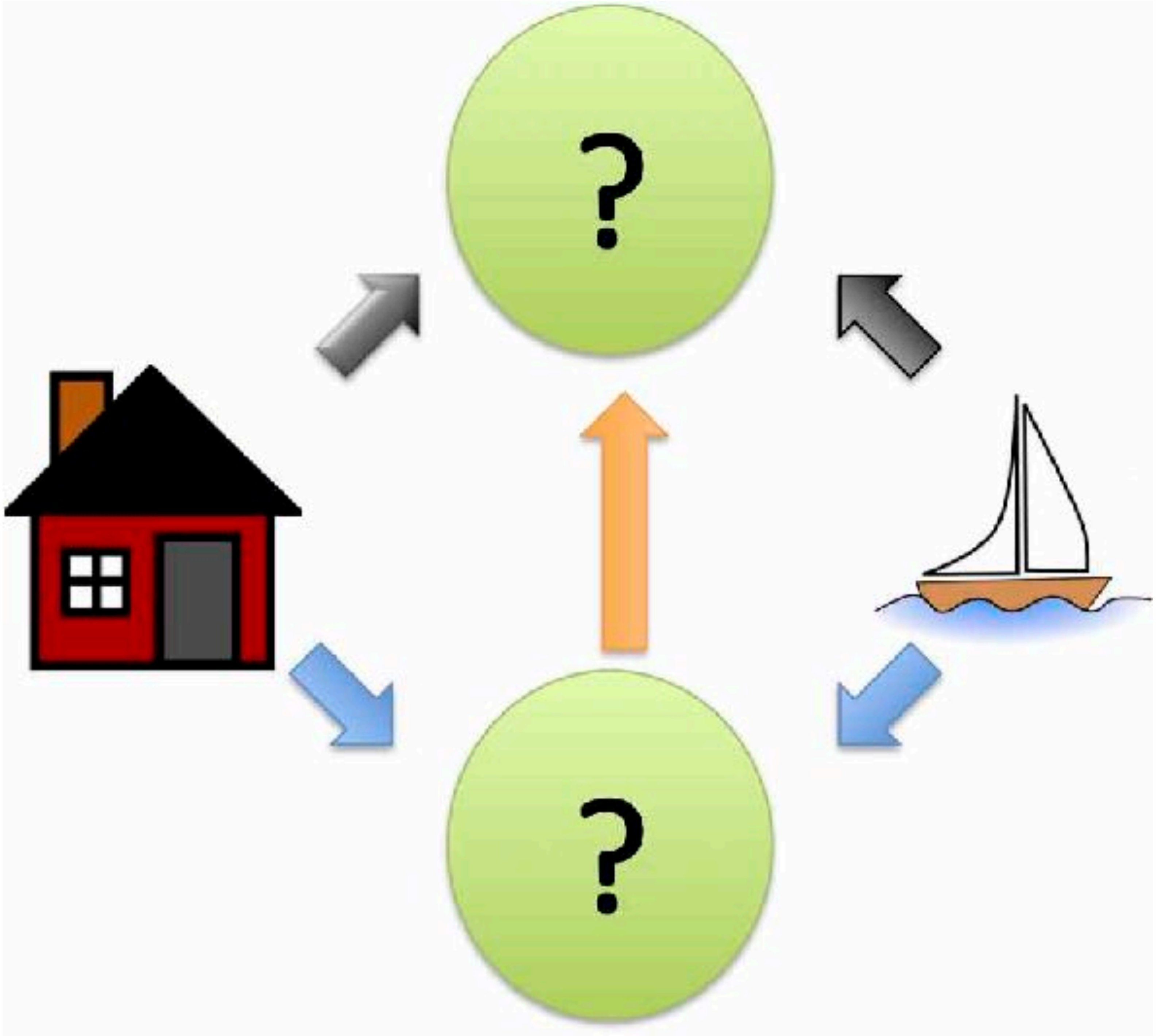
Summarised by Fauconnier & Turner (2003):

- 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
- blends offer challenges to the imagination
- resulting blends can turn out to be highly imaginative



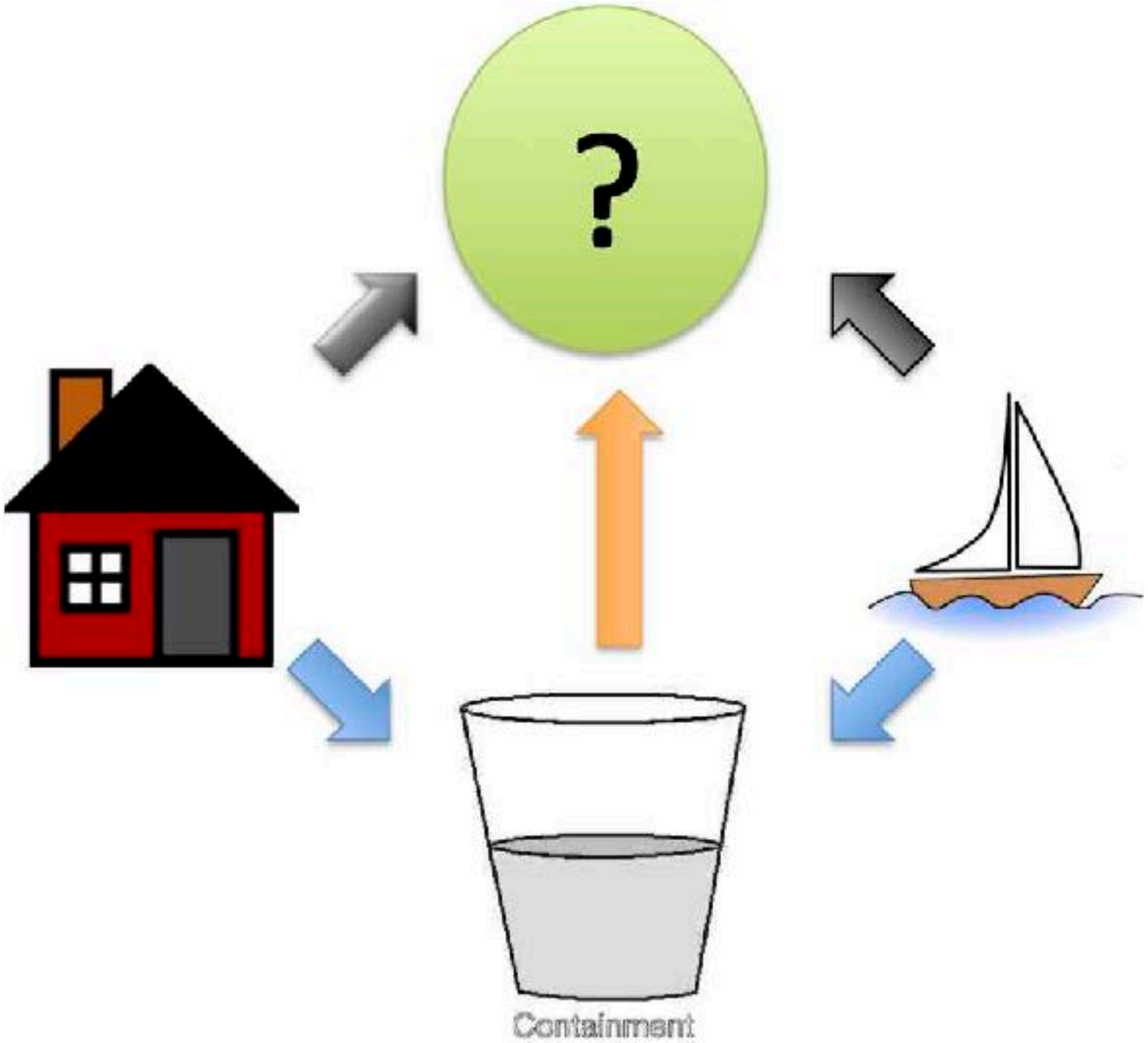
A foldable toothbrush is not an analogy!

Conceptual Blending: Example

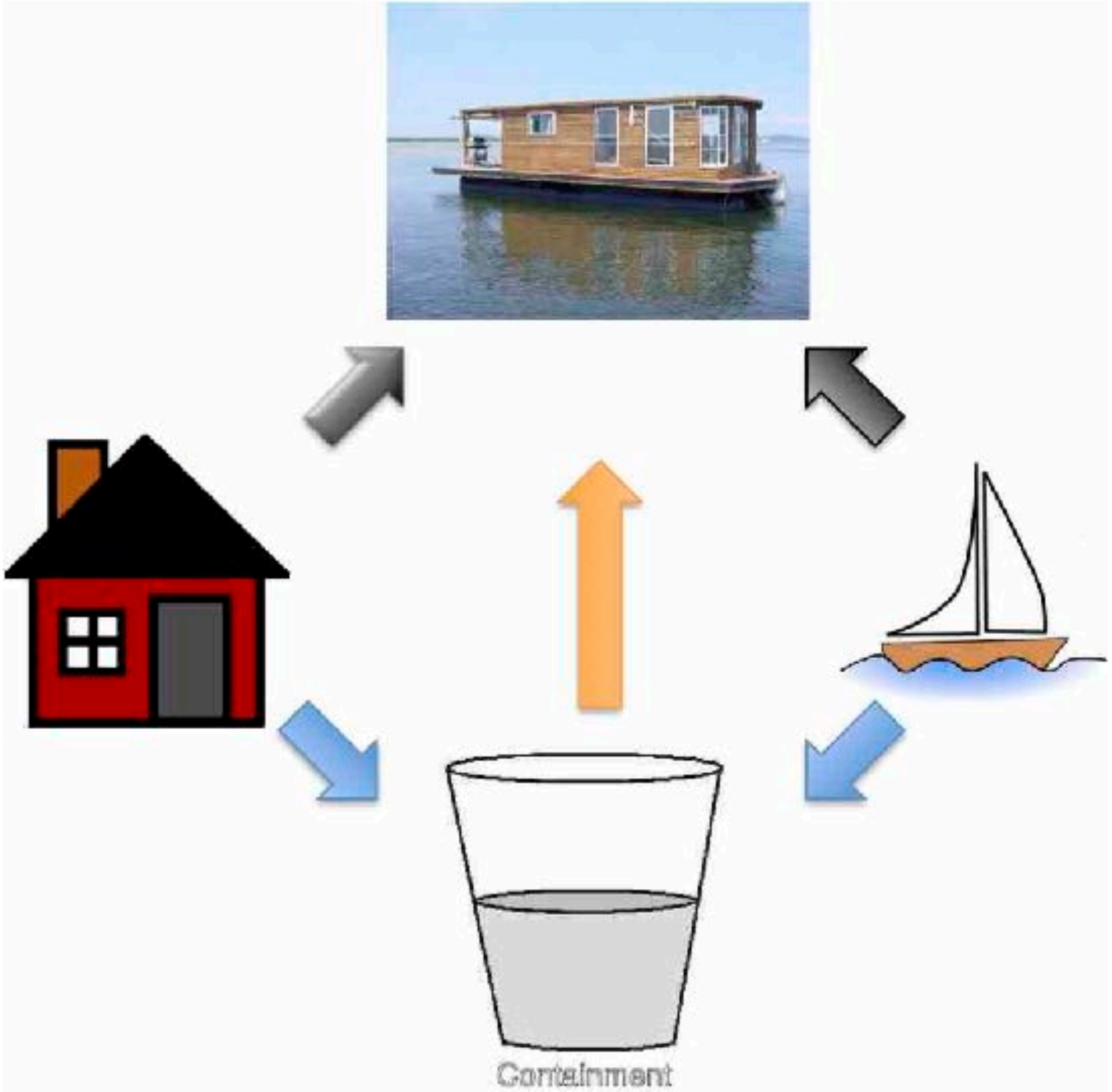


Note: The diagram is upside-down (motivated by the formal model)

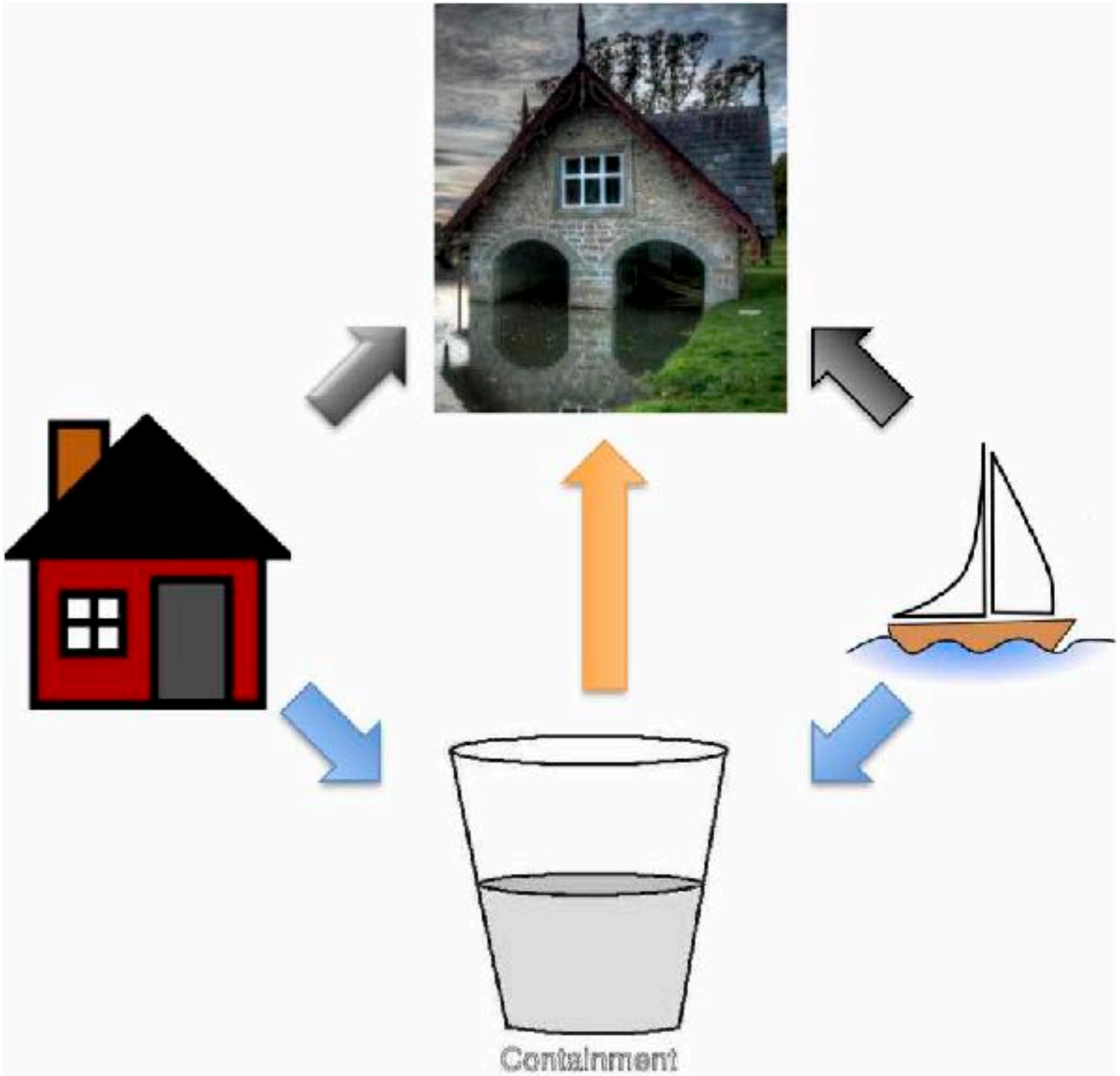
Conceptual Blending: Example



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

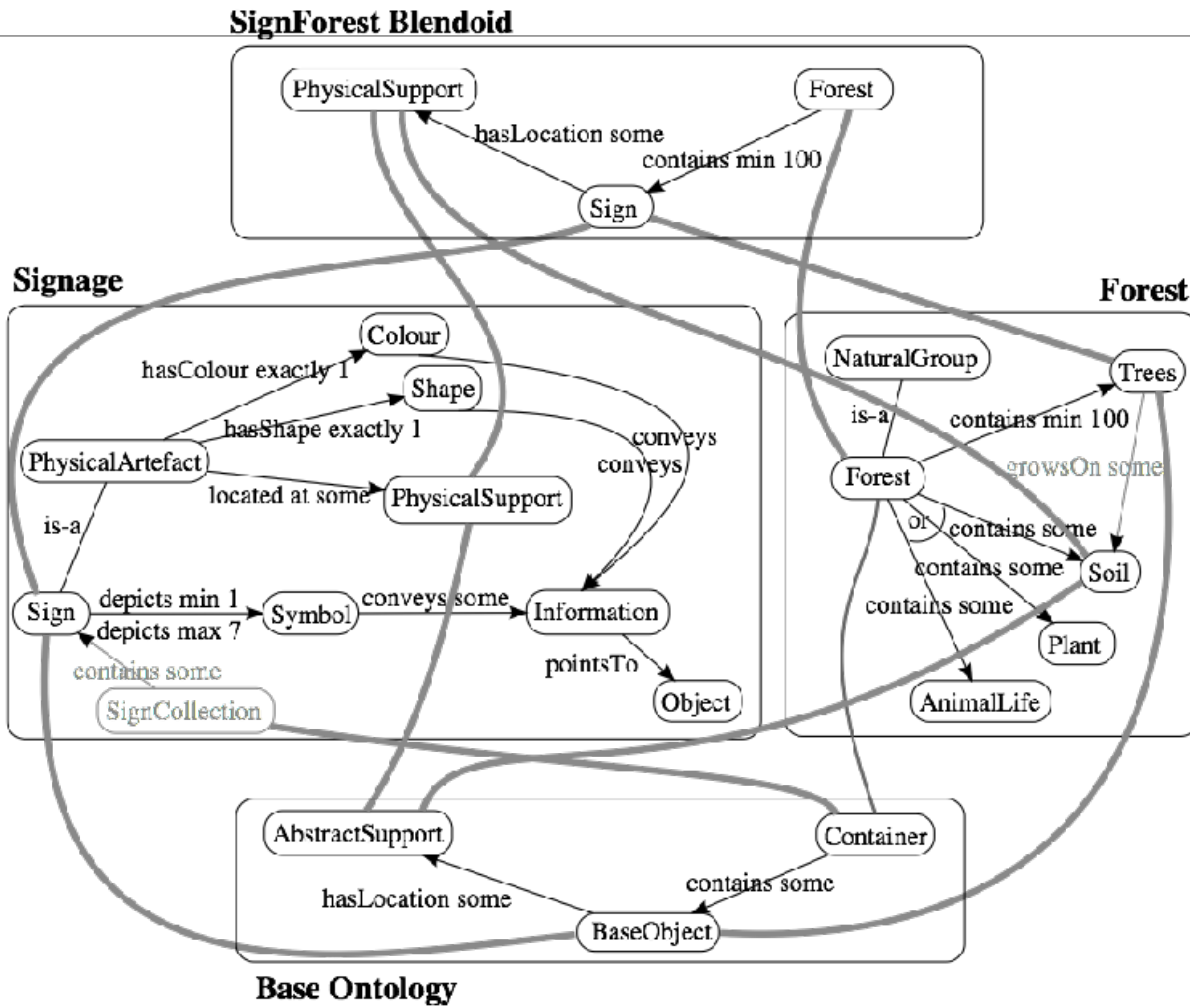
Blending Signs and Forests: Blend 3

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:** ...

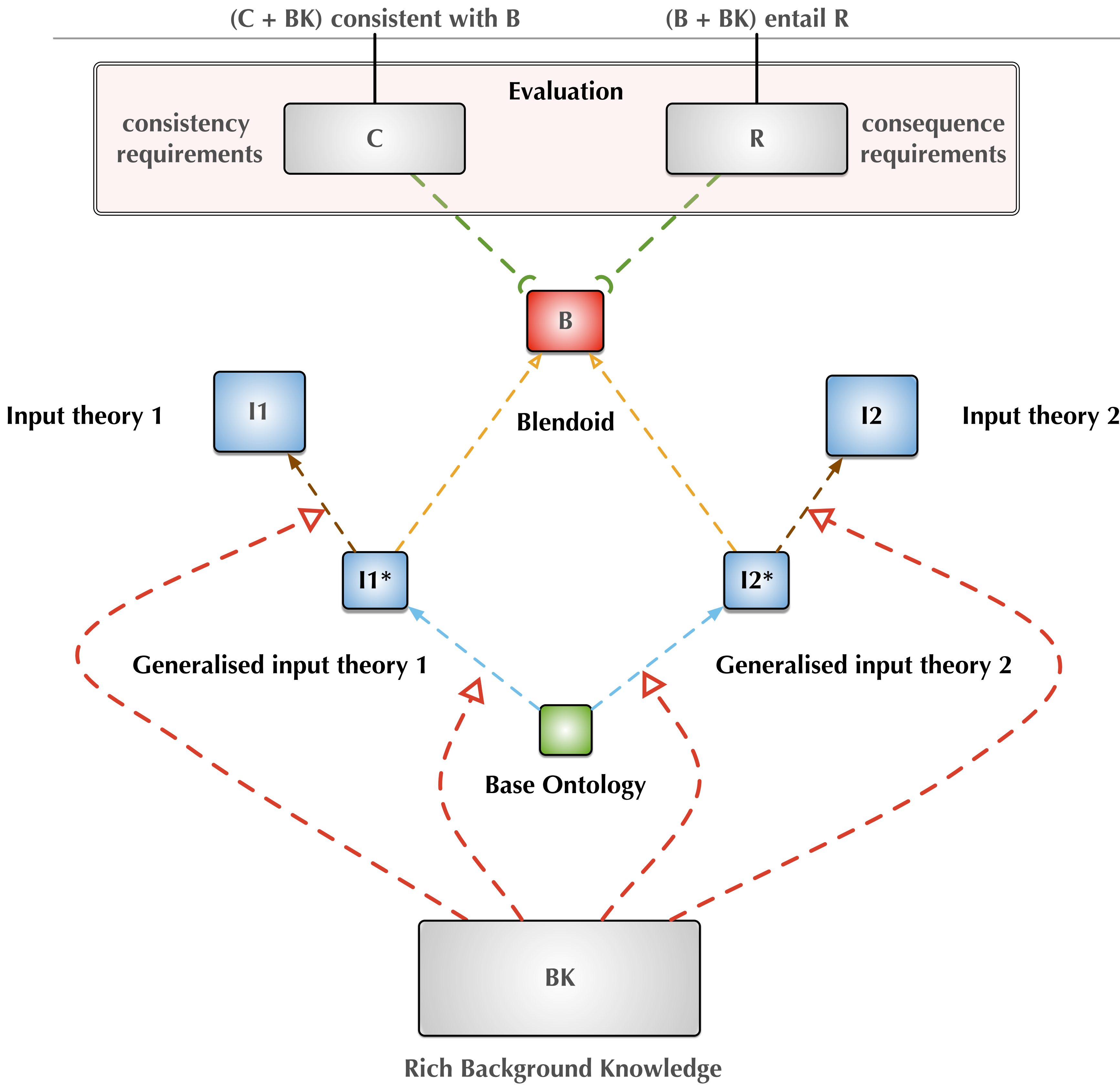
Graphical Representation of a Formal DOL Specification



Part 2:

Abstract Framework and Representation Language

Blending: Formal Model

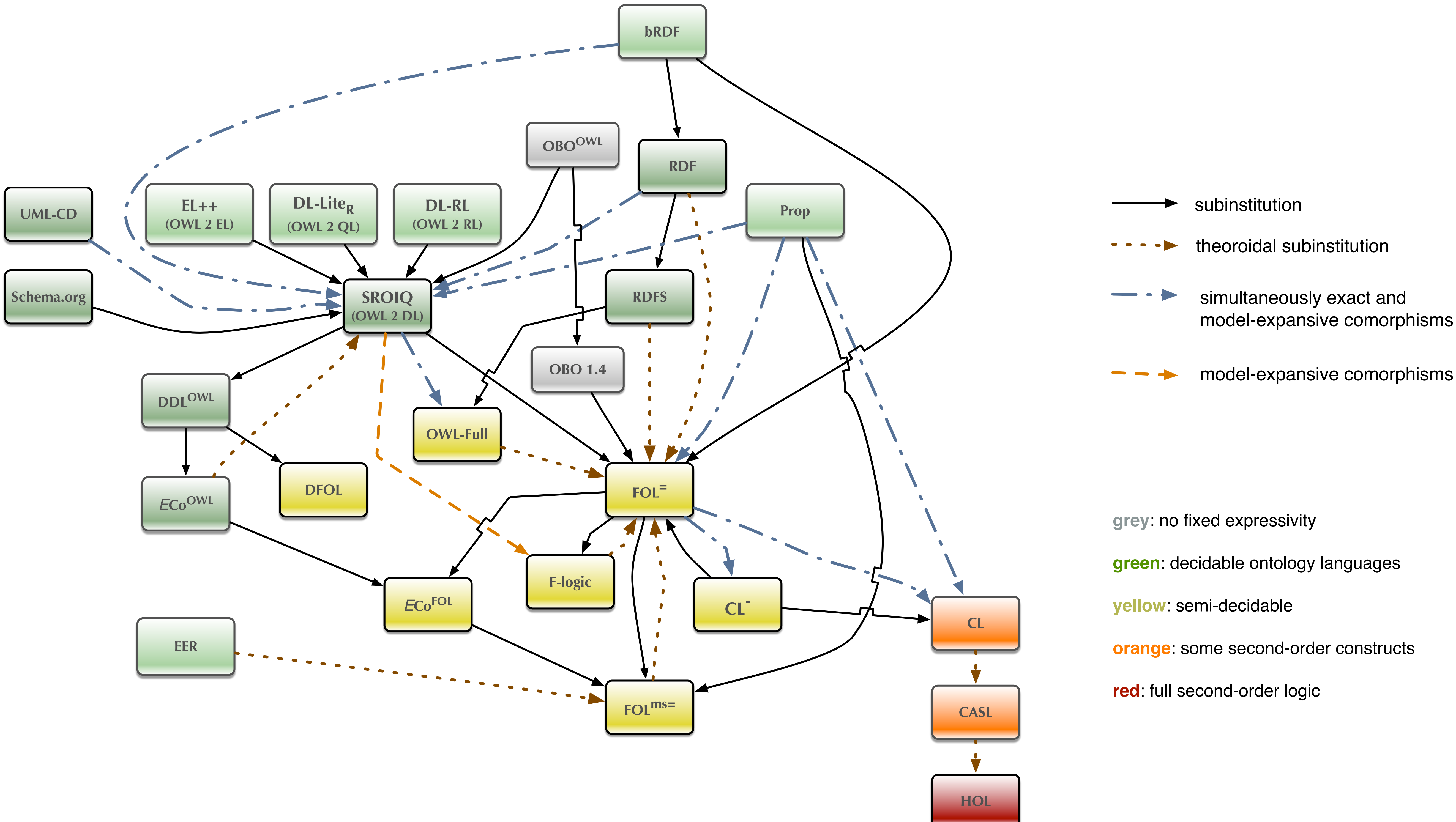


- Creating blends in Ontohub / DOL
- usage of background ontologies
- image schemas as base ontologies
- evaluation features
  - constraints
  - requirements

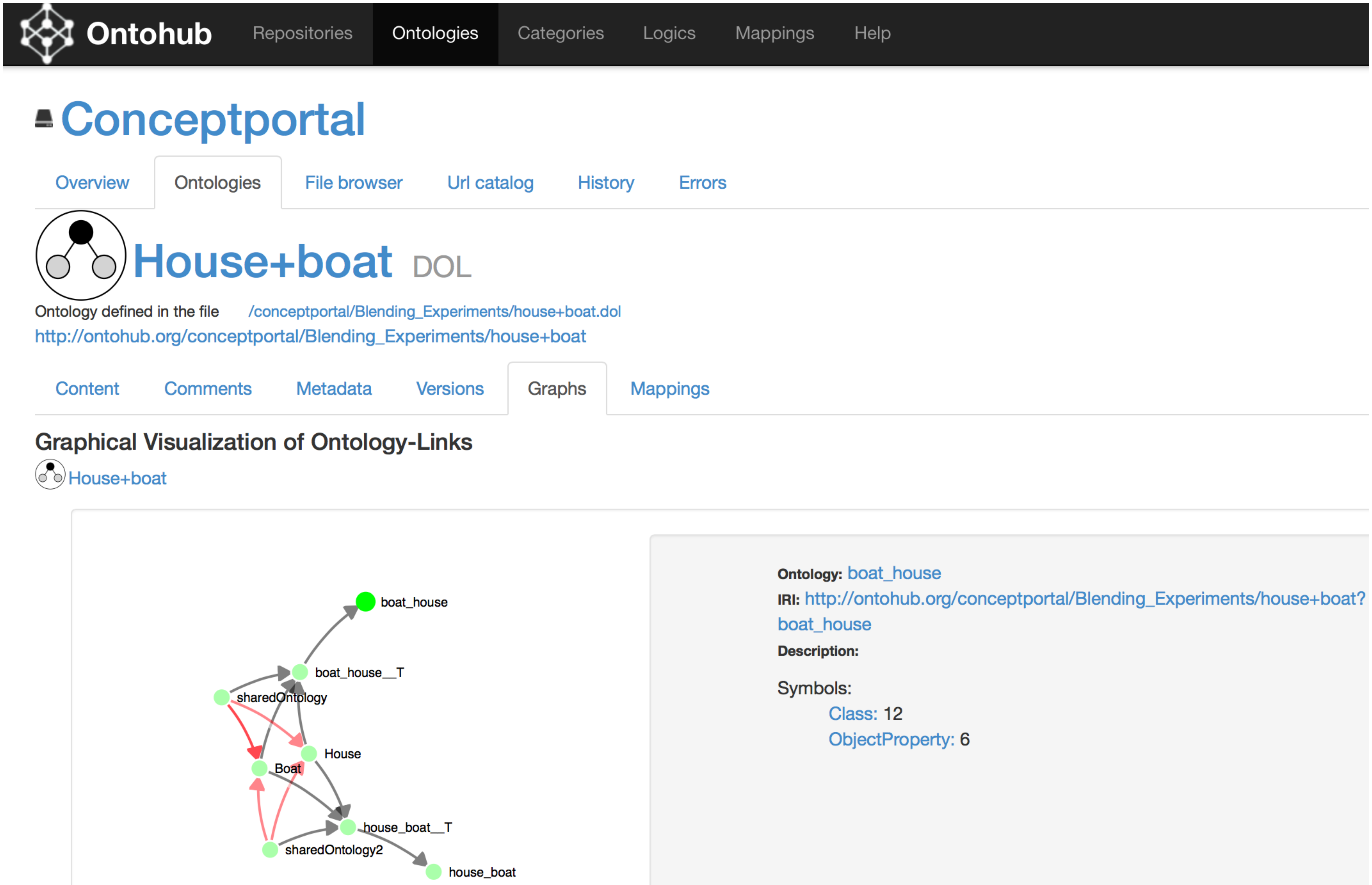
Blending with DOL, Hets, Ontohub

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

Logic Graph supported by DOL



DEMO of ontohub/conceptportal

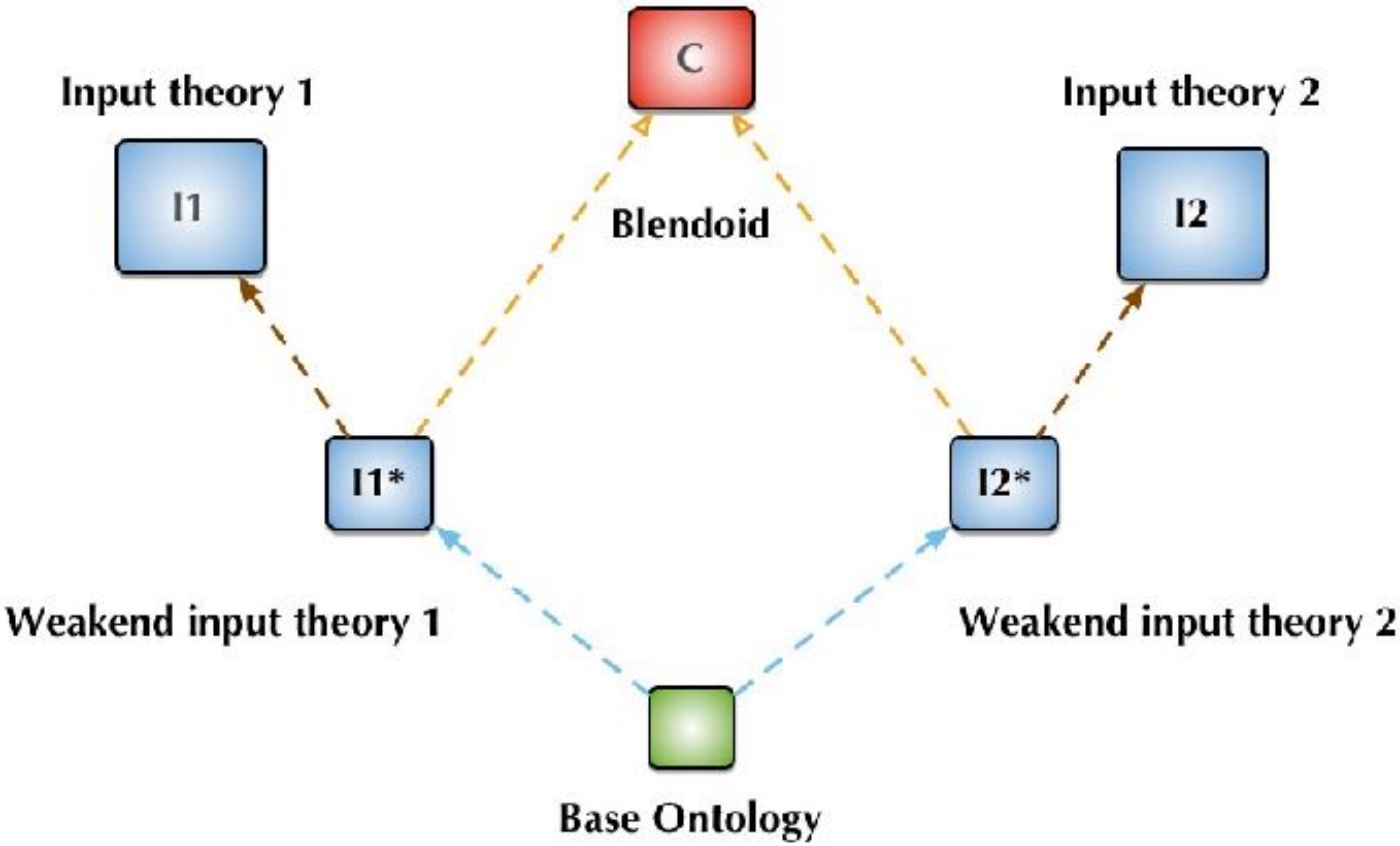


Part 3:

Cognitive Modelling and Computational Approaches

Goal: Computationally Generate Concepts

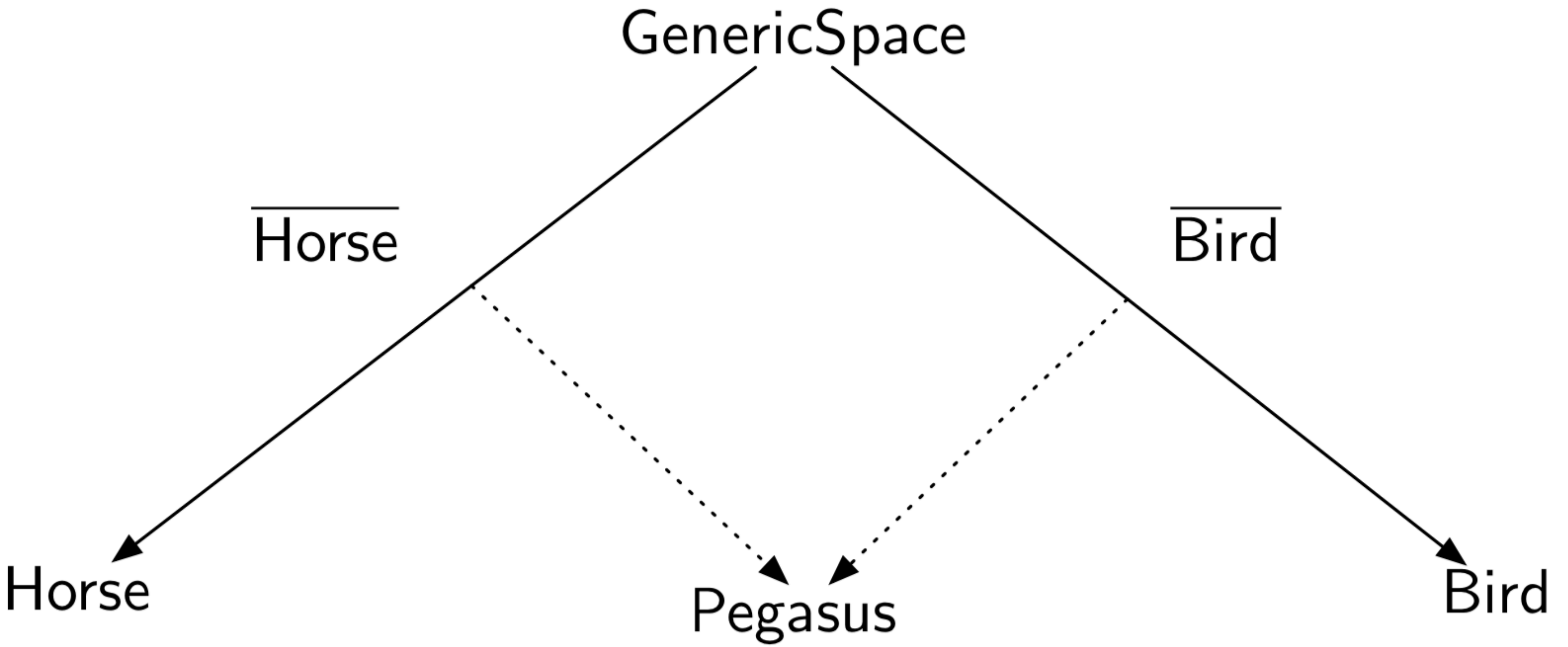
COINVENT's Model for CCB



Challenges:

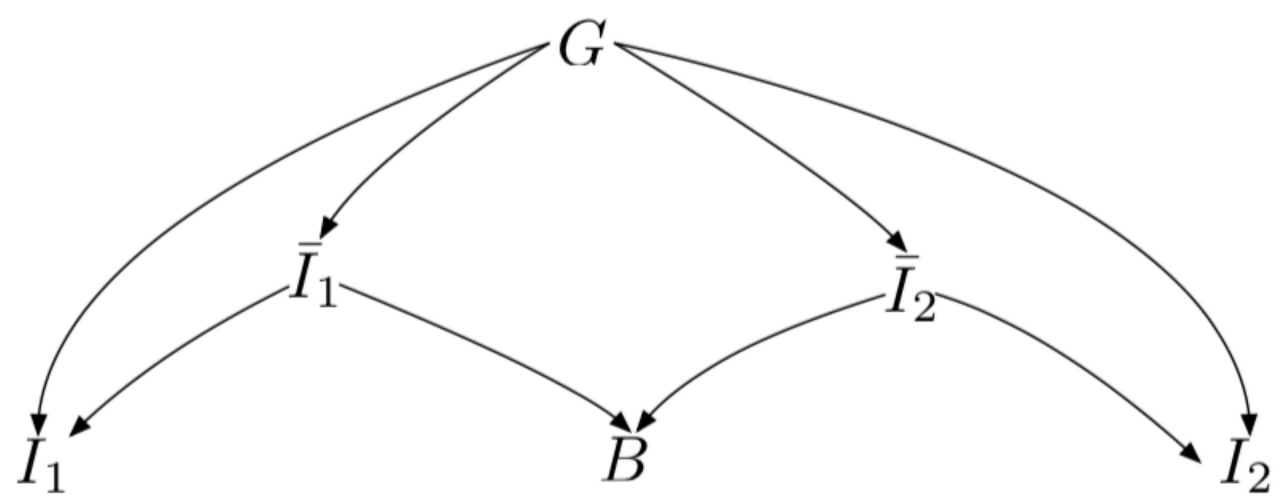
- How to represent the blending process?
- What do we keep from the input spaces?
- How to find the right base space + morphisms?

Creating EL++ Concepts via Conceptual Blending



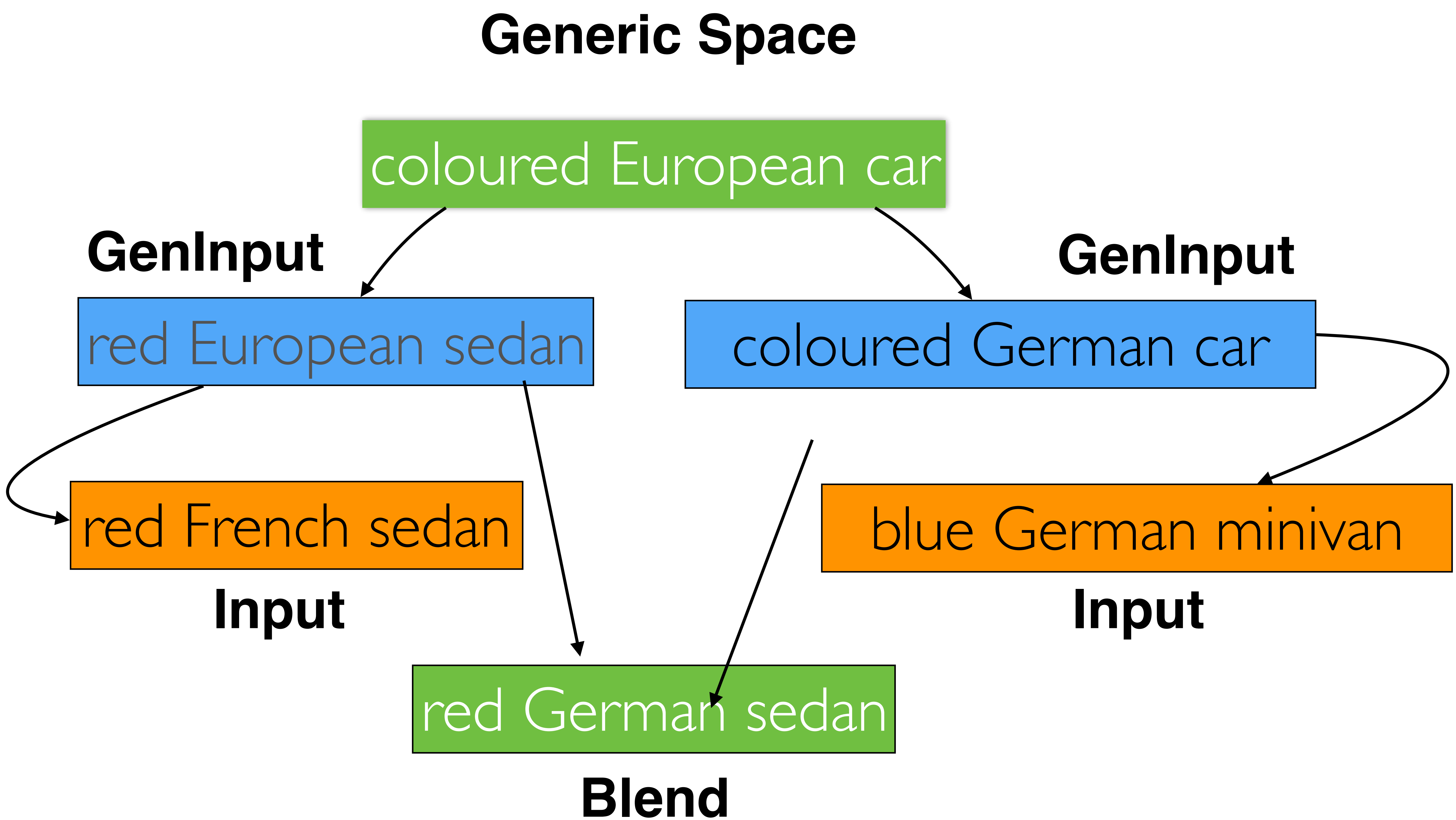
Computational Model of Conceptual Blending: Amalgamation

- 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



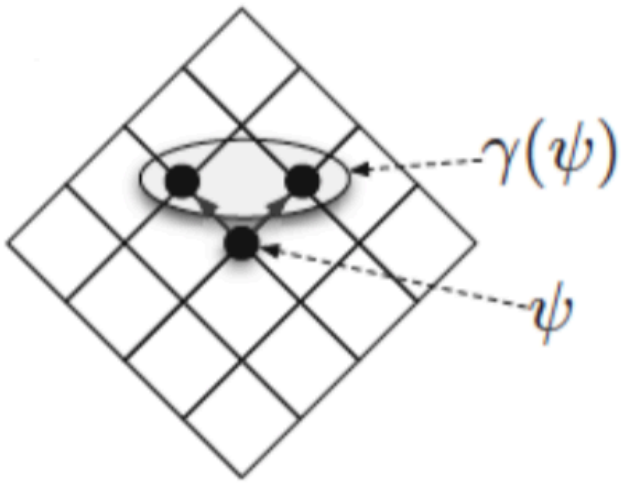
Generalising EL++ Concepts: Why?

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

- 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 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 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:

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

Generalisations and Generic Space

Generalising Horse

$$\mathsf{Mammal} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Torso} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Legs} \sqcap \exists \mathsf{hasAbility}.\mathsf{Walk} \sqcap \exists \mathsf{hasAbility}.\mathsf{Trot}$$

$$\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Torso} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Legs} \sqcap \exists \mathsf{hasAbility}.\mathsf{Walk} \sqcap \exists \mathsf{hasAbility}.\mathsf{Trot}$$

$\ldots \quad \ldots$

$$\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Torso} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Legs} \sqcap \exists \mathsf{hasAbility}.\mathsf{Walk}$$

$\ldots \quad \ldots$

$$\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Torso} \sqcap \exists \mathsf{hasBodyPart}.\mathsf{Legs}$$

Generalisations and Generic Space (cont'd)

Generalising Bird

$$\mathsf{Avialae} \sqcap \exists \mathsf{hasBodyPart.Torso} \sqcap \exists \mathsf{hasBodyPart.Legs} \sqcap$$
$$\quad \exists \mathsf{hasBodyPart.Wings} \sqcap \exists \mathsf{hasAbility.LayEggs} \sqcap \exists \mathsf{hasAbility.Fly}$$
$$\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart.Torso} \sqcap \exists \mathsf{hasBodyPart.Legs} \sqcap$$
$$\quad \exists \mathsf{hasBodyPart.Wings} \sqcap \exists \mathsf{hasAbility.LayEggs} \sqcap \exists \mathsf{hasAbility.Fly}$$

$\ldots \quad \ldots$

$$\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart.Torso} \sqcap \exists \mathsf{hasBodyPart.Legs} \sqcap$$
$$\quad \exists \mathsf{hasBodyPart.Wings} \sqcap \exists \mathsf{hasAbility.LayEggs}$$

$\ldots \quad \ldots$

$$\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart.Torso} \sqcap \exists \mathsf{hasBodyPart.Legs} \sqcap$$
$$\quad \exists \mathsf{hasBodyPart.Wings}$$

$\ldots \quad \ldots$

$$\mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart.Torso} \sqcap \exists \mathsf{hasBodyPart.Legs}$$

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 EL++

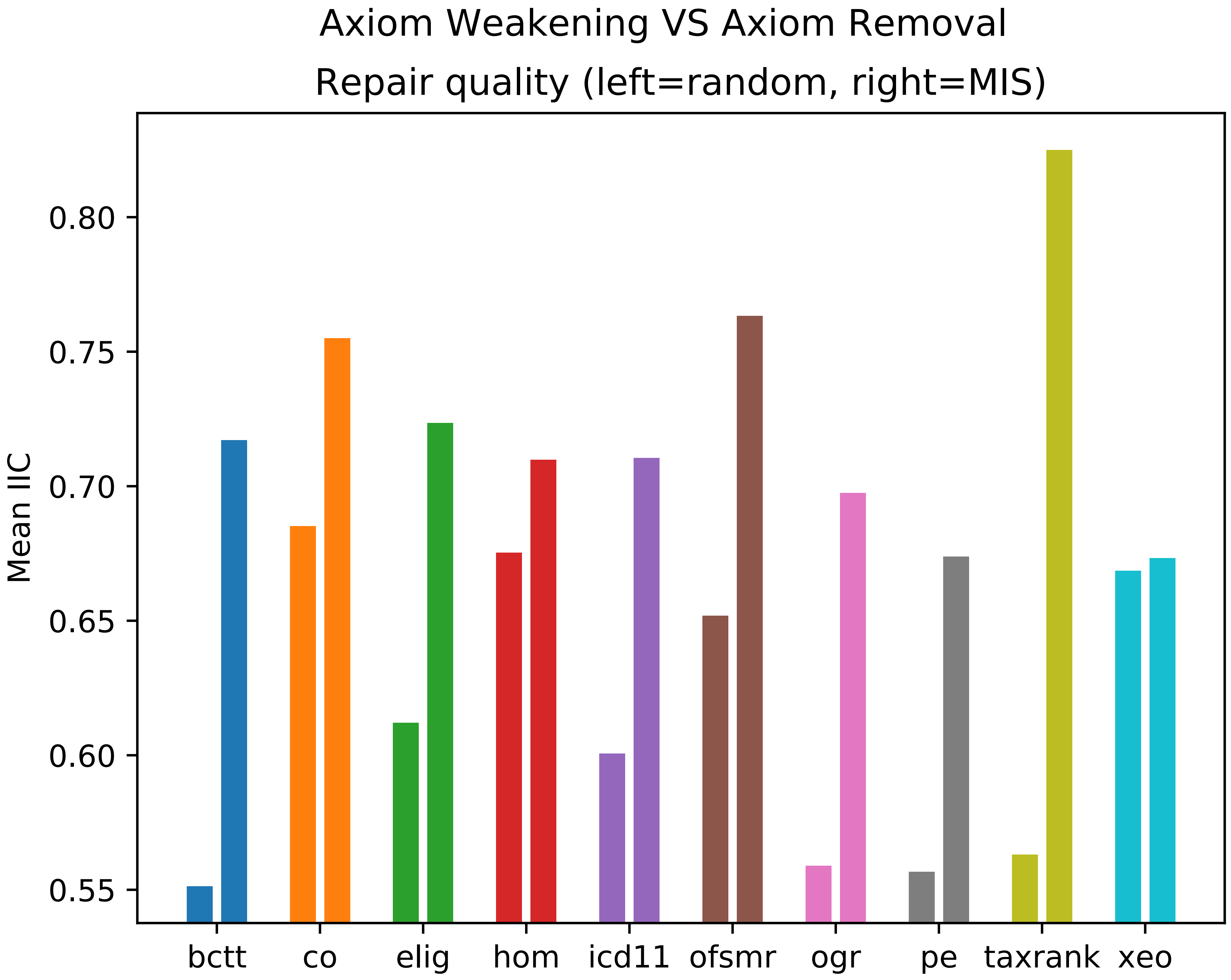
- Blends are computed as most general specialisations (MGS) of pairs of generalised concepts
- In $\mathcal{EL}^{++}$, the MGS is defined by $\sqcap$

$$\begin{aligned}
\overline{\mathsf{Bird}} \equiv\ & \mathsf{Clade} \sqcap \exists \mathsf{hasBodyPart.Torso} \sqcap \exists \mathsf{hasBodyPart.Legs} \sqcap \\
& \exists \mathsf{hasBodyPart.Wings} \sqcap \exists \mathsf{hasAbility.Fly} \\
\overline{\mathsf{Horse}} \equiv\ & \mathsf{Mammal} \sqcap \exists \mathsf{hasBodyPart.Torso} \sqcap \exists \mathsf{hasBodyPart.Legs} \sqcap \\
& \exists \mathsf{hasAbility.Walk} \sqcap \exists \mathsf{hasAbility.Trot}
\end{aligned}$$

Blend

$$\begin{aligned}
\mathsf{Pegasus} \equiv\ & \mathsf{Mammal} \sqcap \exists \mathsf{hasBodyPart.Torso} \sqcap \exists \mathsf{hasBodyPart.Legs} \sqcap \\
& \exists \mathsf{hasBodyPart.Wings} \sqcap \exists \mathsf{hasAbility.Walk} \sqcap \exists \mathsf{hasAbility.Trot} \sqcap \\
& \exists \mathsf{hasAbility.Fly}
\end{aligned}$$

Generalisation vs. Deletion of Axioms



Goal: Computationally Generate Concepts

Hypothesis

How to find the right base ontology for blending?

Hypothesis

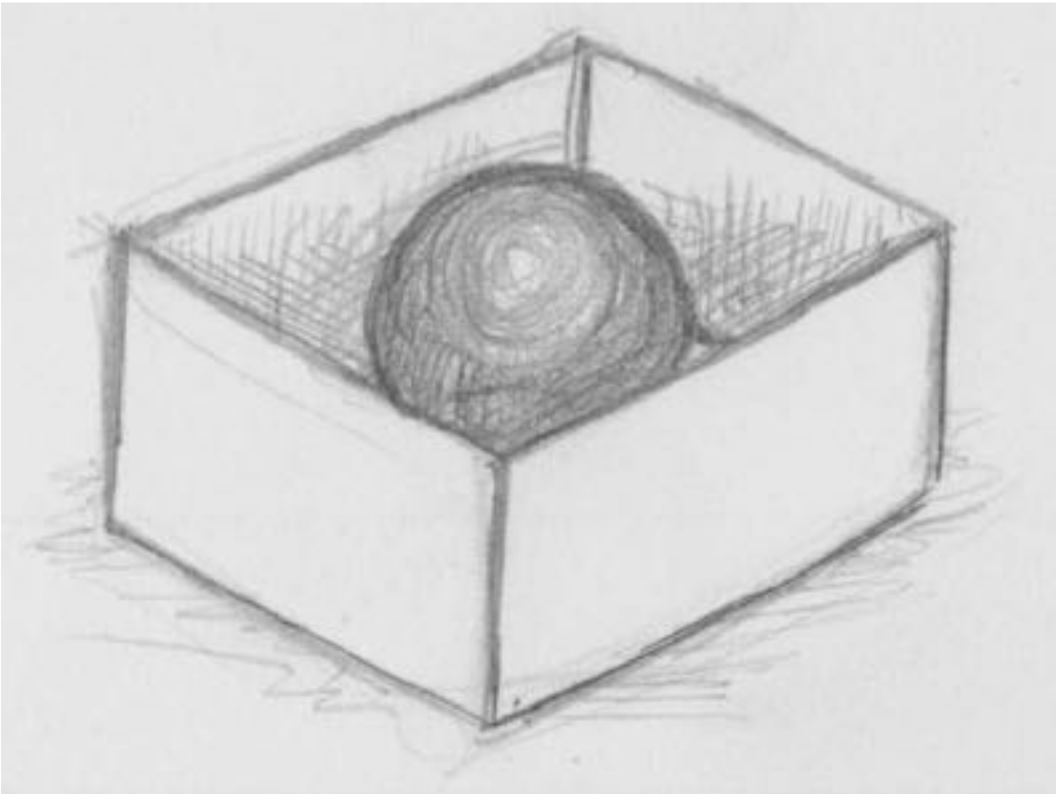
- **Image schemas** may form a conceptual skeleton of bases spaces

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 …



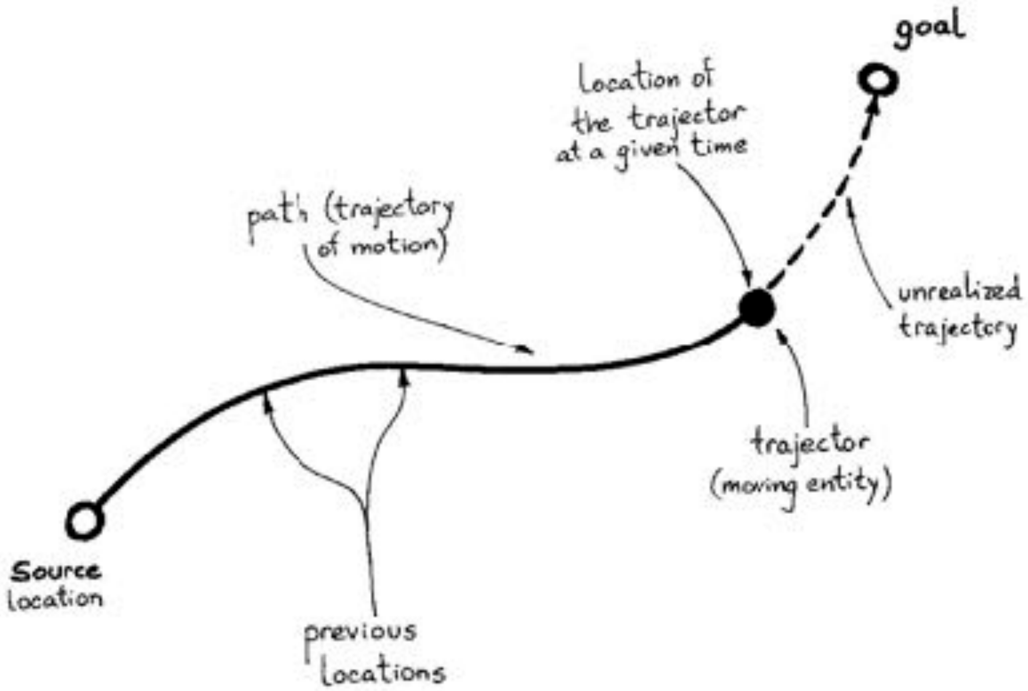


Image Schema Days

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')

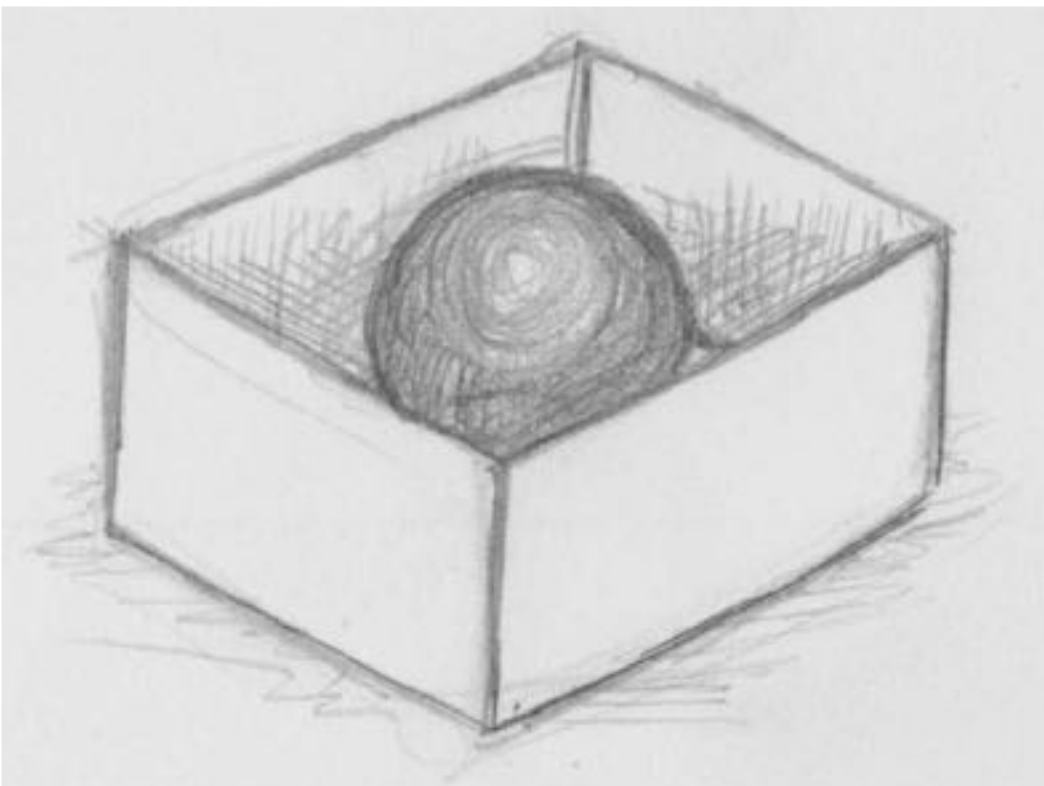
- This space ship
- North Korea
- The universe
- Their marriage
- My bank account

is like a

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

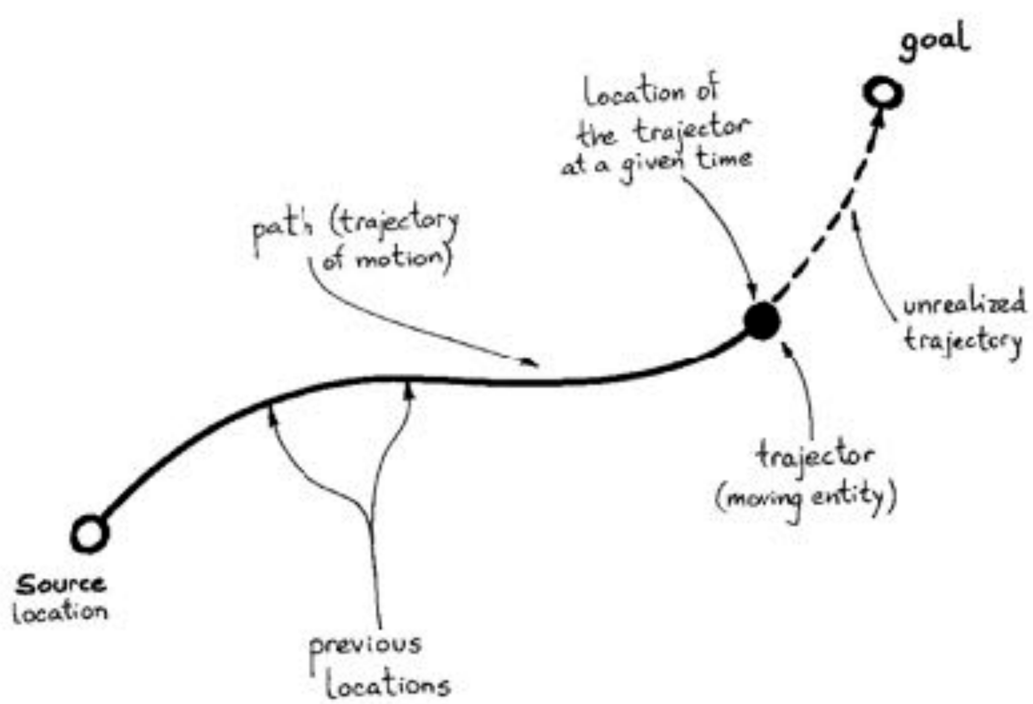
Simile ('Events')

- 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

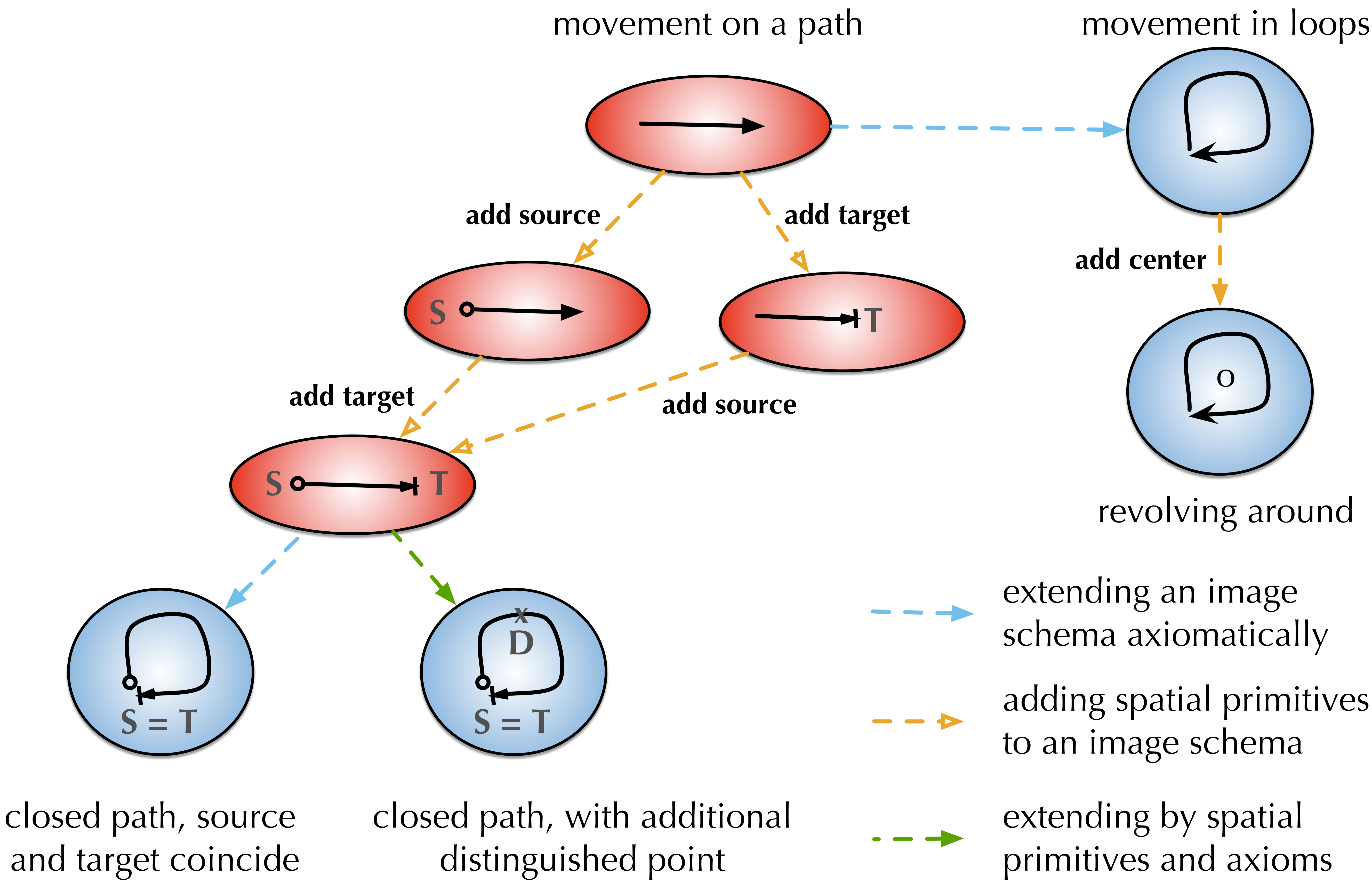
is like

- 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?

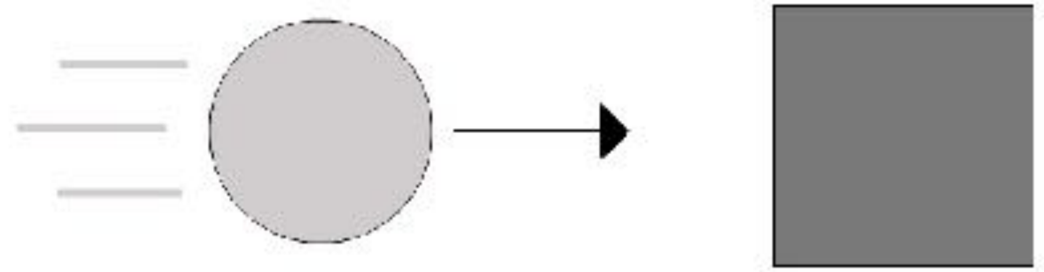
The image schema family of path, loop, and revolving



Event structure / patterns:
Image schema of caused movement

Time 1

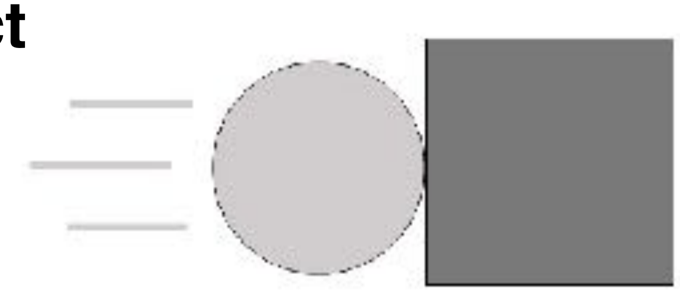
Path



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

Two-object family

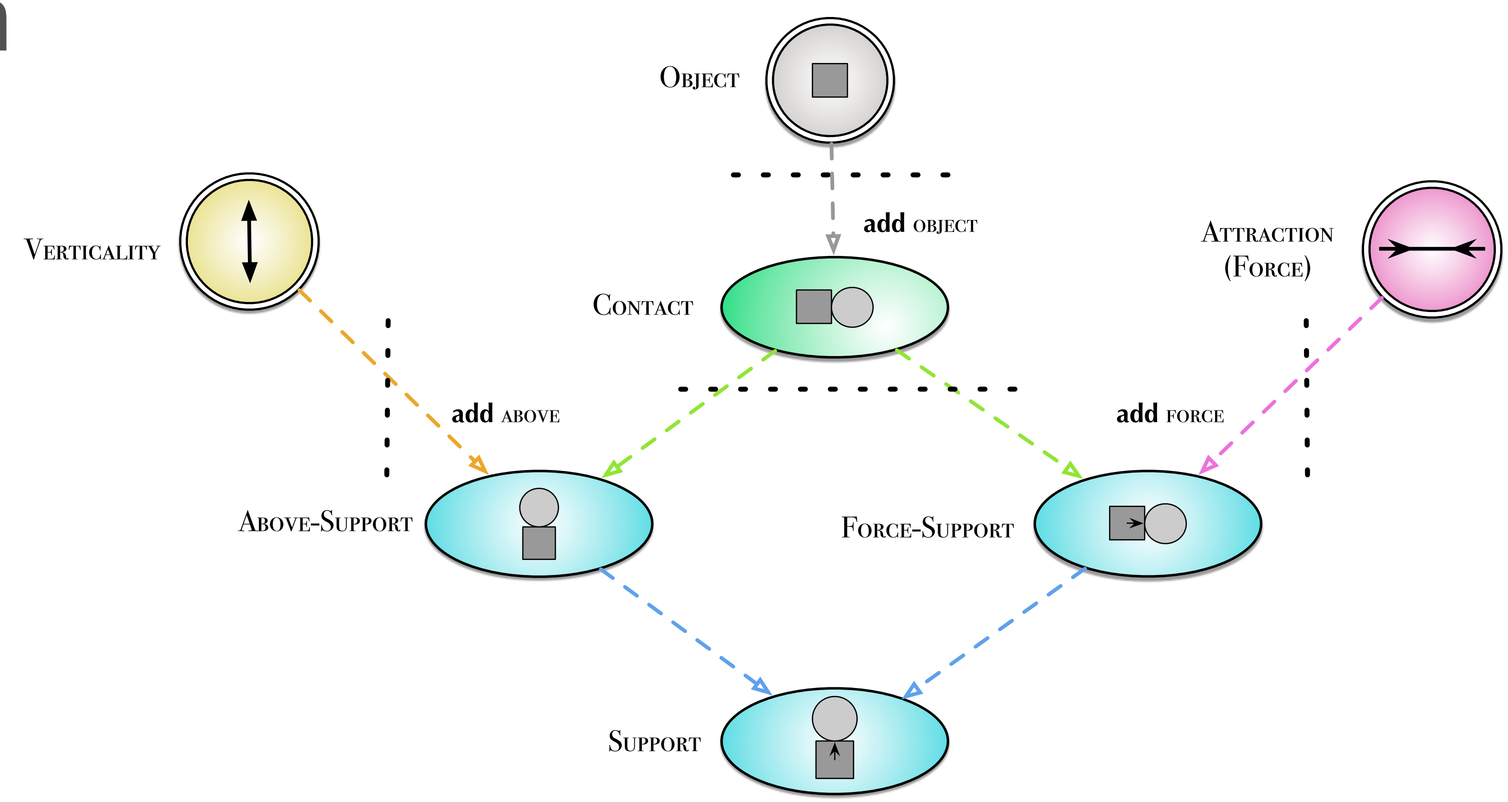
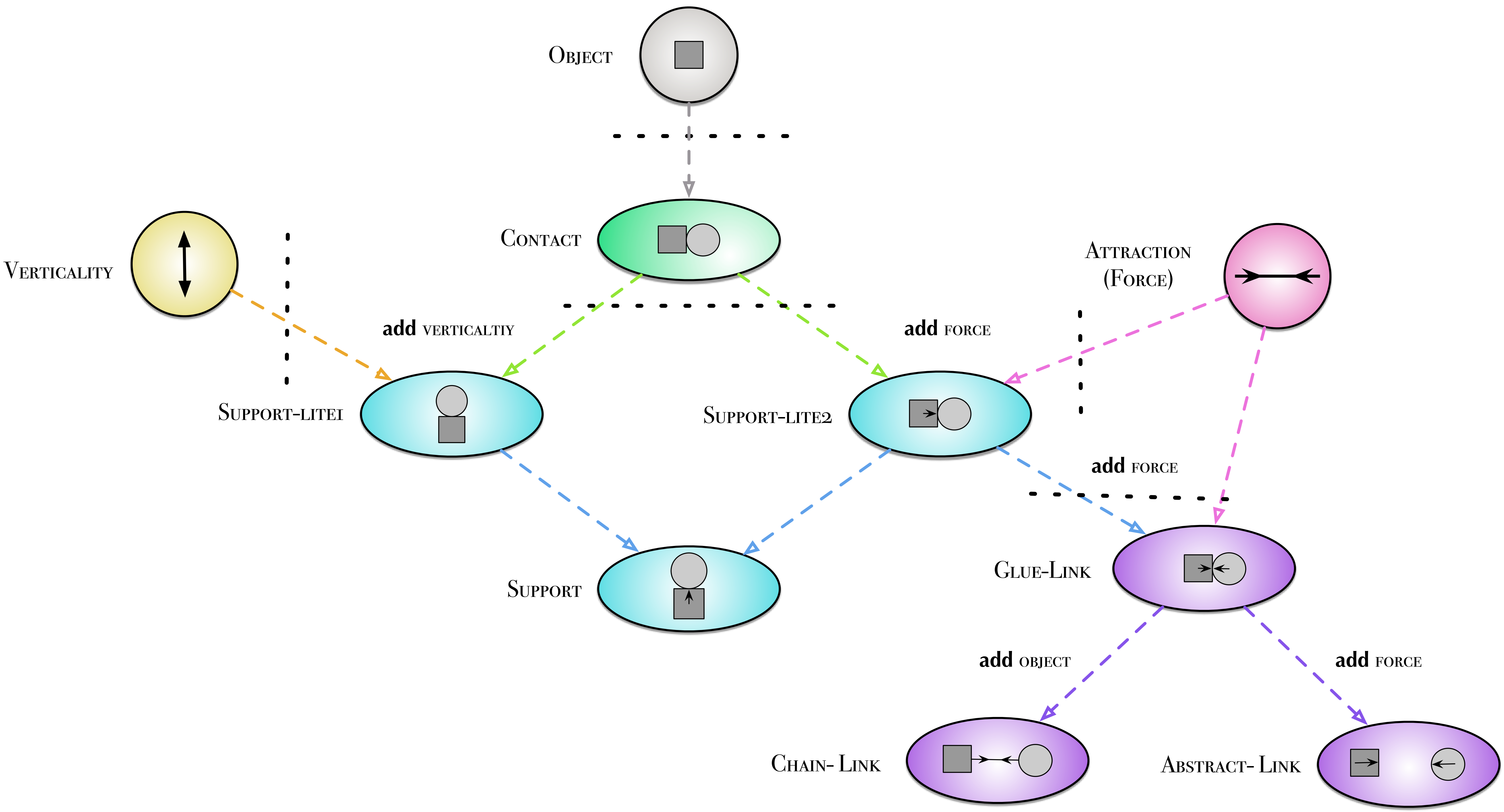


Image Schema Logic ISL: Two-object family

CONTACT: the image schema family of relationships between several objects



Computing Generic Spaces: Summary

- Two basic approaches:
  - **Identification approach**: use the idea of formalised image schema families (ontology patterns) 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.

Adding Agency to ISL (FOIS 2018)

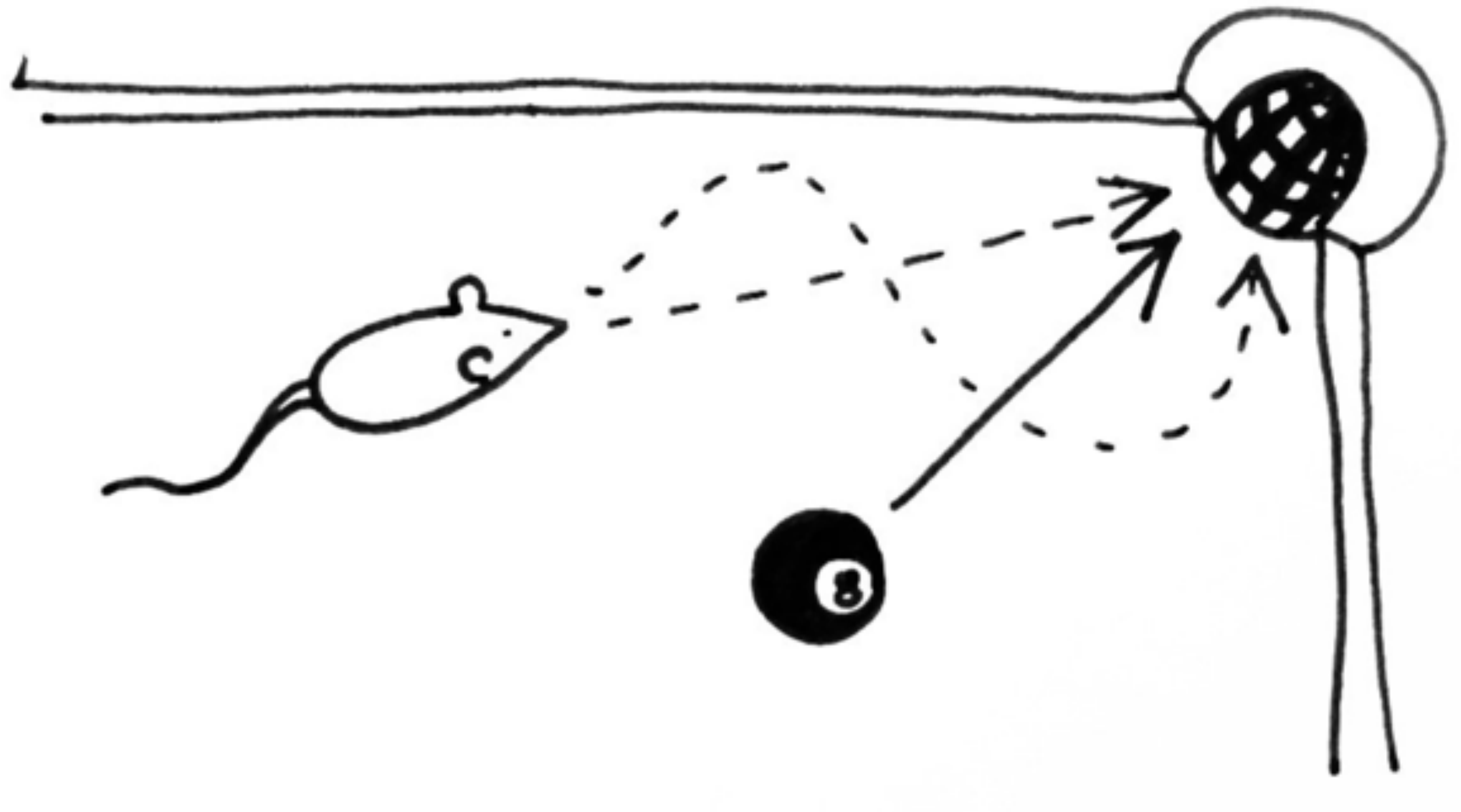


Figure 1. Potential movement pattern of a ball and a mouse.

STIT Theory

- **no ontology of actions:** i.e. categories of actions or events
- **modalities** for
  - 'A sees to it that phi' : Does_A phi
  - historical possibility (Diamond phi)
  - necessity, something is settled (Box phi)
  - Some time in the future (F phi)
  - Always in the future (G phi)

Folk physics

- A typical principle of folk physics is “what goes up must come down.” If e stands for the Earth, and s is the sky, it can be formalised as:

$$Above(s,e) \wedge \mathbf{G} Above(s,e) \wedge x \rightsquigarrow s \to \Box \mathbf{F} x \rightsquigarrow e \quad .$$

- Such a statement, rather than being an axiom of the ISL logic, can be seen as an axiomatic constraint for the naive physics theory involved primarily in image schemas.
- This allows us to avoid encoding physics into the semantics directly.

Levels of agency: Ball

- The billiard ball is an *object* and not an *agent proper*.
- In STIT it is therefore simply modelled in a way that the *choice set* is empty.
- That is, at every moment w, the billiard ball has one unique choice, which consists in selecting all the histories going through w. It cannot interfere with the course of nature.

$$\mathsf{Does}_b\varphi \rightarrow \Box\varphi:$$

Levels of agency: Mouse

- An object/agent a is *truly agentive* for a proposition ϕ when:

$$\Diamond \mathbf{F}(\Diamond \mathsf{Does}_a \mathbf{F}\varphi \wedge \Diamond \mathsf{Does}_a \mathbf{F}\neg\varphi) \quad .$$

- Agent a may never exercise its power to decide whether ϕ or ¬ϕ is eventually true, but there is a history and a moment where it does.

- In fact, if the billiard ball and the mouse are moving towards each other, only the mouse can avoid contact:

$$b \rightsquigarrow m \wedge m \rightsquigarrow b \rightarrow \neg\Diamond \mathsf{Does}_b \mathbf{F}\neg EC(b,m) \wedge \Diamond \mathsf{Does}_m \mathbf{G}\neg EC(m,b)$$

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

Thank you for your attention!

Some Relevant Publications

- 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.
- 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
- 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.
- 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.
- M Eppe, E Maclean, R Confalonieri, O Kutz, M Schorlemmer, E Plaza, K-U Kühnberger: "**A Computational Framework for Conceptual Blending**", Artificial Intelligence, 2017.
- O. Kutz, N. Troquard, M. M. Hedblom, and D. Porello: "**The Mouse and the Ball: Towards a cognitively-based and ontologically grounded logic of agency**", FOIS 2018, Cape Town, South Africa, IOS Press, 2017.