

Reasoning and Consciousness

Teaching a Theorem Prover to let its Mind Wander

Claudia Schon, Ulrich Furbach



**How I lost my OWL:
Retracting Knowledge from *EL* Concepts**

Masterarbeit

zur Erlangung des Grades einer Master of Science (MSc.)
im Studiengang Literaturwissenschaft

vorgelegt von
Holger Johannes Heinz



Bernhard Baars

- Global Workspace Theorie
- Theatre metaphor

- Consciousness is a gateway to vast domains of knowledge and control
- we can create access to any part of the brain using consciousness

„Consciousness may be considered as the gateway to these unconscious sources of knowledge.“

Teaching a theorem prover to let its mind wander...

What's that good for?

Choice of Plausible Alternatives Challenge (COPA)

Choice of Plausible Alternatives Challenge [Roemmele et al., 2011]:

1: My body cast a shadow over the grass. What was the CAUSE of this?

Alternative 1: The sun was rising.

Alternative 2: The grass was cut.

Cause Category

13: The pond froze over for the winter. What happened as a RESULT?

Alternative 1: People skated on the pond.

Alternative 2: People brought boats to the pond.

Result Category

Chains of Thoughts

13: The pond froze over for the winter. What happened as a RESULT?

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Chains of Thoughts



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Chains of Thoughts

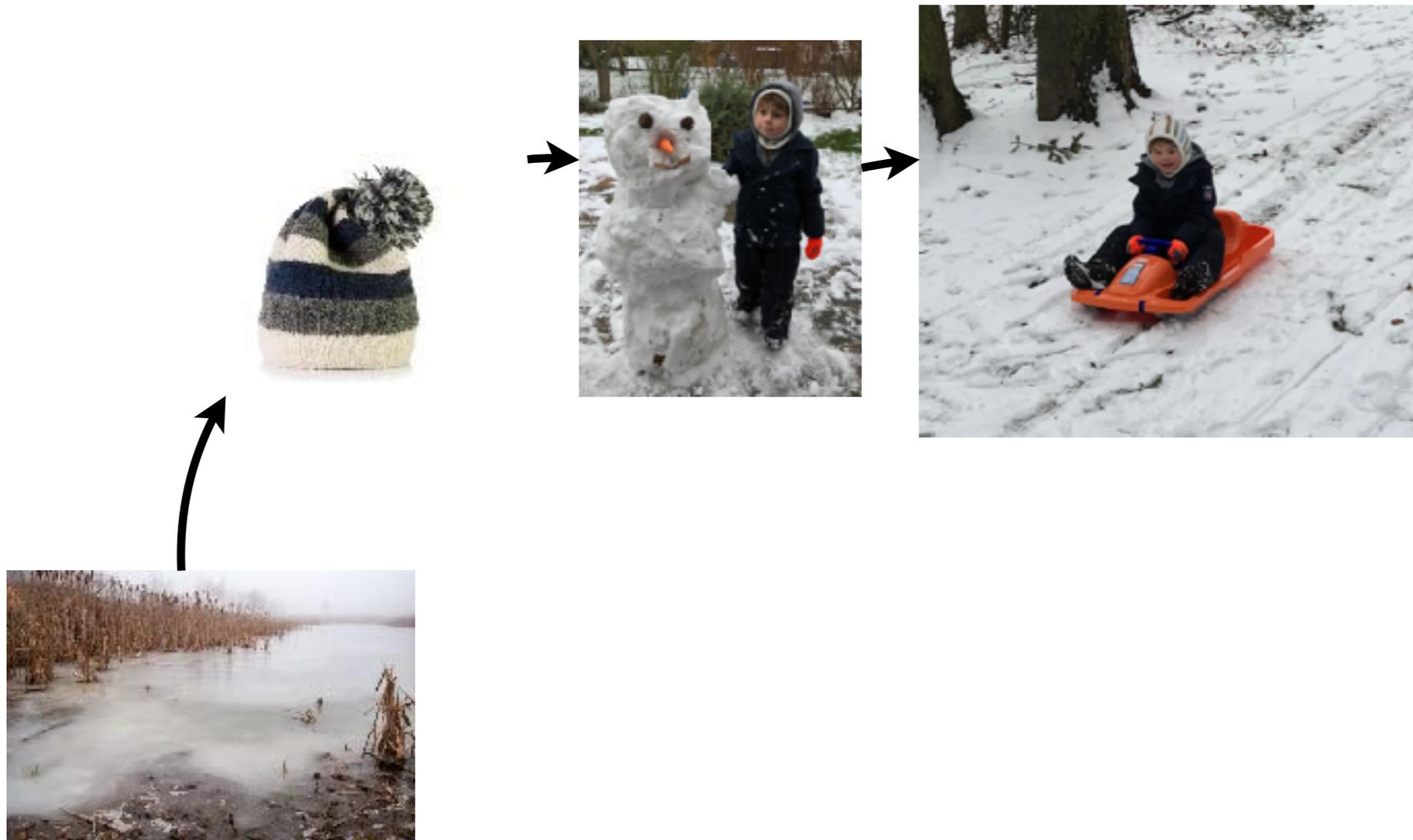


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Chains of Thoughts

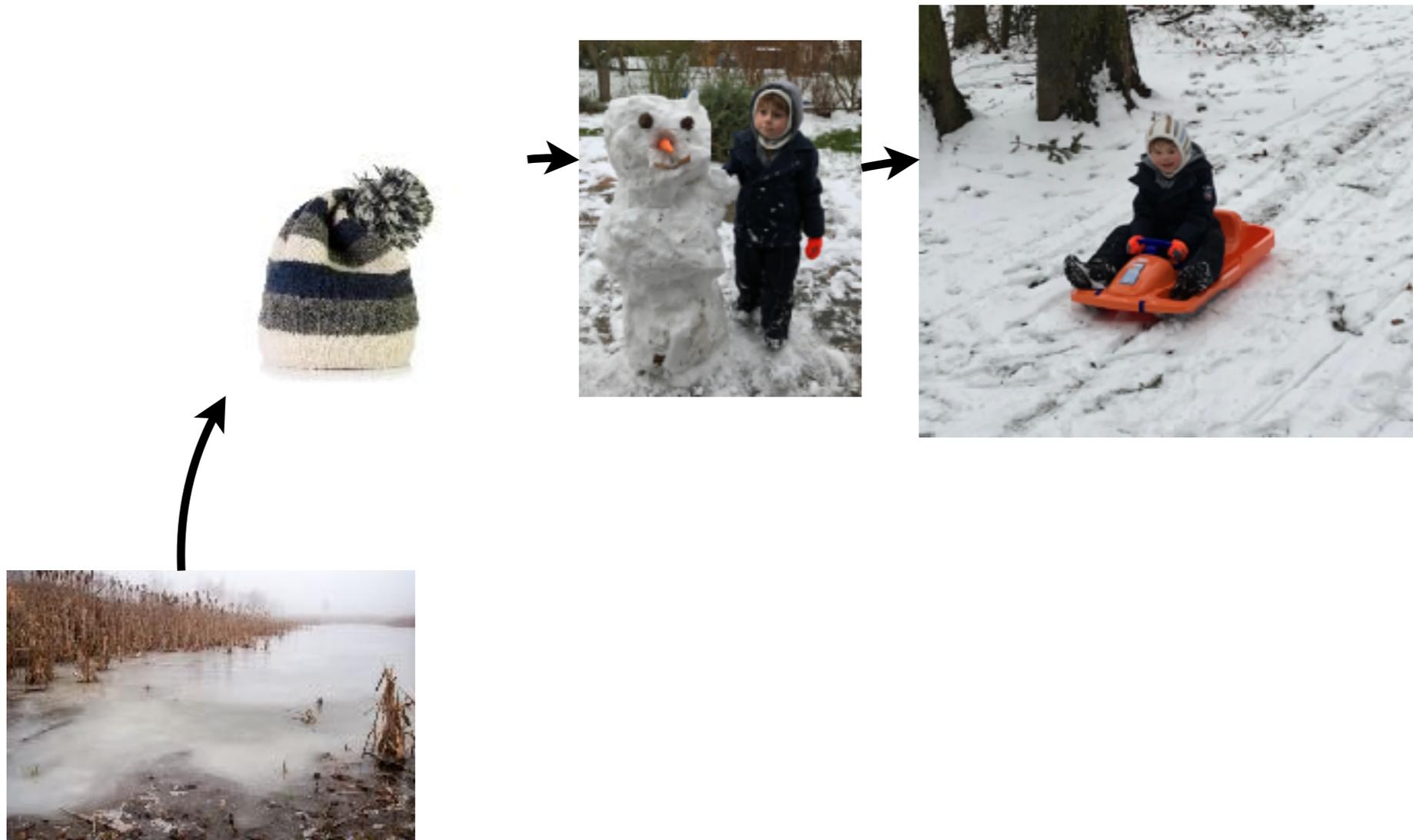


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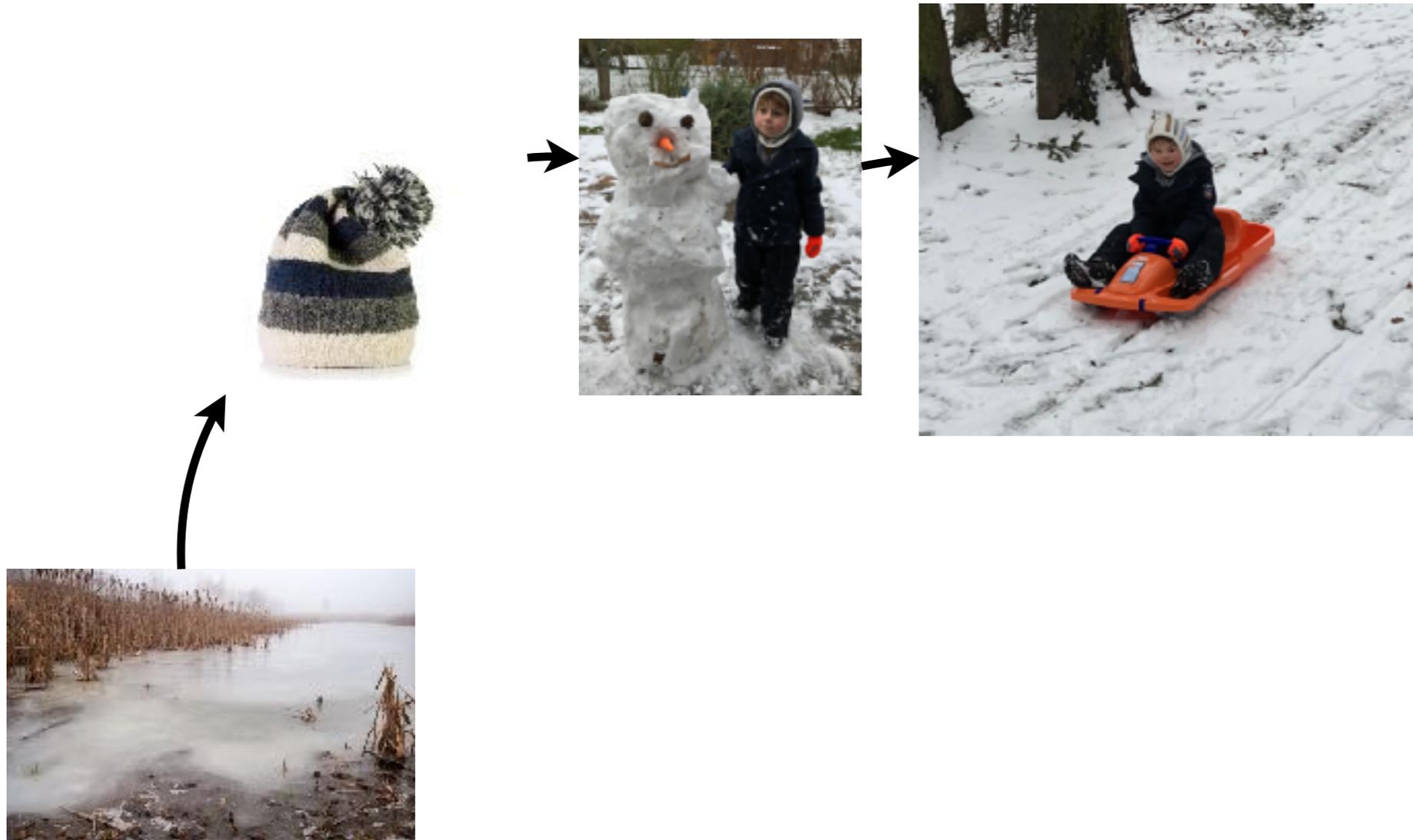


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Distance to skate and boat?

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Word Embeddings

Distance to skate and boat?

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Word Embeddings

Distance to skate and boat?
Closer to skate!

13: The pond froze over for the winter. What happened as a RESULT?

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Chains of Thoughts



Word Embeddings

Distance to skate and boat?
Closer to skate!
Choose alternative 1!

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Word Embeddings

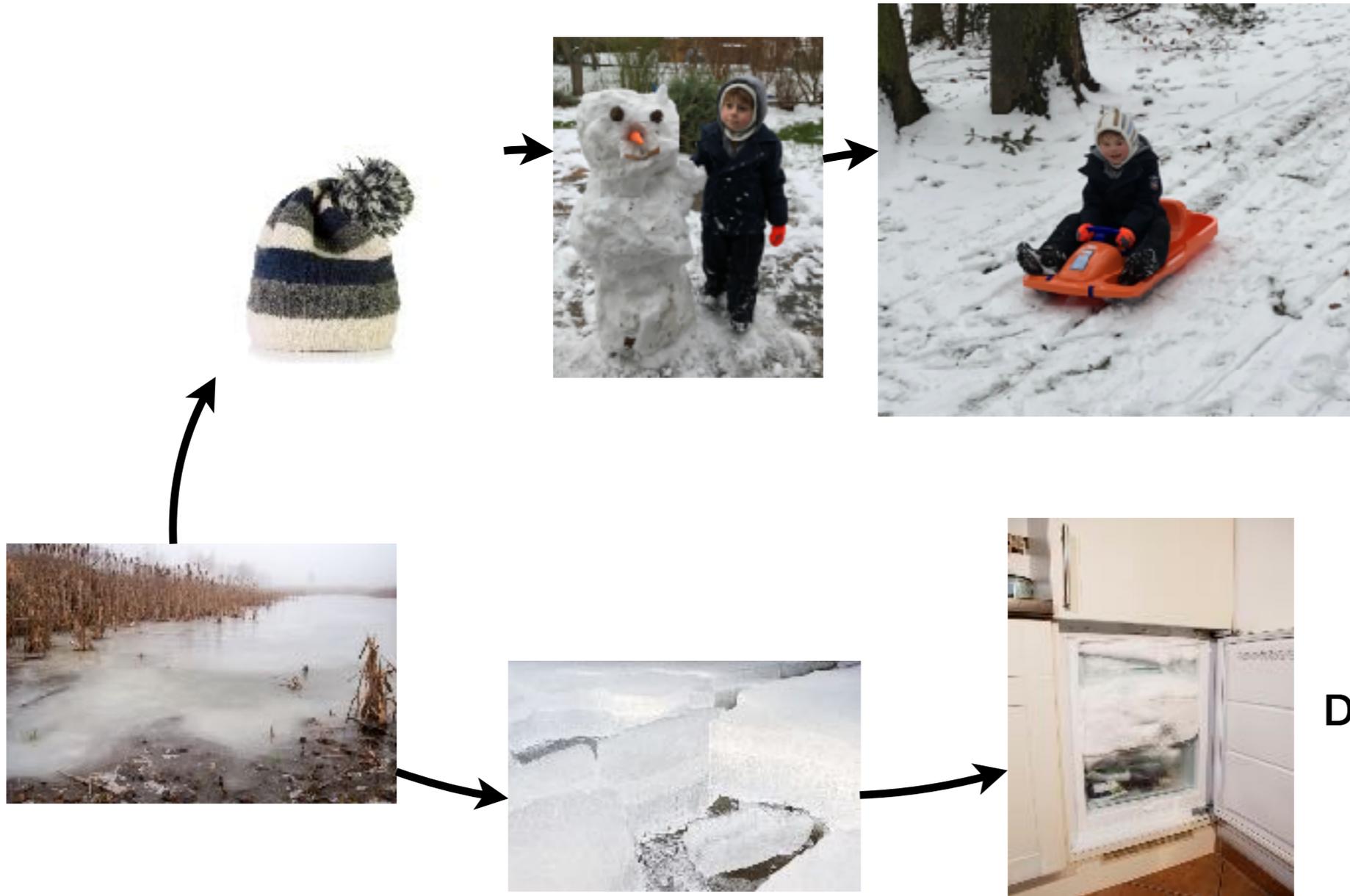
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Word Embeddings

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Distance to skate and boat?

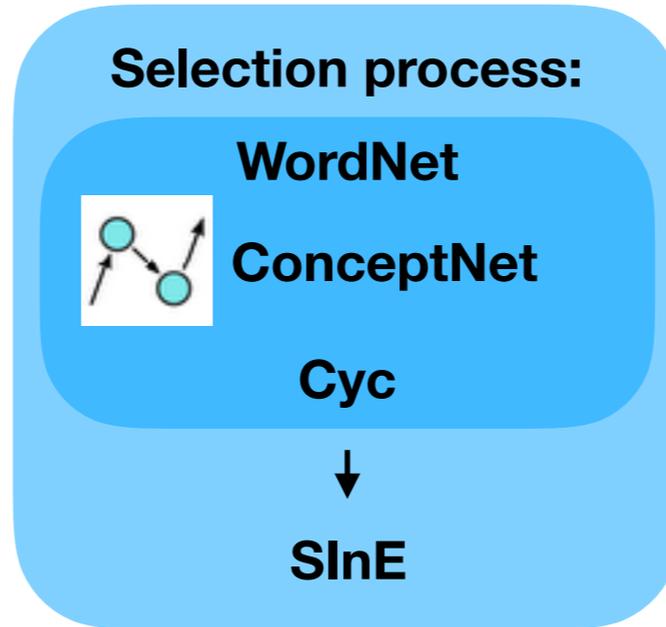
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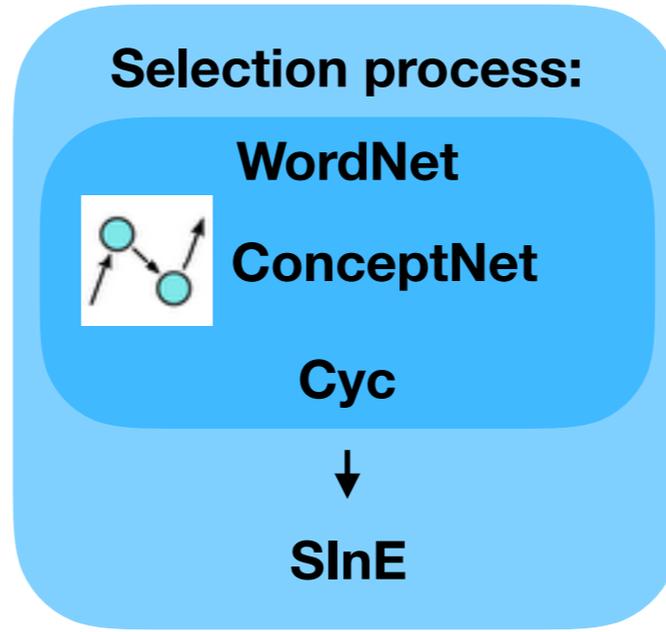
Alternative 2: People brought boats to the pond.

**FOL
Formula**

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Formula**

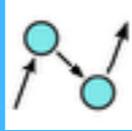


**FOL
Formula**



Selection process:

WordNet



ConceptNet

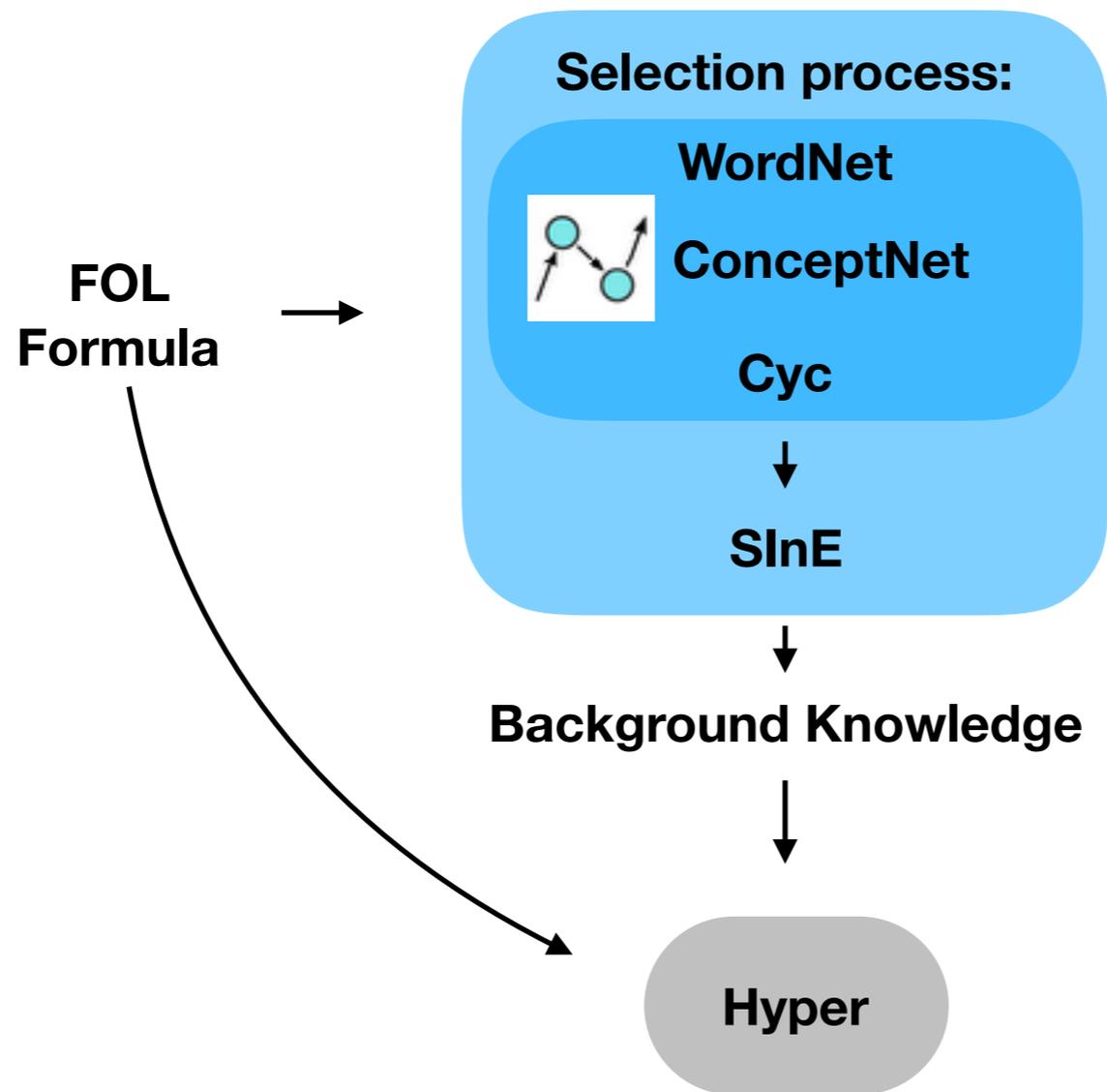
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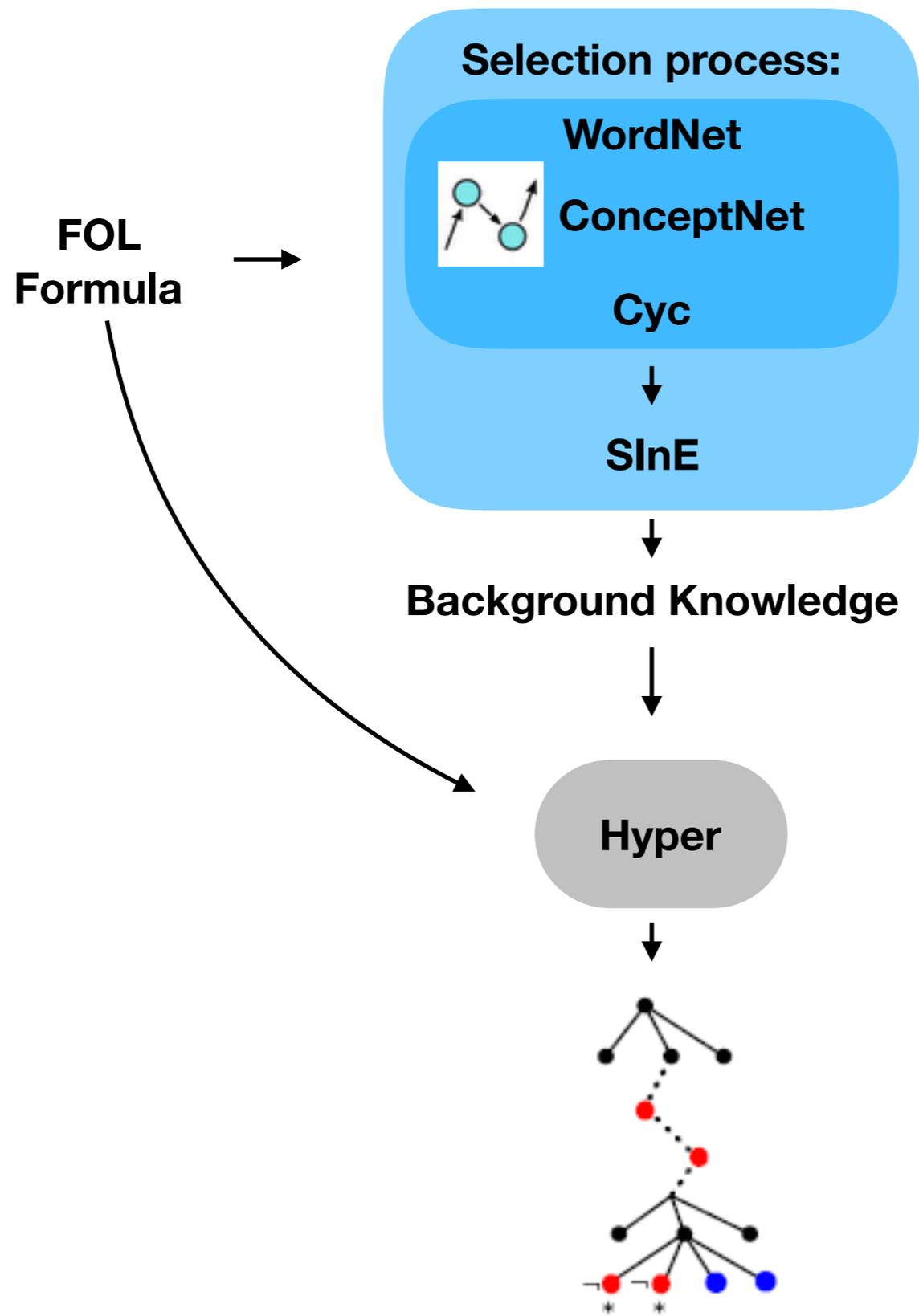


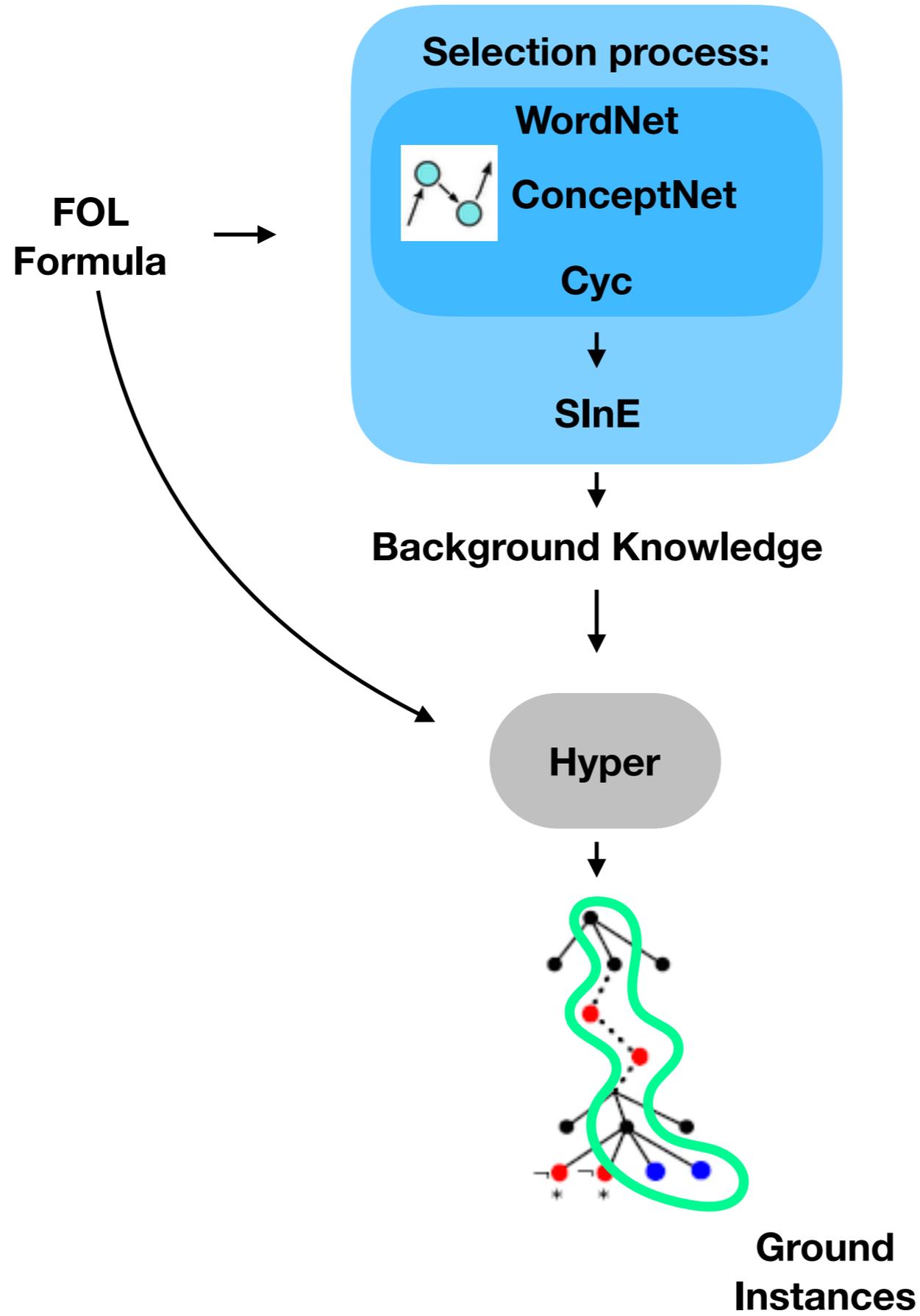
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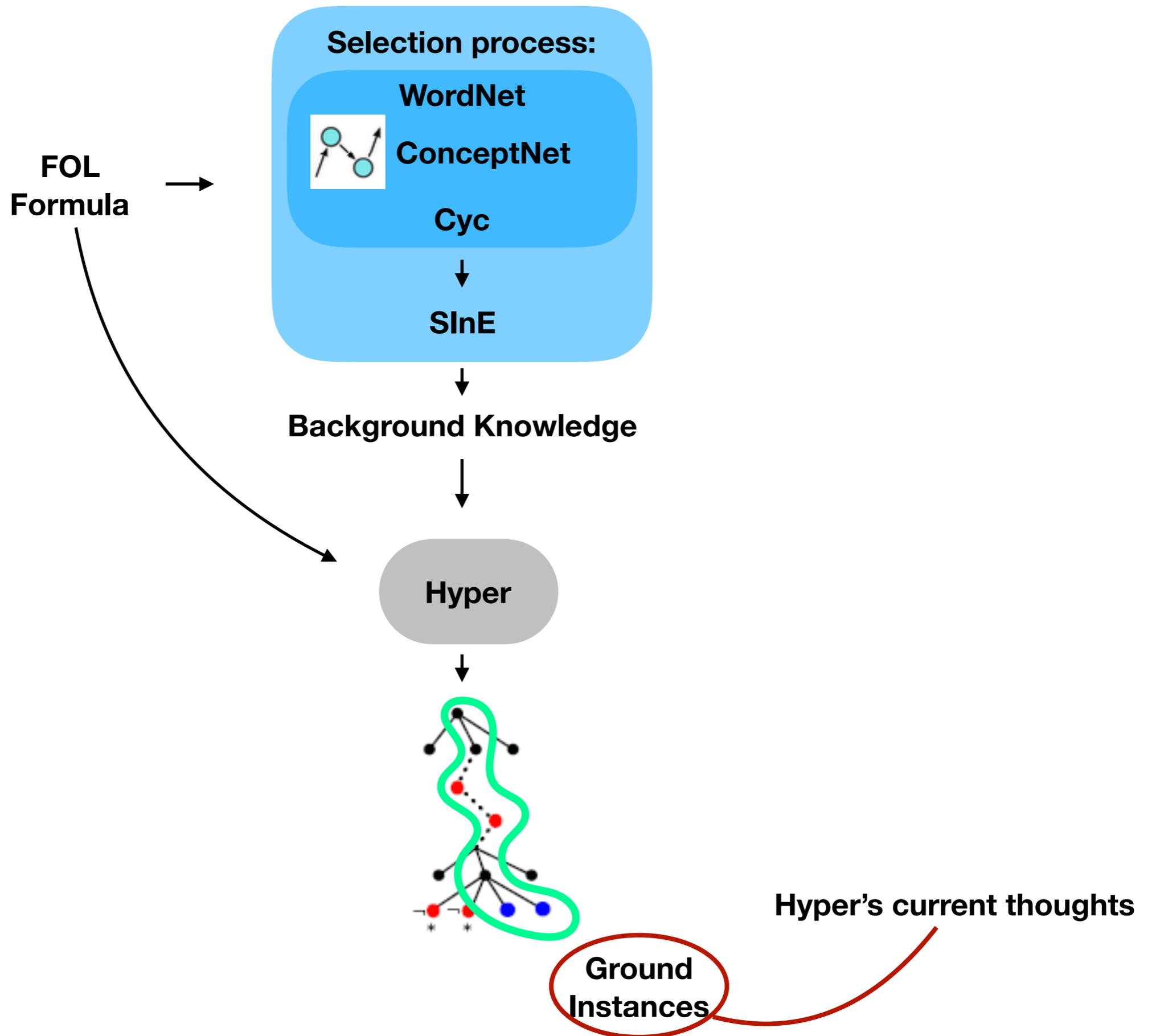


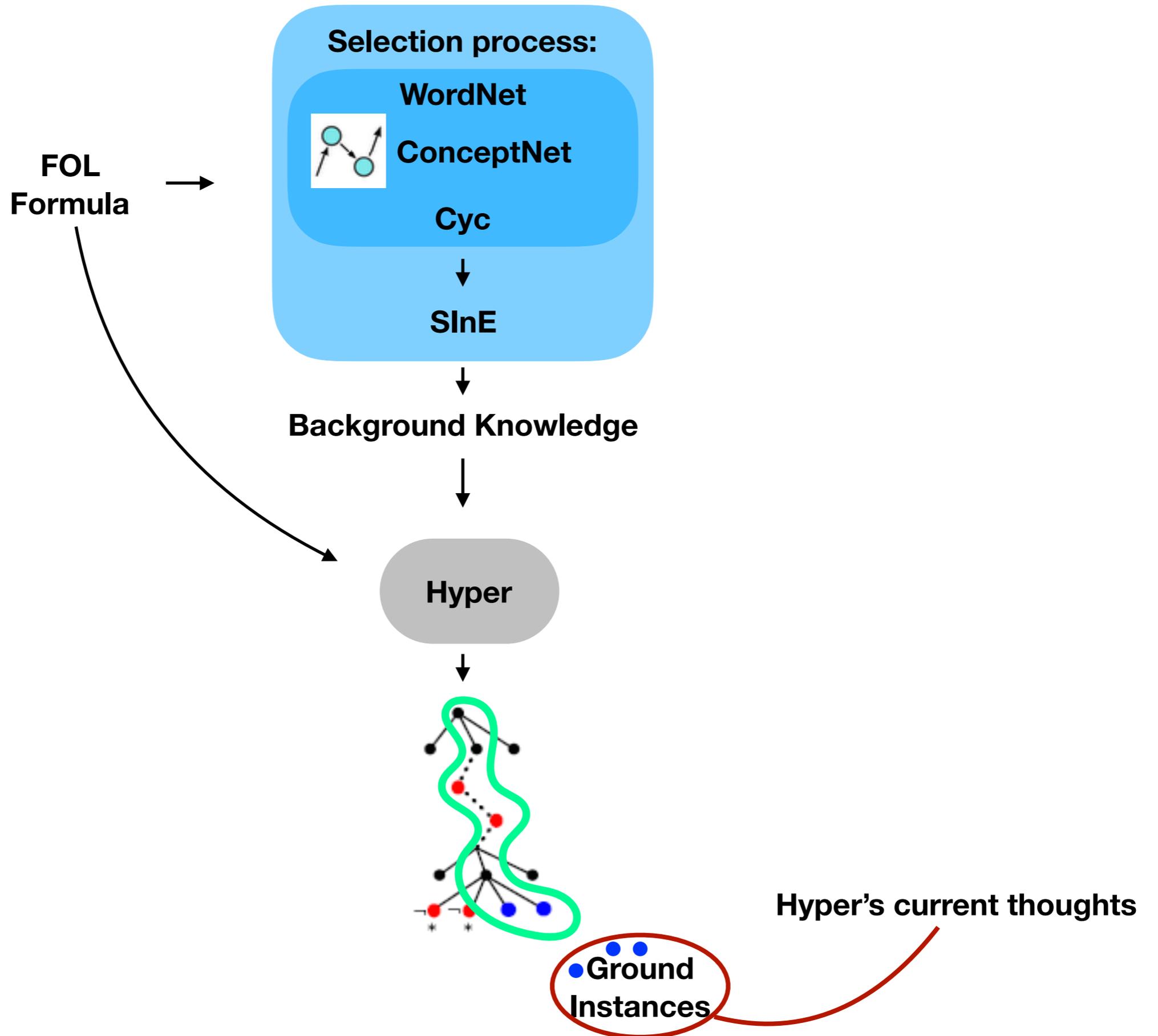
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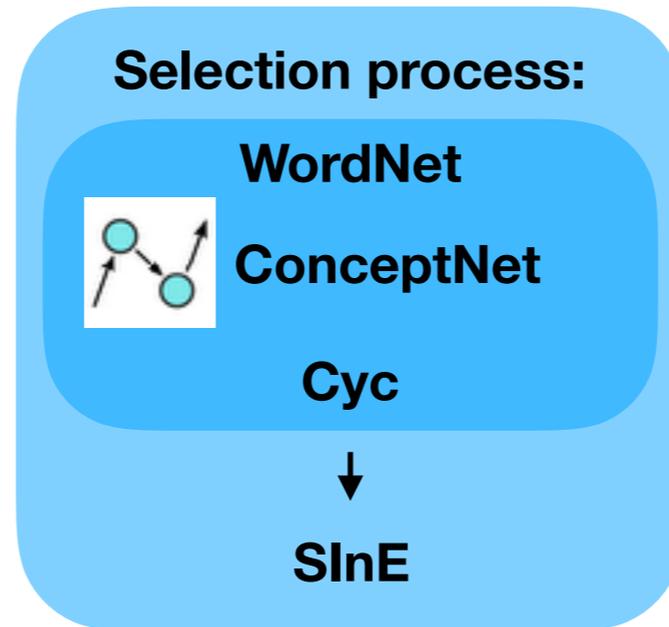




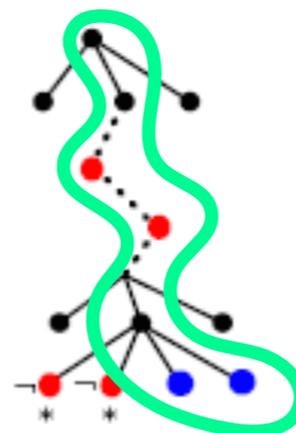




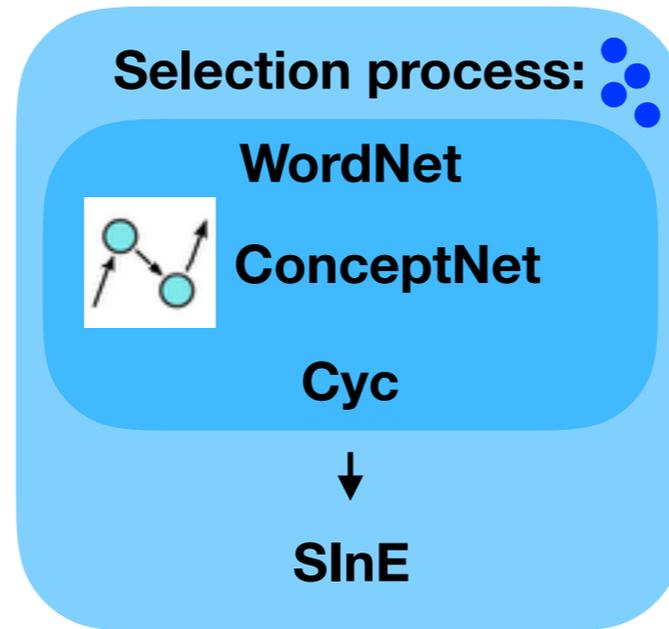




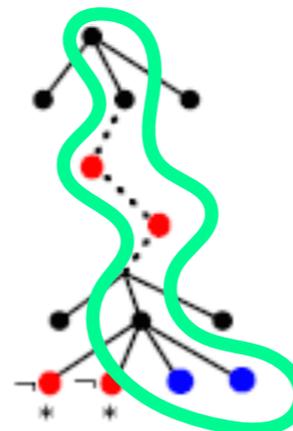
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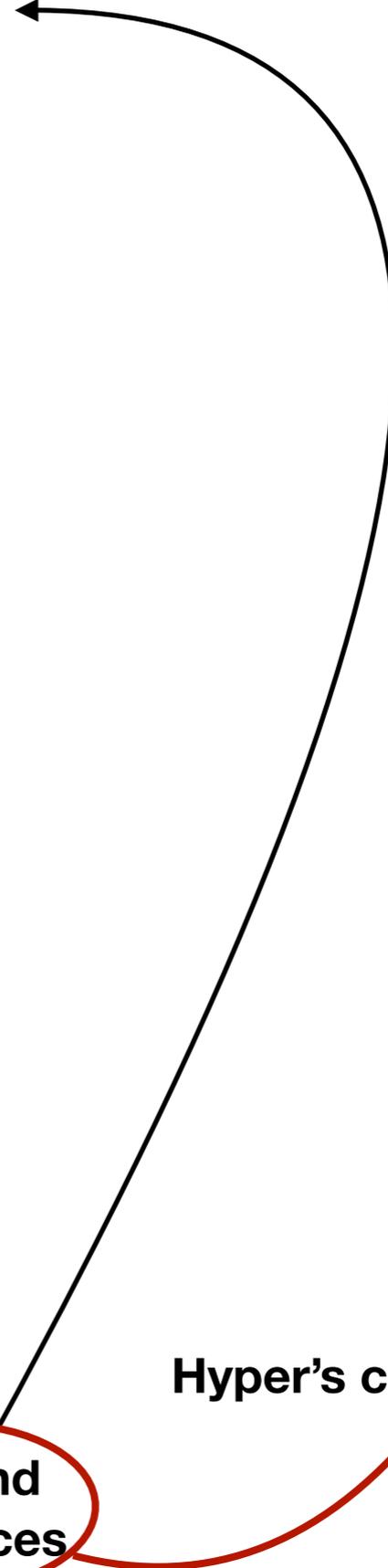
Hyper's current thoughts

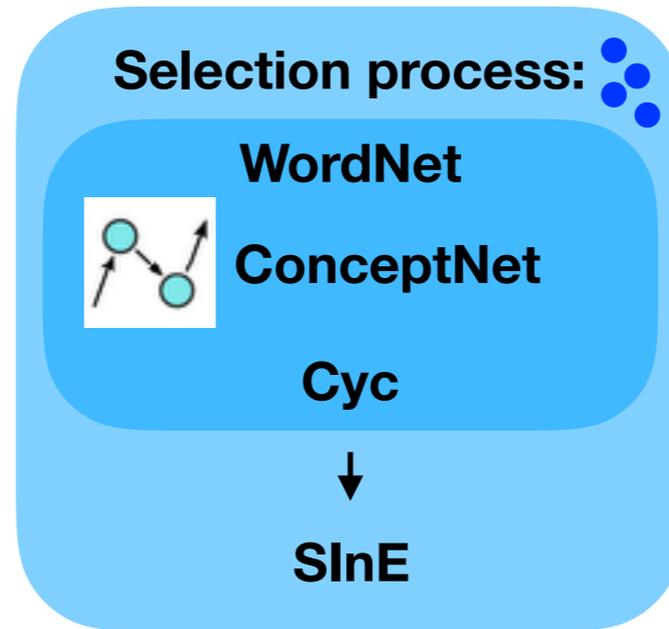


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Background Knowledge

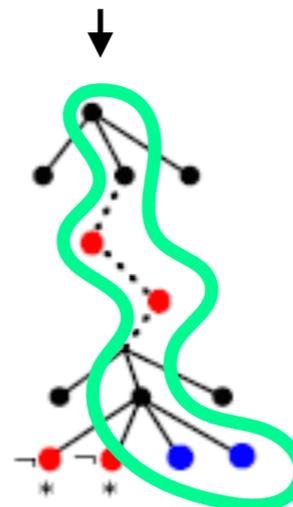


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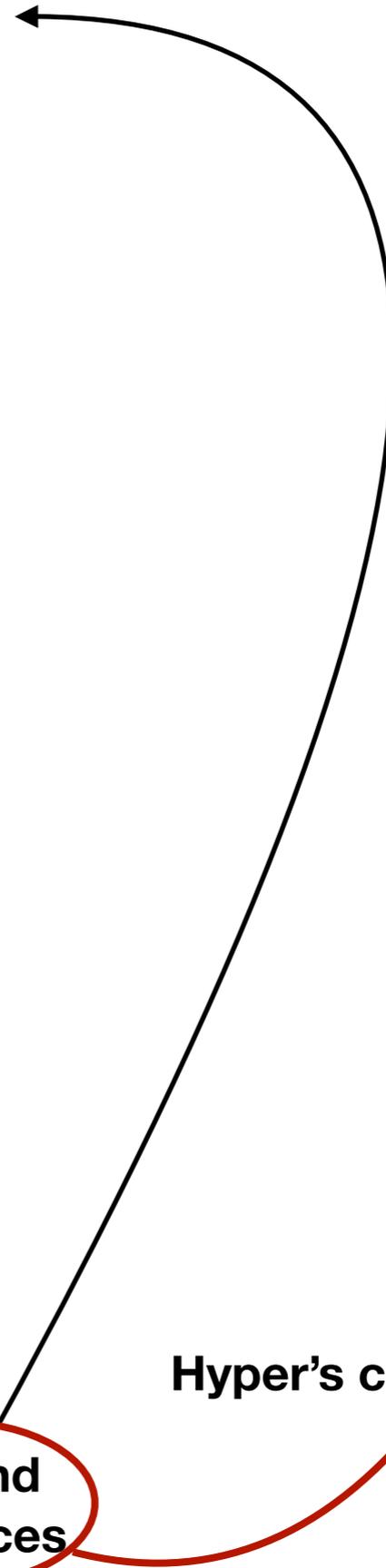


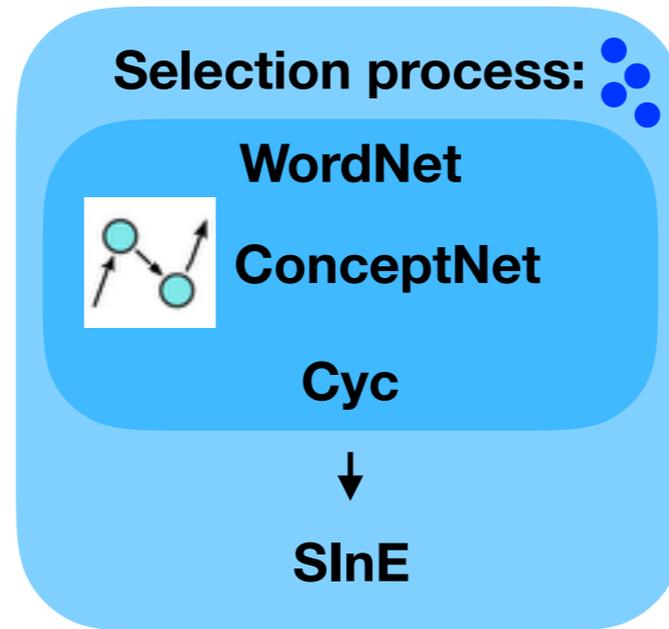


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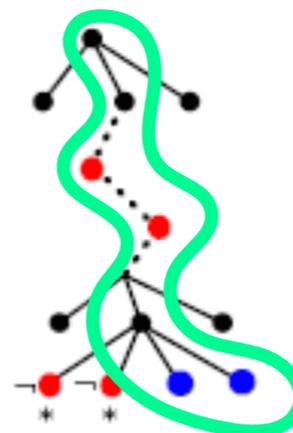


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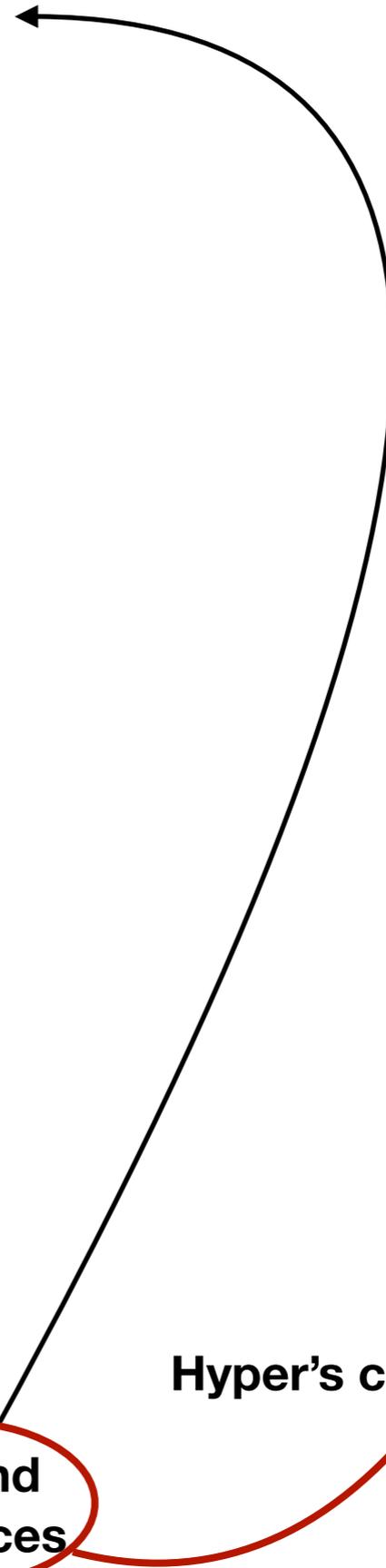


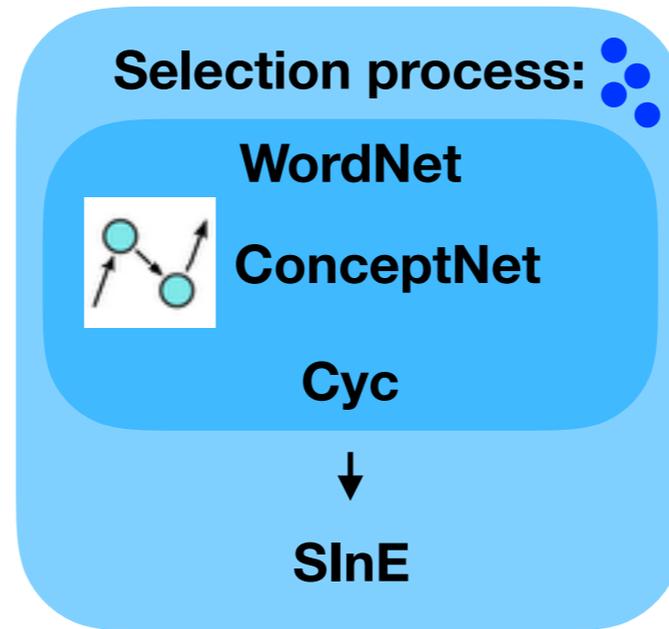


Background Knowledge



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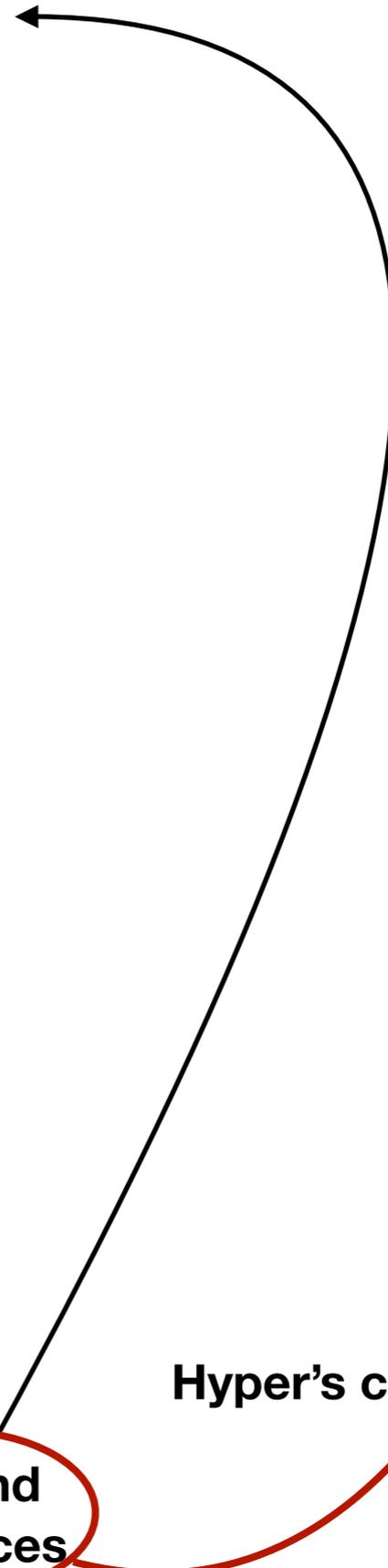


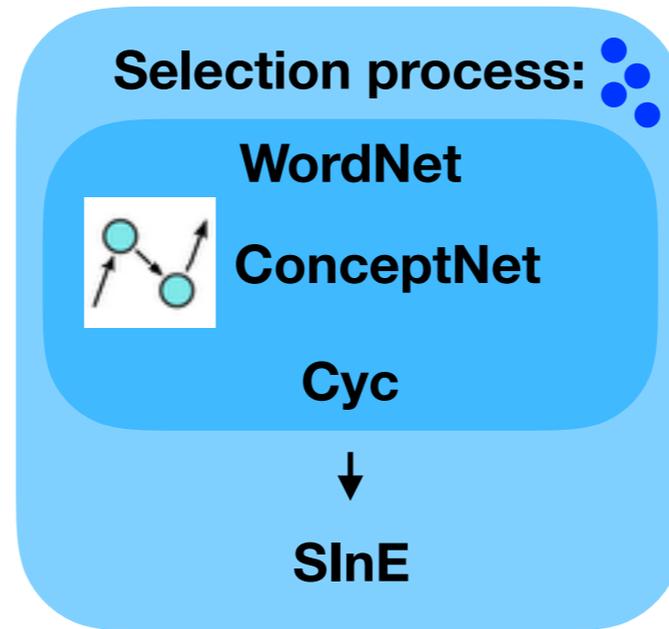
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Background Knowledge



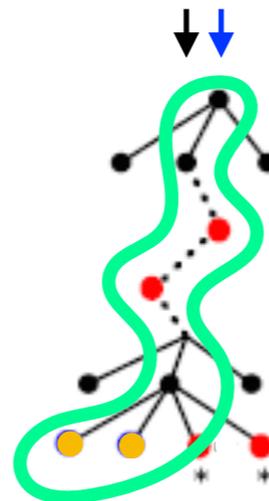
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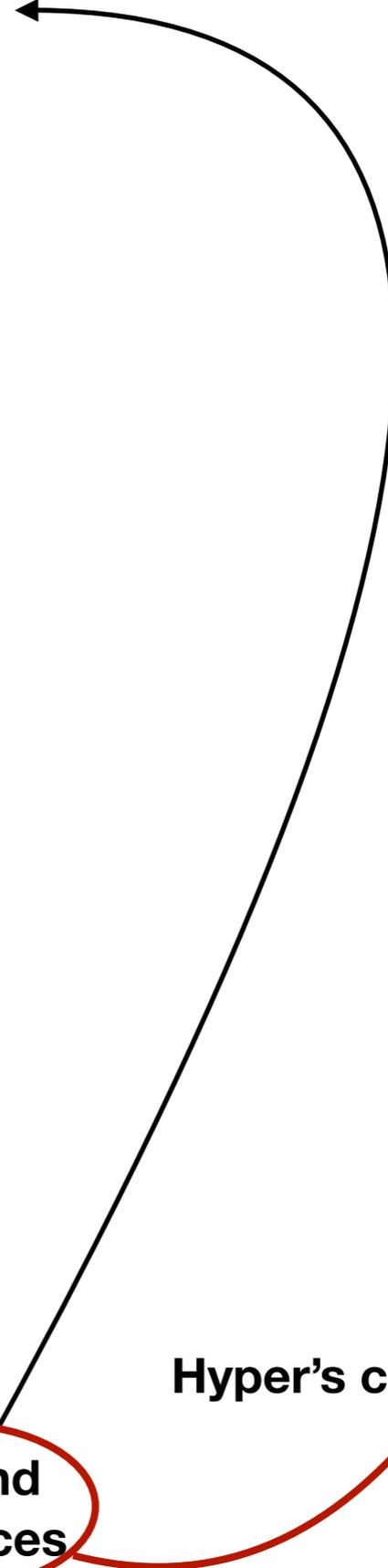


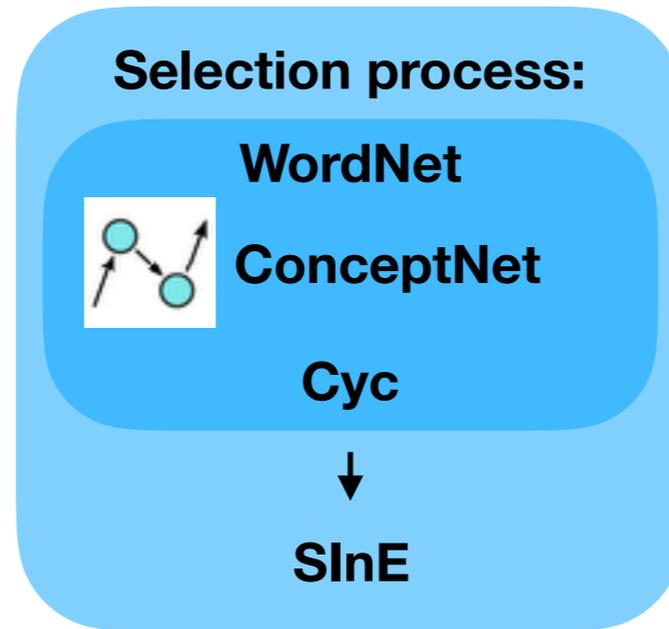
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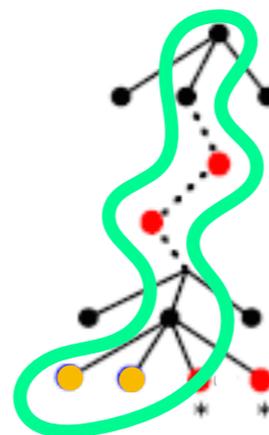


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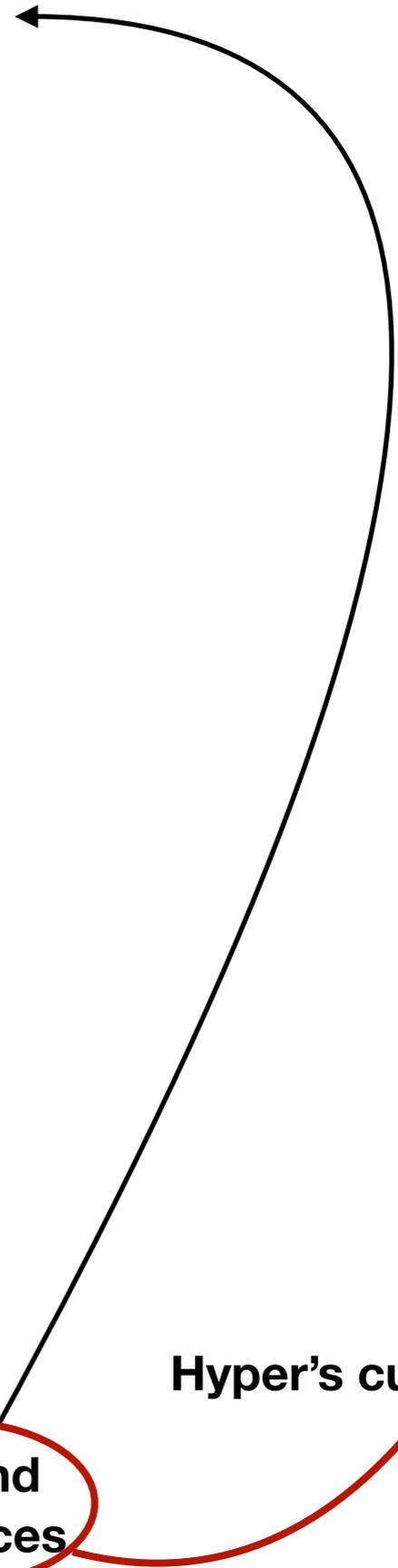


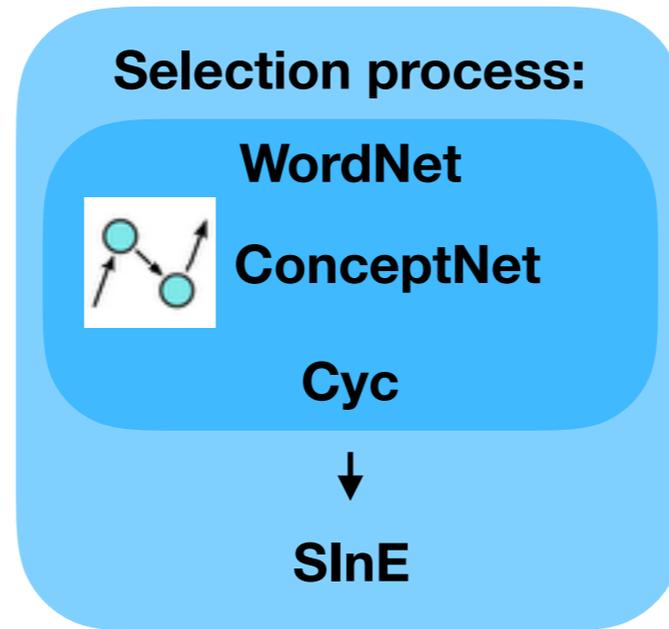
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Background Knowledge



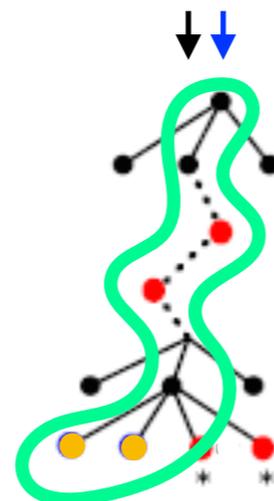
Ground Instances

Hyper's current thoughts

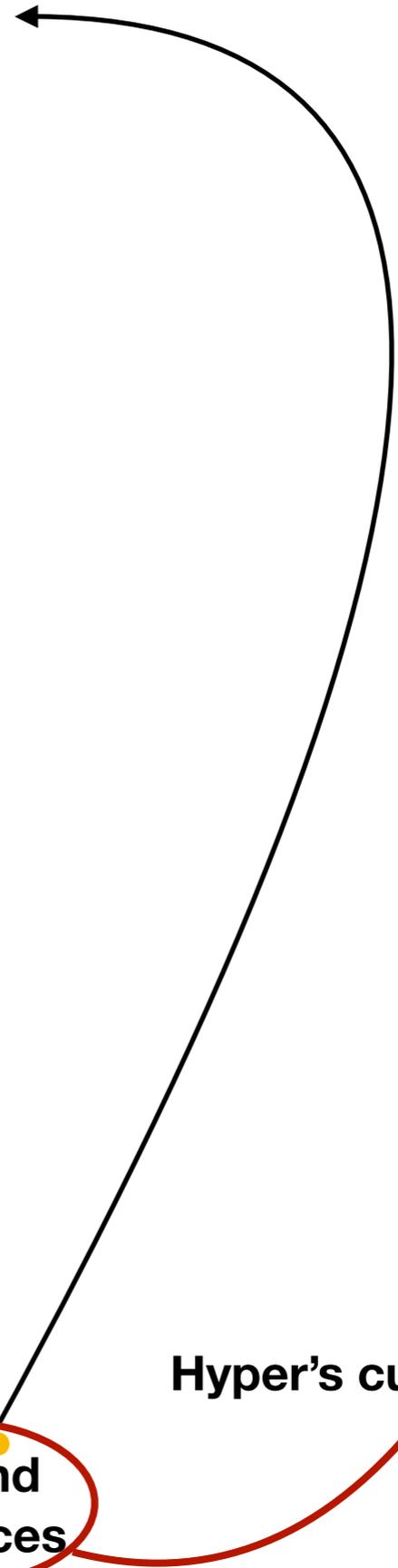


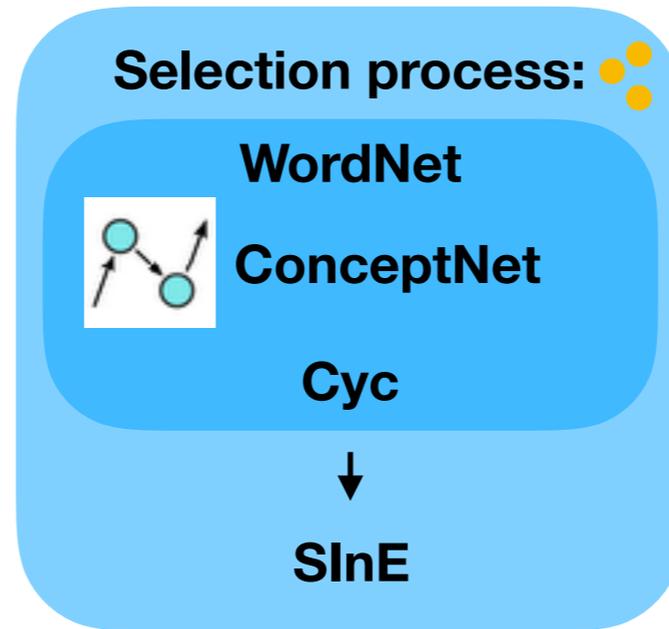


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Background Knowledge

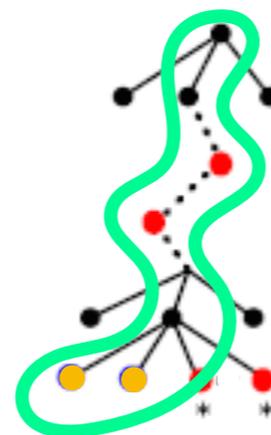


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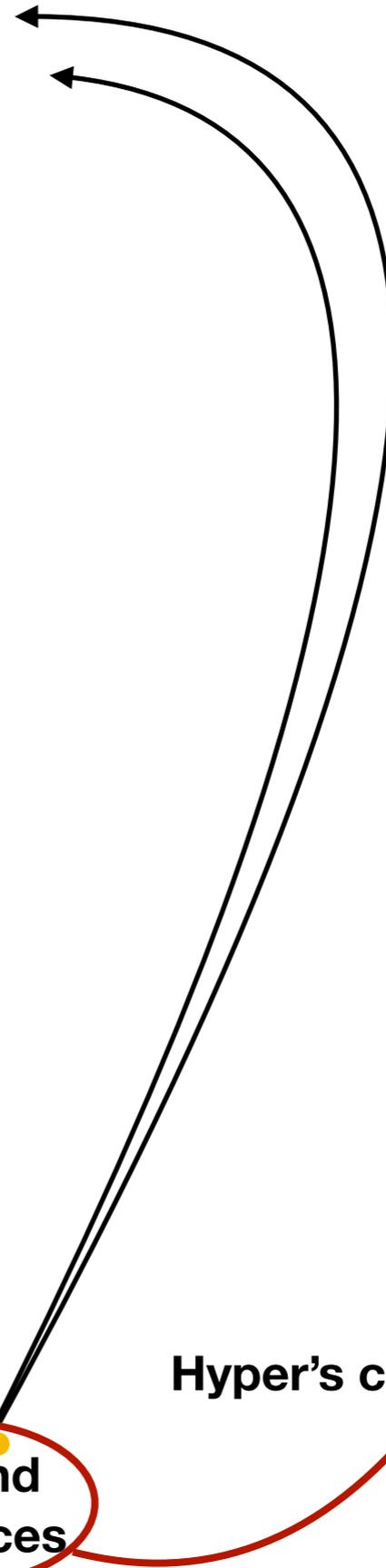


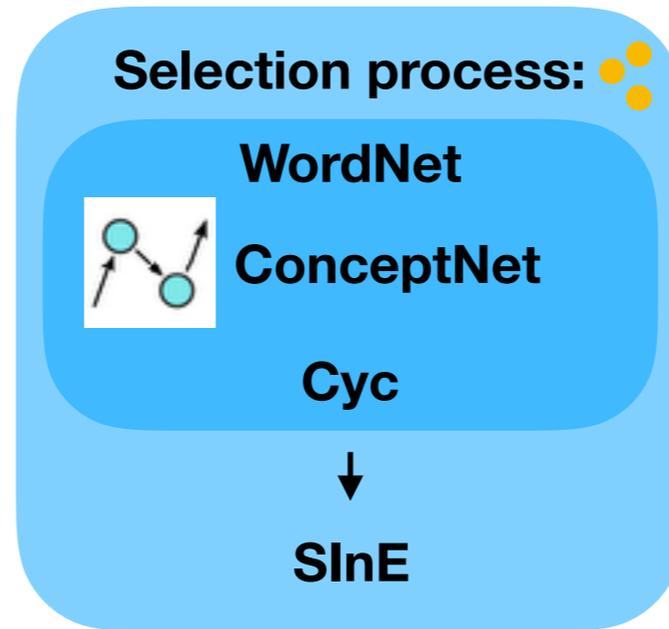


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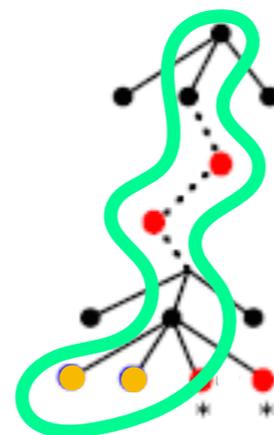


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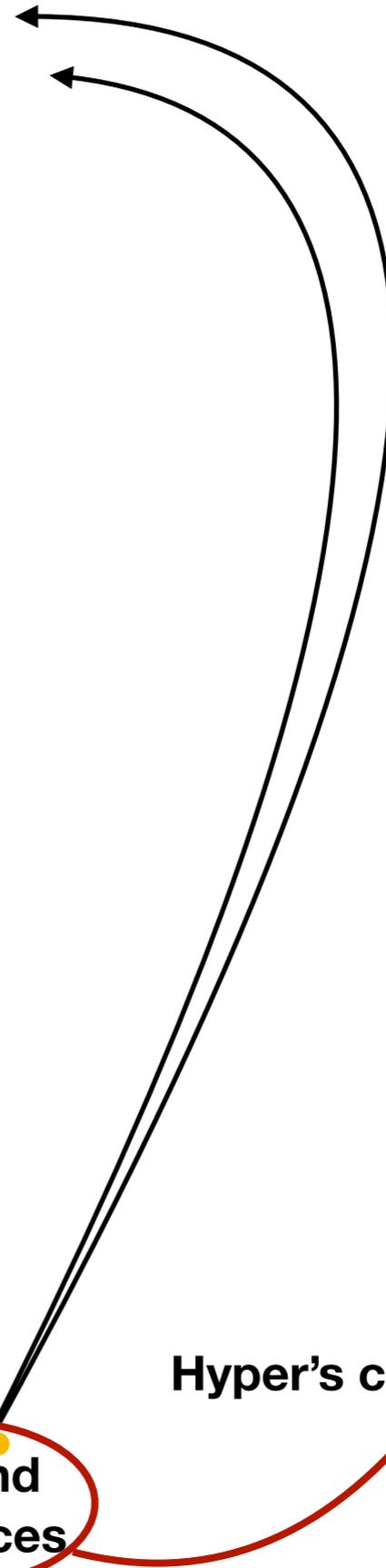


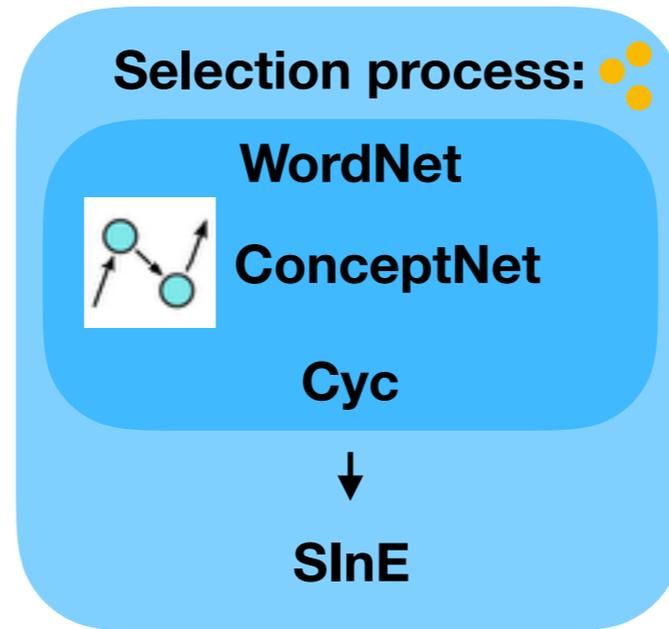


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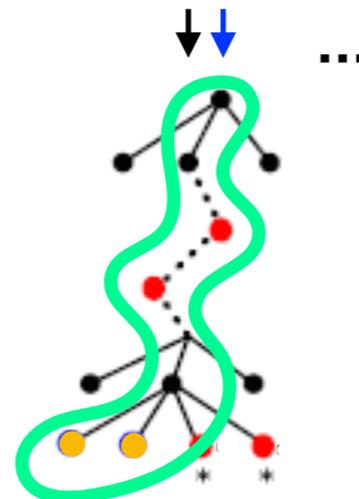
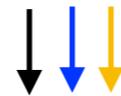


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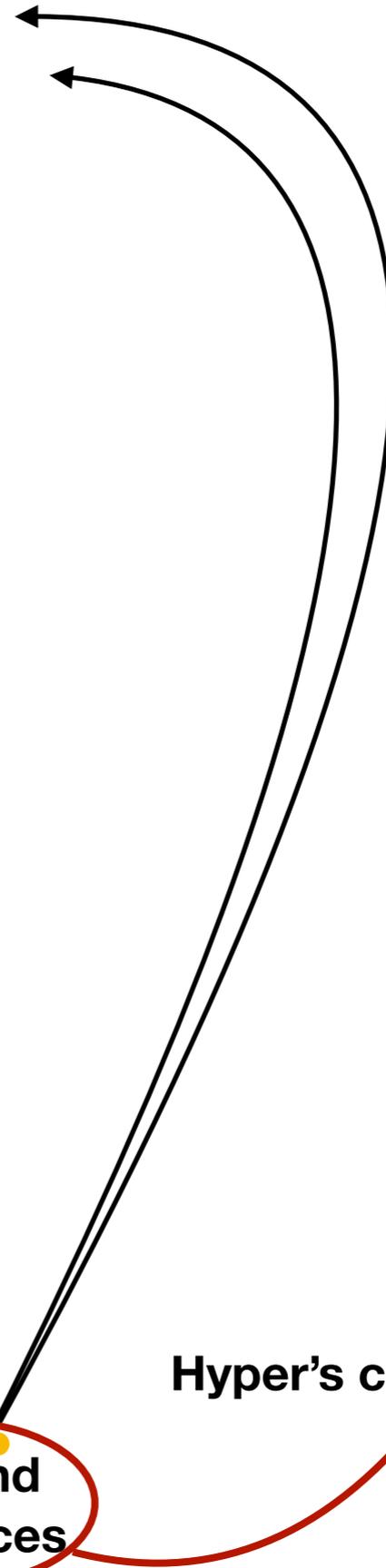




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Background Knowledge



Hyper's current thoughts



Gathering Background Knowledge

1: My body cast a shadow over the grass. What was the CAUSE of this?

Alternative 1: The sun was rising.

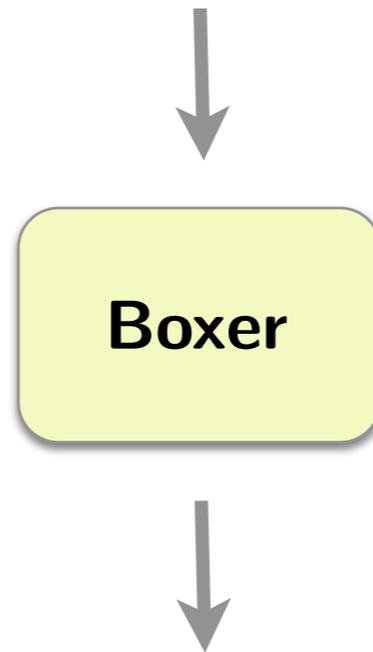
Alternative 2: The grass was cut.

Gathering Background Knowledge

1: My body cast a shadow over the grass. What was the CAUSE of this?

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$$\begin{aligned} &\exists A, B((n1grass(A) \wedge n1sun(B)) \wedge \exists C, D, E((r1over(C, A) \wedge \\ &(r1Theme(C, D) \wedge (r1Actor(C, E) \wedge (v1cast(C) \wedge (n1shadow(D) \wedge \\ &(n1body(E) \wedge (r1of(E, D) \wedge n1person(D)))))))))) \wedge \\ &\exists F((r1Actor(F, B) \wedge v1rise(F)) \wedge \exists G(r1Theme(G, A) \wedge v1cut(G)))) \end{aligned}$$

Gathering Background Knowledge

FO-representation of COPA problem:

$\exists A, B((n1grass(A) \wedge n1sun(B)) \wedge \exists C, D, E((r1over(C, A) \wedge$
 $(r1Theme(C, D) \wedge (r1Actor(C, E) \wedge (v1cast(C) \wedge (n1shadow(D) \wedge$
 $(n1body(E) \wedge (r1of(E, D) \wedge n1person(D)))))))) \wedge$
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Background
Knowledge:
OpenCyc

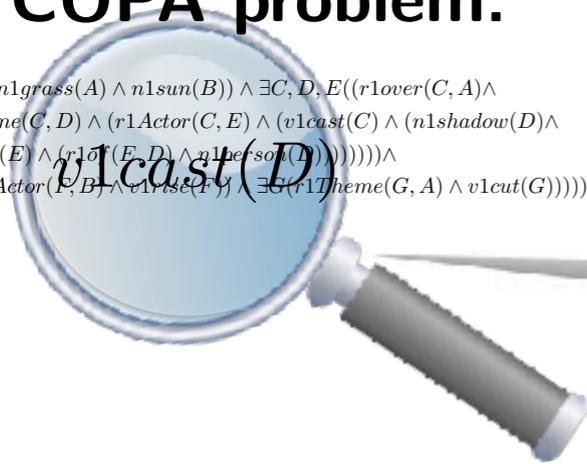


Gathering Background Knowledge

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Background
Knowledge:
OpenCyc



Gathering Background Knowledge

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Background Knowledge:

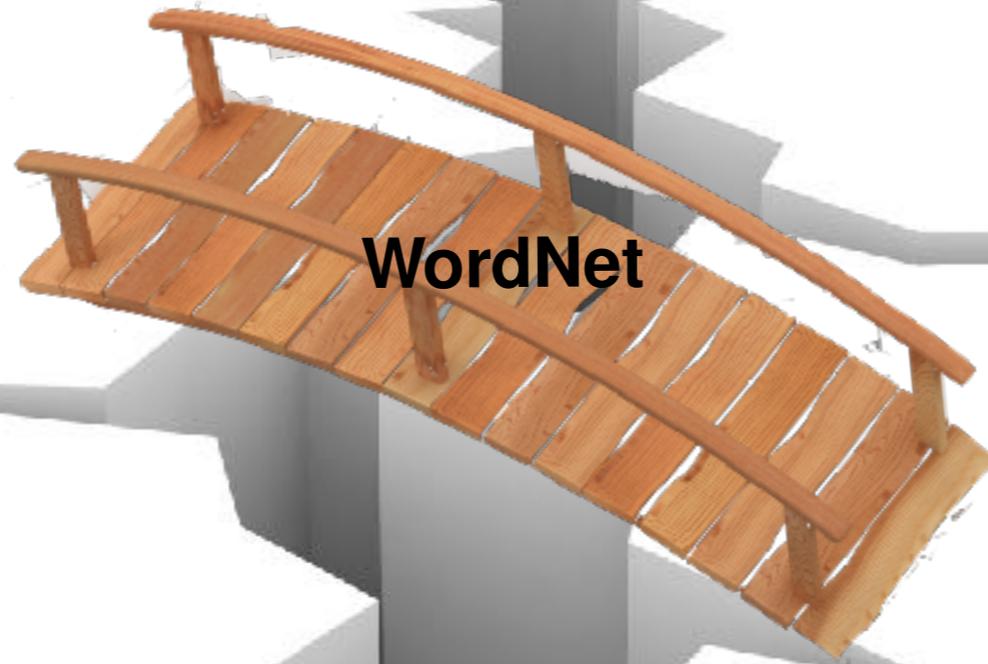
OpenCyc
project(X)



Gathering Background Knowledge

FO-representation of COPA problem:

$\exists A, B((n1grass(A) \wedge n1sun(B)) \wedge \exists C, D, E((r1lover(C, A) \wedge (r1Theme(C, D) \wedge (r1Actor(C, E) \wedge (v1cast(C) \wedge (n1shadow(D) \wedge (n1body(E) \wedge (r1\sigma^*(E, D) \wedge n1person(D)))))))) \wedge \exists F((r1Actor(F, B) \wedge v1rise(F)) \wedge \exists G(r1Theme(G, A) \wedge v1cut(G))))))$



Background Knowledge:

OpenCyc
project(X)



WordNet Search - 3.1

- [WordNet home page](#) - [Glossary](#) - [Help](#)

Word to search for:

Display Options:

Key: "S:" = Show Synset (semantic) relations, "W:" = Show Word (lexical) relations

Display options for sense: (gloss) "an example sentence"

Noun

- [S:](#) (n) [cast](#), [cast of characters](#), [dramatis personae](#) (the actors in a play)
- [S:](#) (n) [mold](#), [mould](#), [cast](#) (container into which liquid is poured to create a given shape when it hardens)
- [S:](#) (n) [cast](#), [mold](#), [mould](#), [stamp](#) (the distinctive form in which a thing is made) "*pottery of this cast was found throughout the region*"
- [S:](#) (n) [form](#), [shape](#), [cast](#) (the visual appearance of something or someone) "*the delicate cast of his features*"
- [S:](#) (n) [cast](#), [plaster cast](#), [plaster bandage](#) (bandage consisting of a firm covering (often made of plaster of Paris) that immobilizes broken bones while they heal)
- [S:](#) (n) [cast](#), [casting](#) (object formed by a mold)
- [S:](#) (n) [cast](#), [roll](#) (the act of throwing dice)
- [S:](#) (n) [casting](#), [cast](#) (the act of throwing a fishing line out over the water by means of a rod and reel)
- [S:](#) (n) [hurl](#), [cast](#) (a violent throw)

Verb

- [S:](#) (v) [project](#), [cast](#), [contrive](#), [throw](#) (put or send forth) "*She threw the flashlight beam into the corner*"; "*The setting sun threw long shadows*"; "*cast a spell*"; "*cast a warm light*"

Gathering Background Knowledge

Bridging formulae

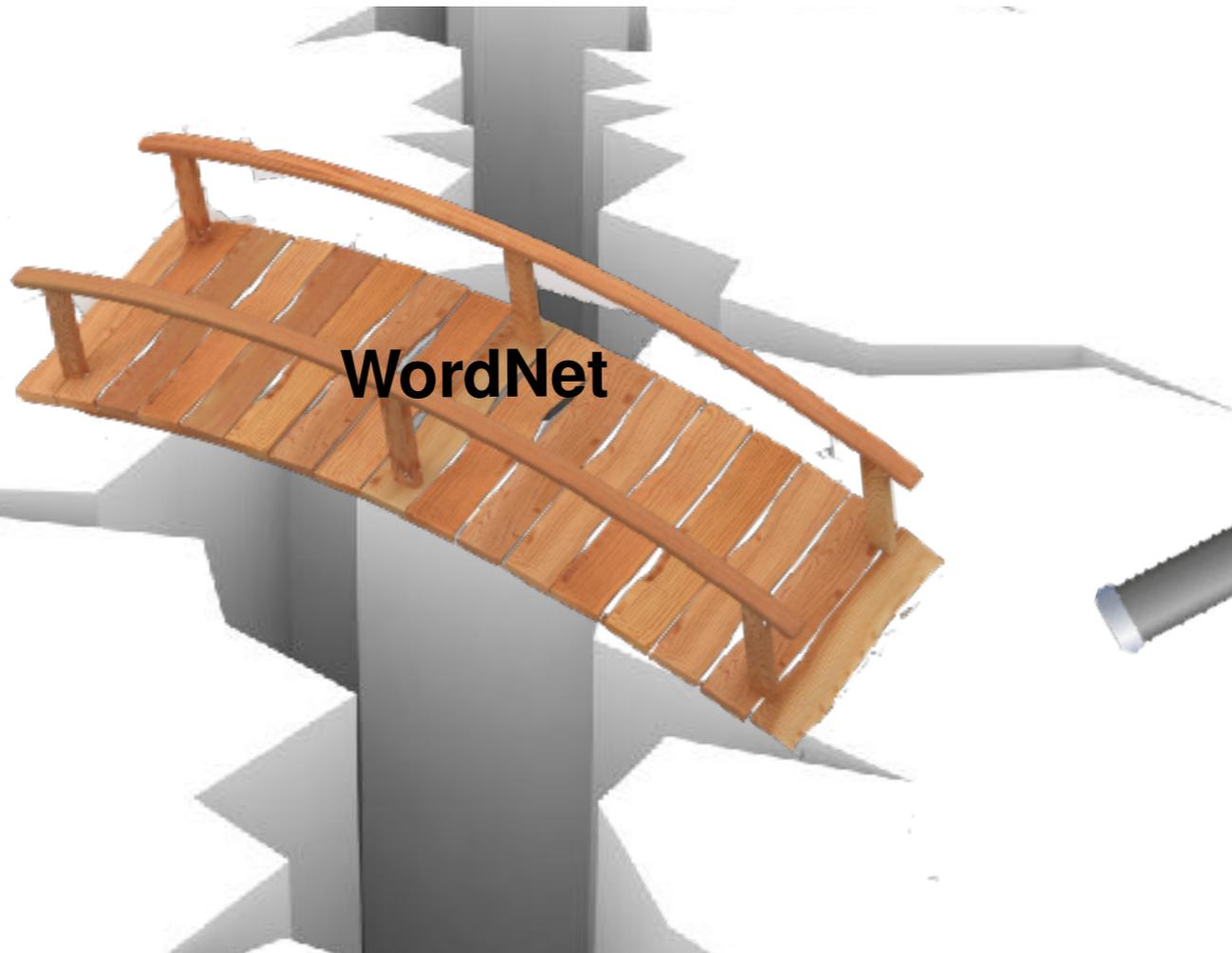
$$\forall X (v1cast(X) \leftrightarrow project(X))$$

FO-representation of COPA problem:

$\exists A, B((n1grass(A) \wedge n1sun(B)) \wedge \exists C, D, E((r1lover(C, A) \wedge$
 $(r1Theme(C, D) \wedge (r1Actor(C, E) \wedge (v1cast(C) \wedge (n1shadow(D) \wedge$
 $(n1body(E) \wedge (r1\sigma^*(E, D) \wedge n1person(D)))))) \wedge$
 $v1cast(D)) \wedge \exists F((r1Actor(F, B) \wedge v1rise(F)) \wedge \exists G((r1Theme(G, A) \wedge v1cut(G))))))$

Background Knowledge:

OpenCyc
 $project(X)$



WordNet

Gathering Background Knowledge

Bridging formulae

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 $\exists F((r1Actor(F, B) \wedge v1rise(F)) \wedge \exists G(r1Theme(G, A) \wedge v1cut(G))))$

Background
Knowledge:
OpenCyc

Gathering Background Knowledge

FO-representation of COPA problem:

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Bridging formulae

$$\forall X(v1cast(X) \leftrightarrow project(X))$$

Background
Knowledge:
OpenCyc

Gathering Background Knowledge

FO-representation of COPA problem:

$$\exists A, B((n1grass(A) \wedge n1sun(B)) \wedge \exists C, D, E((r1lover(C, A) \wedge (r1Theme(C, D) \wedge (r1Actor(C, E) \wedge (v1cast(C) \wedge (n1shadow(D) \wedge (n1body(E) \wedge (r1of(E, D) \wedge n1person(D)))))))))) \wedge \exists F((r1Actor(F, B) \wedge v1rise(F)) \wedge \exists G(r1Theme(G, A) \wedge v1cut(G))))$$

Bridging formulae

$$\forall X(v1cast(X) \leftrightarrow project(X))$$

Background
Knowledge:
OpenCyc

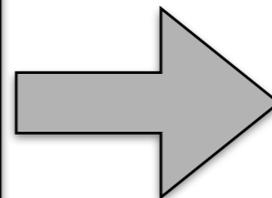
Gathering Background Knowledge

**FO-representation
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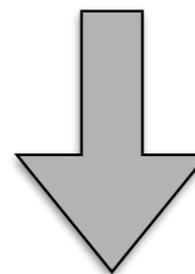
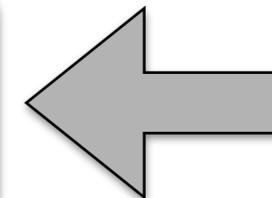
$\exists A, B((n1grass(A) \wedge n1sun(B)) \wedge \exists C, D, E((r1lover(C, A) \wedge (r1Theme(C, D) \wedge (r1Actor(C, E) \wedge (v1cast(C) \wedge (n1shadow(D) \wedge (n1body(E) \wedge (r1of(E, D) \wedge n1person(D)))))))) \wedge \exists F((r1Actor(F, B) \wedge v1rise(F)) \wedge \exists G(r1Theme(G, A) \wedge v1cut(G))))))$

Bridging formulae

$\forall X(v1cast(X) \leftrightarrow project(X))$

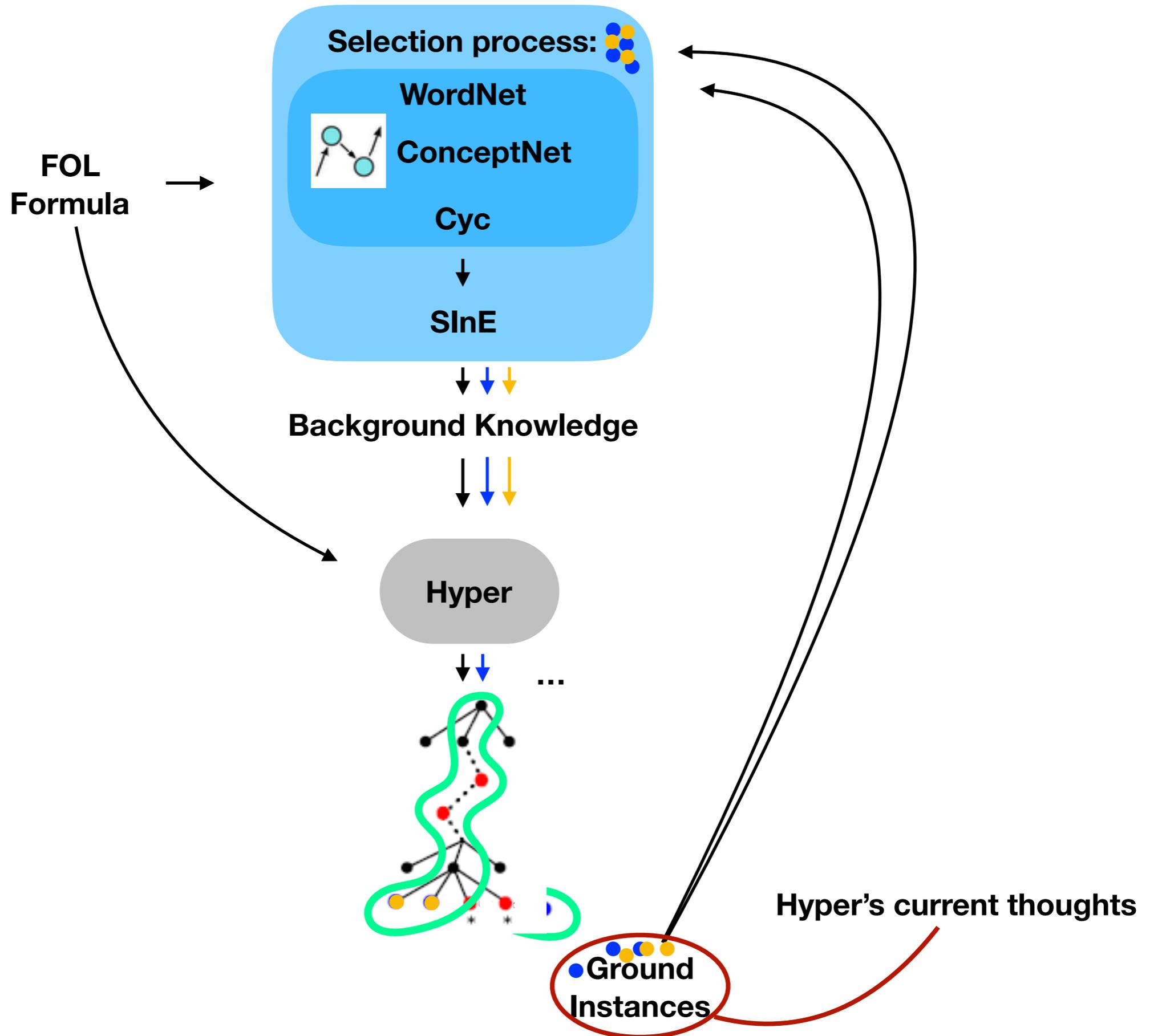


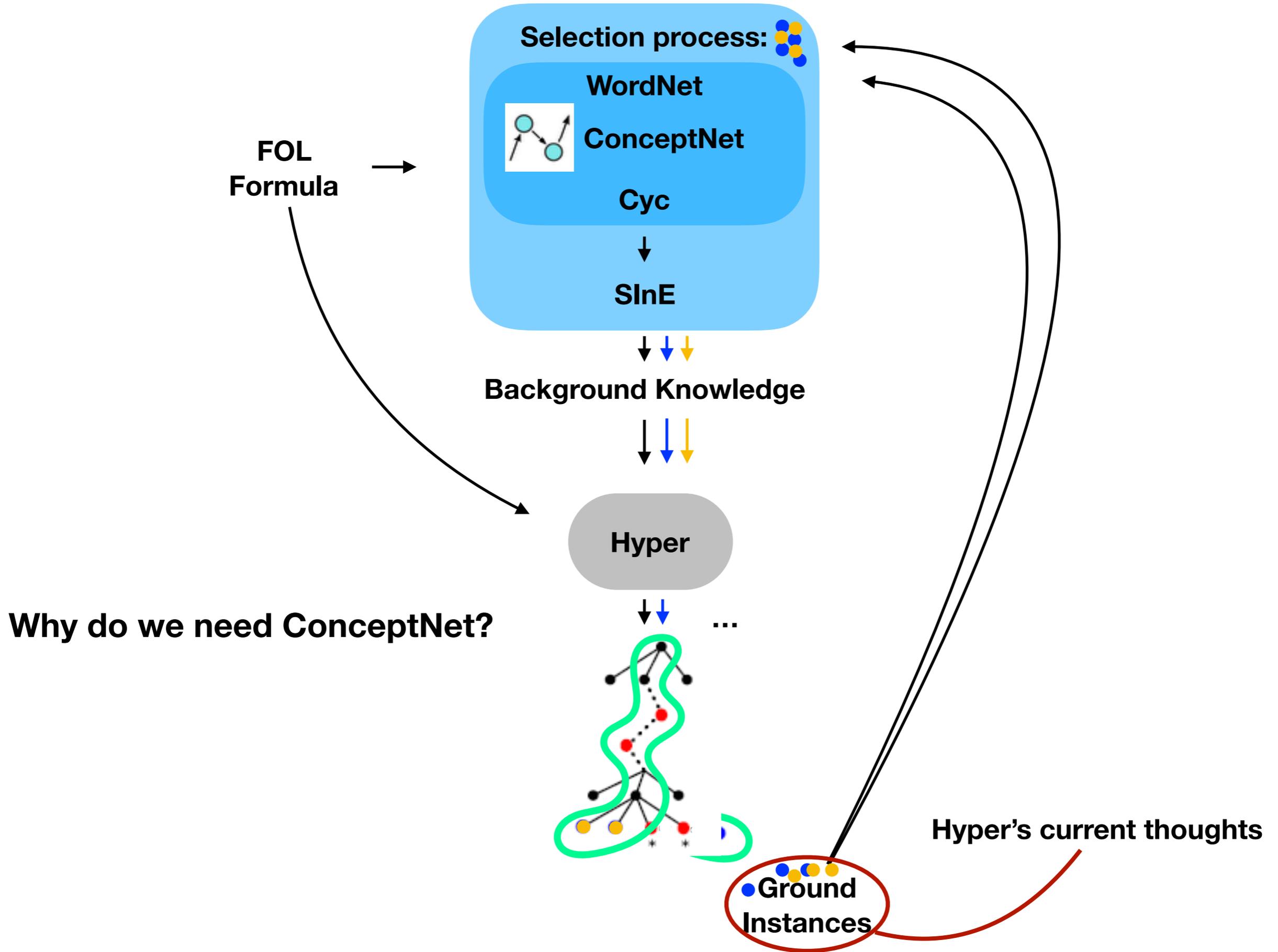
SInE & k-NN



**Selected background
knowledge**

**Background
Knowledge:
OpenCyc**





**FOL
Formula**

Selection process:

WordNet

ConceptNet

Cyc

SInE

Background Knowledge

Hyper

Why do we need ConceptNet?

Hyper's current thoughts

**Ground
Instances**

Why do we need ConceptNet?

- Without ConceptNet, at some point no new knowledge will be selected.

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creative step



creative step



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Use ConceptNet for this creative step:

- Knowledge graph representing commonsense knowledge



creative step



creative step



Why do we need ConceptNet?

The screenshot shows a web browser window with the URL `conceptnet.io`. The page title is "en freeze" and it is described as "An English term in ConceptNet 5.6". The sources listed are Open Mind Common Sense contributors, JMDict 1.07, Verbosity players, German Wiktionary, English Wiktionary, French Wiktionary, and Open Multilingual WordNet. There is a link to "View this term in the API".

Navigation links in the top right corner include: Documentation, FAQ, Chat, and Blog.

The main content is divided into three columns:

- Synonyms:** A list of terms from various languages (ar, ja) with their respective scripts and parts of speech (v, n).
- Related terms:** A list of terms from various languages (fr, en, sh) with their respective scripts and parts of speech (v, a).
- freeze is a way of...:** A list of English terms (en) with their parts of speech (v).

Synonyms	Related terms	freeze is a way of...
ar تَتَجَلَّجُ (v) →	fr congeler →	en act (v) →
ja フリーズ (n) →	fr crédit →	en suffer (v) →
ar التَّجَلُّدُ (n) →	en frozen (a) →	en change (v) →
ja 凍える (v) →	fr geler →	en change state (v) →
ar تَتَجَلَّجُ (n) →	sh lediti (v) →	en interrupt (v) →
ar تَجَلَّدُ (v) →	fr gel →	en withhold (v) →
ja 凍おる (v) →	en block →	en stand still (v) →
ar تَجَلُّدُ (n) →	sh slediti (v) →	en anesthetize (v) →
ar تَجَلَّدُ (v) →	fr glacer →	en solidify (v) →
ar تَجَمِيدُ (n) →	sh sleđivati (v) →	
ar تَجَلَّدُ (v) →	en cold →	
ja 凍てつく (v) →	fr se figer →	
ar تَجَلَّدُ (v) →	en asset →	
	en halt →	

Why do we need ConceptNet?

The screenshot shows the ConceptNet website interface with the following sections:

- freeze is a type of...**
 - en limitation (n) →
 - en pause (n) →
 - en cold weather (n) →
 - en cooling (n) →
 - en phase change (n) →
- Word forms**
 - en freezes (n) →
 - en froze (v) →
 - en freezes (v) →
 - en freezest (v) →
 - en freezeth (v) →
 - en freezing (v) →
 - en froze (v) →
 - en frozen (v) →
- Context of this term**
 - en operation (n) →
 - tr finance →
 - en computer →
 - en physics (n) →
 - en curling →
 - en finance →
 - en specifically →
- Things capable of freeze**
 - en water →
 - en Cold items →
 - en carbon dioxide →
 - en oxygen →
- Antonyms**
 - en thaw →
 - en boil (v) →
 - en go (v) →
 - en defrost →
 - en thaw (v) →
 - en unfreeze (v) →
 - en thaw →
 - en burn →
 - en melt →
- Etymologically related**
 - cy rhew →
 - de frieren →
 - ang freosan →
 - cy rhew →
 - de frieren →
 - enm fresen →
 - fy frieze →
 - la pruina →
 - nds freern →

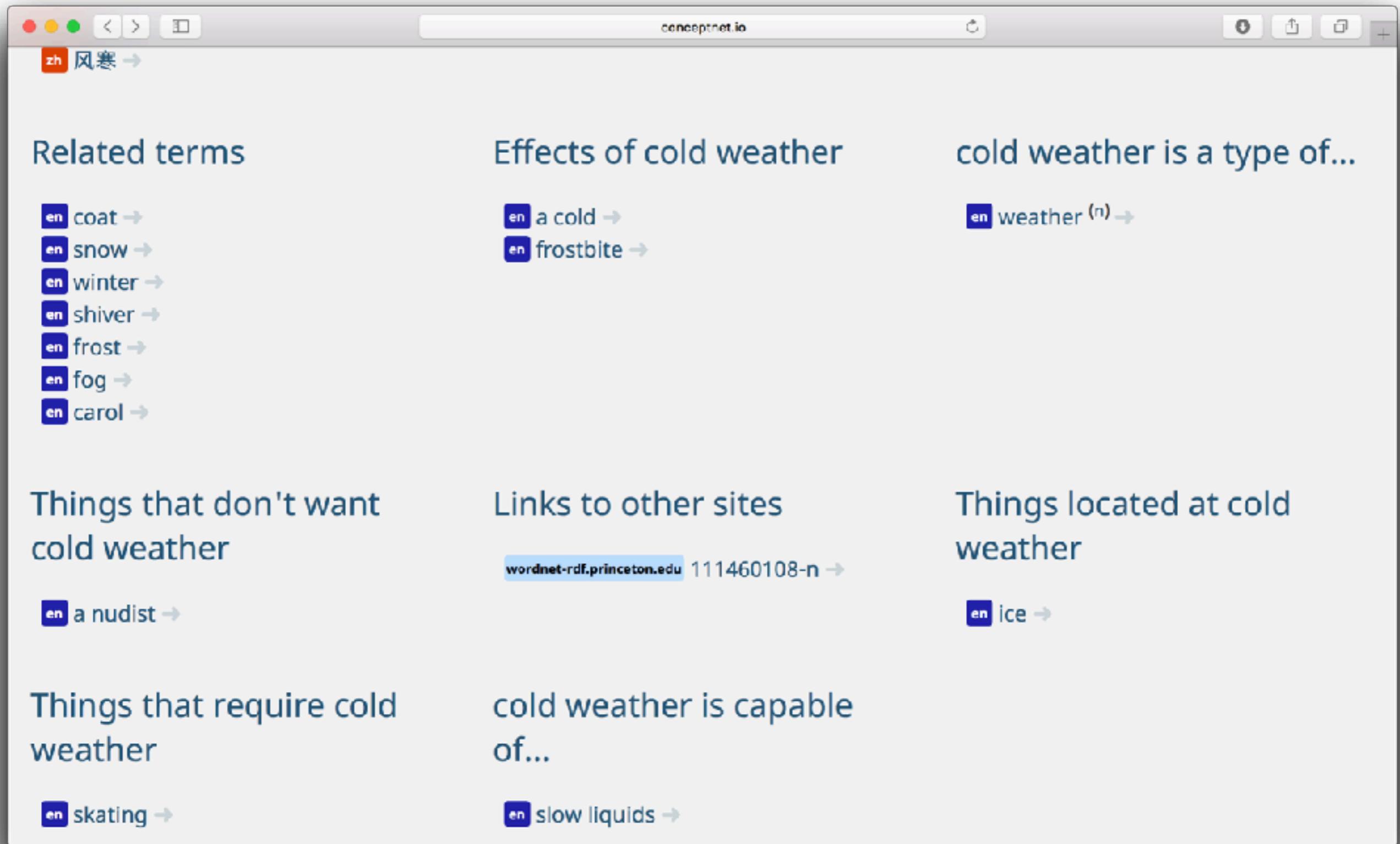
Why do we need ConceptNet?

The screenshot shows a web browser window with the URL `conceptnet.io`. The page title is **en cold weather**, with the subtitle "An English term in ConceptNet 5.6". On the right side, there are links for "Documentation", "FAQ", "Chat", and "Blog". Below the title, it lists sources: "Open Mind Common Sense contributors, CC-CEDICT 2017-10, JMDict 1.07, Verbosity players, and Open Multilingual WordNet", and a link to "View this term in the API".

The main content is divided into three sections:

- Synonyms:** A list of terms from various languages with their respective language codes and part-of-speech tags in parentheses, followed by a right-pointing arrow. The list includes: `eu hotzaldi (n)`, `ja 冷氣 (n)`, `ja 寒ぞら (n)`, `fi kylmä sää (n)`, `ja 寒空 (n)`, `it gelo (n)`, `ja さむ空 (n)`, `zh 冷天`, `zh 天冷`, `ja 寒ぞら (n)`, `ja 寒空 (n)`, `zh 天寒地冻`, and `zh 天寒地凍`.
- cold weather makes you want...:** A list of actions in English, each preceded by a language code and followed by a right-pointing arrow. The actions are: `en start a fire`, `en bake a cake`, `en buy a shirt`, `en chop firewood`, `en drive`, `en start a flame or a fire`, and `en stay in bed`.
- Types of cold weather:** A list of related concepts in English, each preceded by a language code and followed by a right-pointing arrow. The concepts are: `en It might snow when there` and `en freeze (n)`.

Why do we need ConceptNet?



The screenshot shows a web browser window with the URL `conceptnet.io`. The page displays the Chinese term `zh 风寒` and its English translation `en cold weather`. The page is organized into several sections, each showing related concepts and their relationships:

- Related terms:** A list of related terms including `en coat`, `en snow`, `en winter`, `en shiver`, `en frost`, `en fog`, and `en carol`.
- Effects of cold weather:** A list of effects including `en a cold` and `en frostbite`.
- cold weather is a type of...:** A list of superordinate terms including `en weather (n)`.
- Things that don't want cold weather:** A list of things that dislike cold weather, including `en a nudist`.
- Links to other sites:** A link to `wordnet-rdf.princeton.edu 111460108-n`.
- Things located at cold weather:** A list of things located in cold weather, including `en ice`.
- Things that require cold weather:** A list of things that require cold weather, including `en skating`.
- cold weather is capable of...:** A list of things cold weather is capable of, including `en slow liquids`.

Why do we need ConceptNet?

The screenshot shows a web browser window with the URL `conceptnet.io`. The page title is "en snow" and the subtitle is "An English term in ConceptNet 5.6". The sources listed are: Open Mind Common Sense contributors, DBPedia 2015, JMDict 1.07, OpenCyc 2012, /s/resource/unicode/ddr/32.0.1, Verbosity players, German Wiktionary, English Wiktionary, French Wiktionary, and Open Multilingual WordNet. There is a link to "View this term in the API".

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The main content is divided into three columns:

- Synonyms:** A list of terms from various languages with their respective language codes and parts of speech. Examples include: `ja` スノー (n) →, `ar` تساقط الثلج (v) →, `pt` Neve (n) →, `ar` سَقَطَ (v) →, `ar` تساقط الثلج (n) →, `ja` 六花 (n) →, `ar` سَقَطَ الثلج (v) →, `ja` 天花 (n) →, `ar` ثَلَجَ (n) →, `ja` 天華 (n) →, `ar` سَقَطَ (n) →, `ca` nevar (v) →, `ca` neu (n) →.
- Related terms:** A list of related terms in English and French. Examples include: `fr` neige →, `en` white →, `fr` neiger →, `fr` nom de famille →, `en` bluff →, `en` cold →, `en` winter →, `en` blanket →, `en` confusing →, `en` draw poker →, `en` cocaine →, `en` rain →, `en` hoodwink →, `en` color →, `en` precipitation →.
- Derived terms:** A list of derived terms in English. Examples include: `en` snow queen →, `en` snowish →, `en` buy when it snows sell when it goes →, `en` acid snow →, `en` snowless →, `en` oversnow →, `en` snow in →, `en` snowman →, `en` apple snow →, `en` snow out →, `en` artificial snow →, `en` as pure as driven snow →, `en` snow under →, `en` snow up →.

Why do we need ConceptNet?

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Use ConceptNet for this creative step:

- Knowledge graph representing commonsense knowledge



creative step



creative step



First Experiments

===== Copa Dev 114 =====

The surfer caught the wave. What happened as a RESULT?

The wave carried her to the shore.

She paddled her board into the ocean.

First Experiments

===== Copa Dev 114 =====

The surfer caught the wave. What happened as a RESULT?

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===== Thought iteration 1 =====

=====

```
fof(gr0,axiom,catch(sK2)).
fof(gr1,axiom,surprise(sK2)).
fof(gr2,axiom,wave(sK0)).
fof(gr3,axiom,surfer(sK1)).
fof(gr4,axiom,surfboarder(sK1)).
fof(gr5,axiom,swimmer(sK1)).
fof(gr6,axiom,natator(sK1)).
fof(gr7,axiom,bather(sK1)).
fof(gr9,axiom,female(c_tptpsquare)).
fof(gr10,axiom,paddle(c_tptpsquare)).
```

First Experiments

===== Copa Dev 114 =====

The surfer caught the wave. What happened as a RESULT?
The wave carried her to the shore.
She paddled her board into the ocean.

===== Thought iteration 2 =====

fof(gr24, axiom, beauty(sK2)).
fof(gr30, axiom, sweetheart(sK2)).
fof(gr48, axiom, woman(sK2)).
fof(gr51, axiom, adult_female(sK2)).
fof(gr74, axiom, aestheticquality(sK2)).

===== Thought iteration 3 =====

fof(gr20, axiom, amazement(sK2)).
fof(gr117, axiom, sweetie(sK0)).
fof(gr133, axiom, truelove(sK0)).
fof(gr141, axiom, lover(sK0)).
fof(gr201, axiom, appearance(sK0)).
fof(gr235, axiom, female_person(sK0)).

Future Work

Inconsistencies in the background knowledge:

- Terminate the thinking process

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Insufficient background knowledge:

- Use other ontologies (Yago, Sumo)

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Future Work

Inconsistencies in the background knowledge:

- Terminate the thinking process

Insufficient background knowledge:

- Use other ontologies (Yago, Sumo)
- Include (more) knowledge graphs (BabelNet,...)
- Improve the integration of ConceptNet

A person's hands are visible at the bottom, holding a white rectangular sign with the words "THANK YOU!" written in bold, black, uppercase letters. The background behind the sign is black.

All Pictures:
colourbox.de