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Formalizing Problem Solving in Computational Thinking: an Ontology approach

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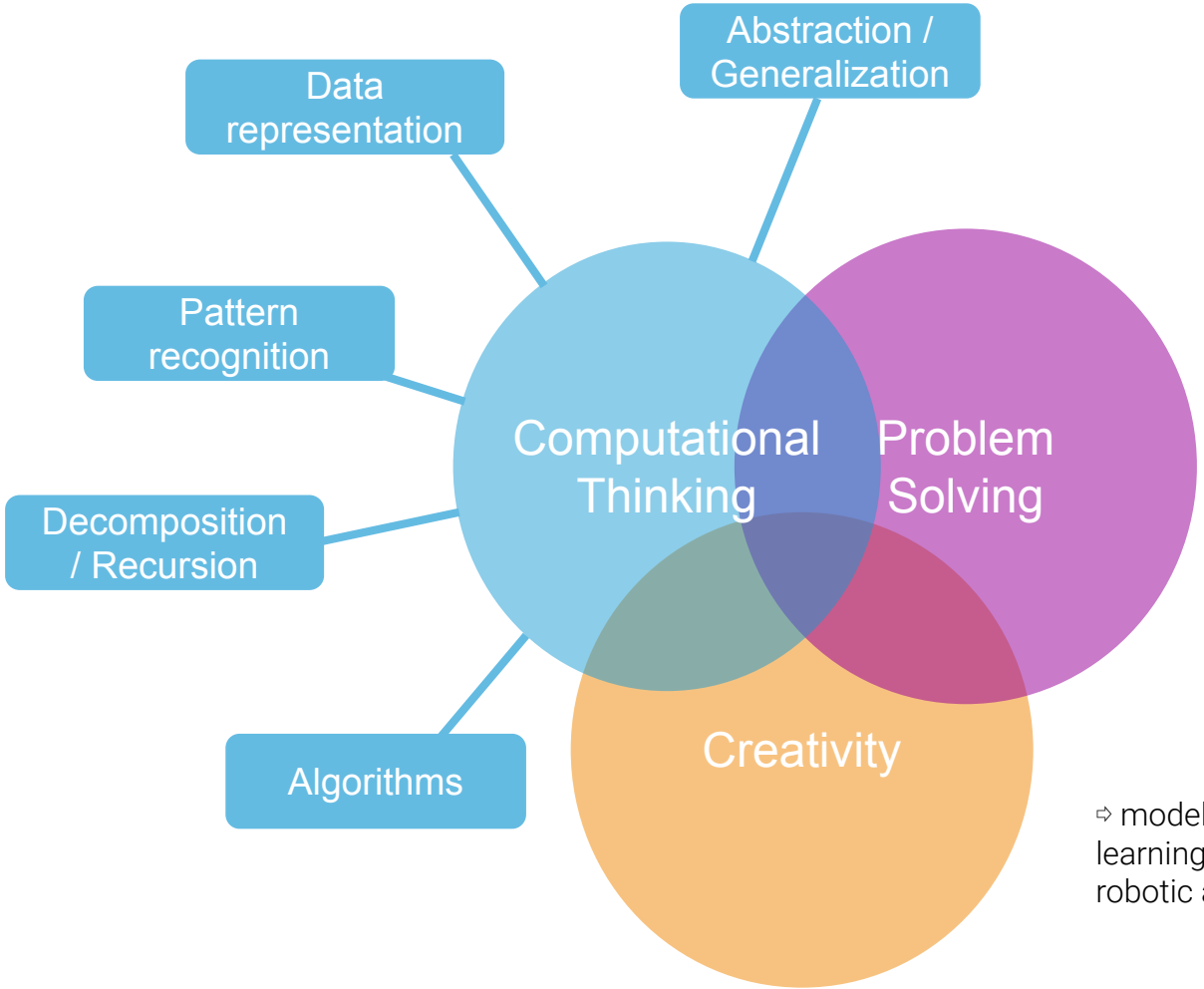


"21st century skills"

⇨ model a creative problem-solving learning activity involving modular robotic artefacts.

CreaCube: a creative problem-solving task

Problem
"Build a vehicle composed of 4 items, moving autonomously from a black point to a red point"

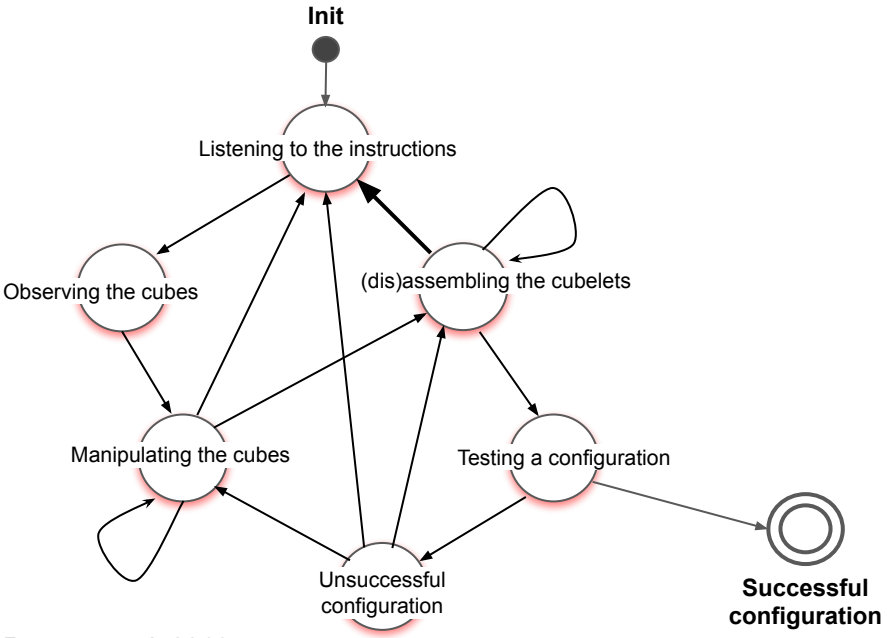
Material to solve the problem

Solution ?

CreaCube: a creative problem-solving task

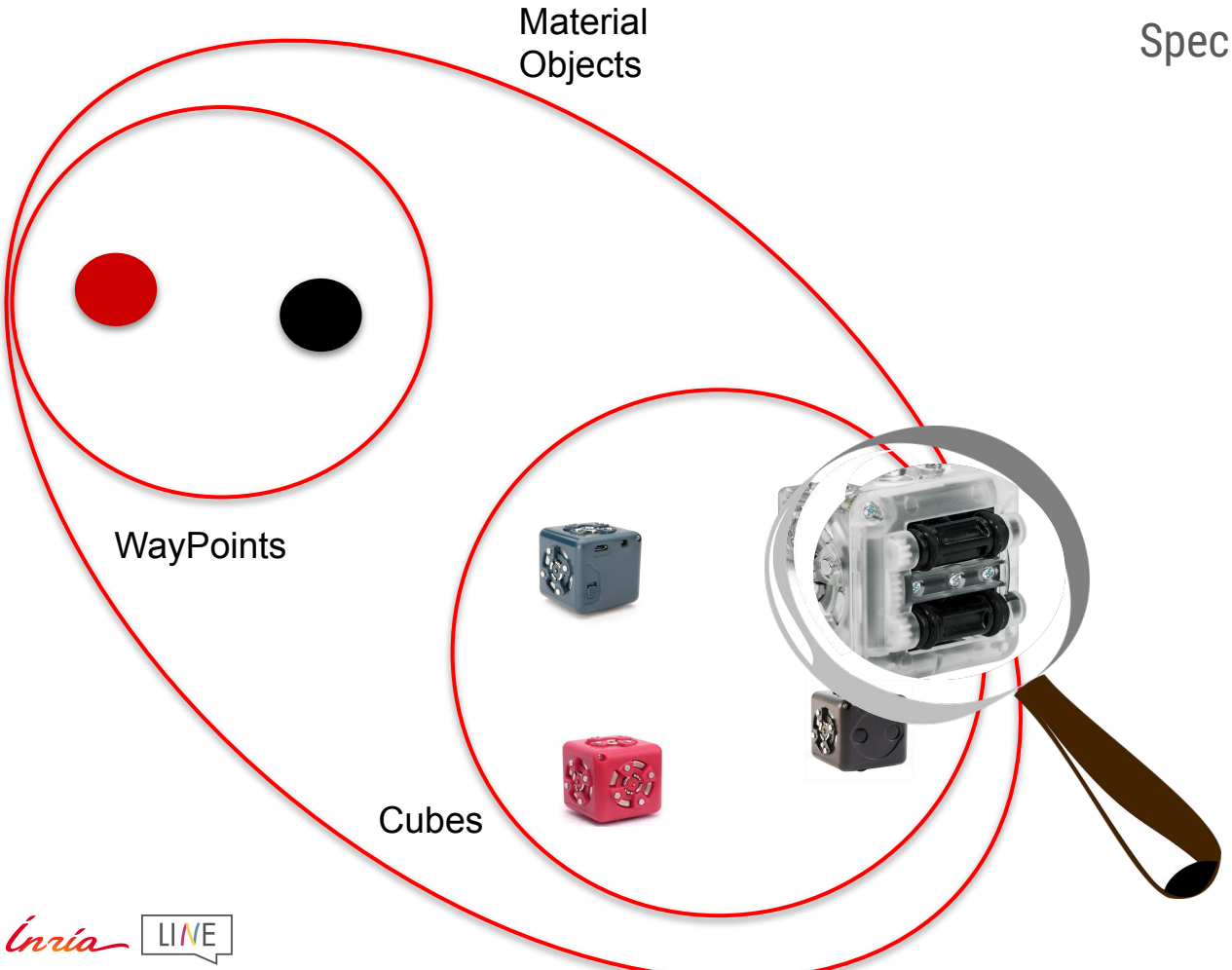
Problem

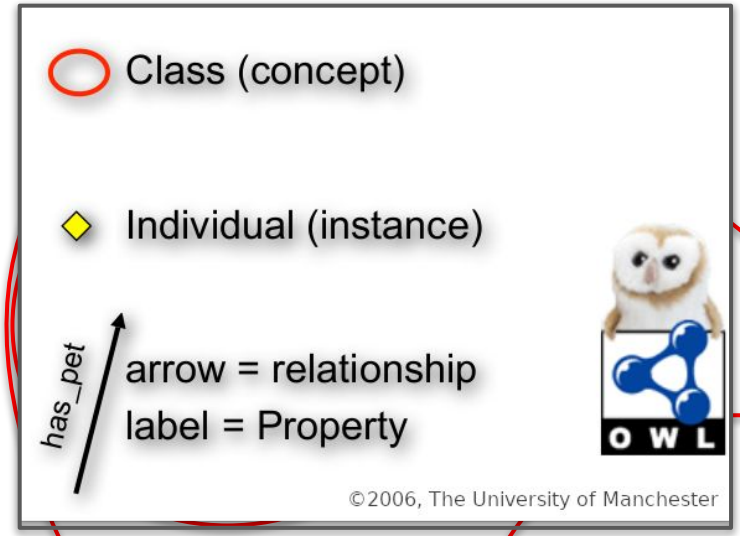
"Build a vehicle composed of 4 items, moving autonomously from a black point to a red point"

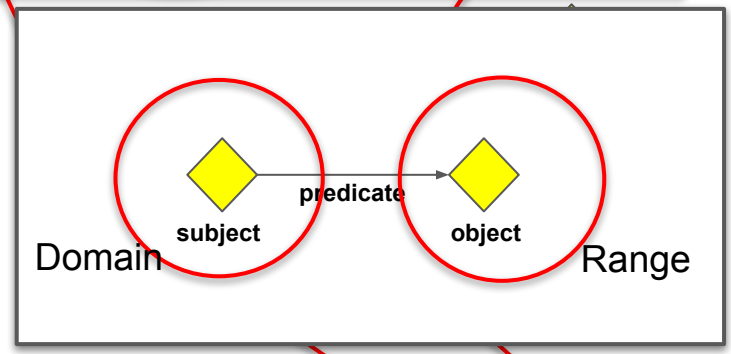


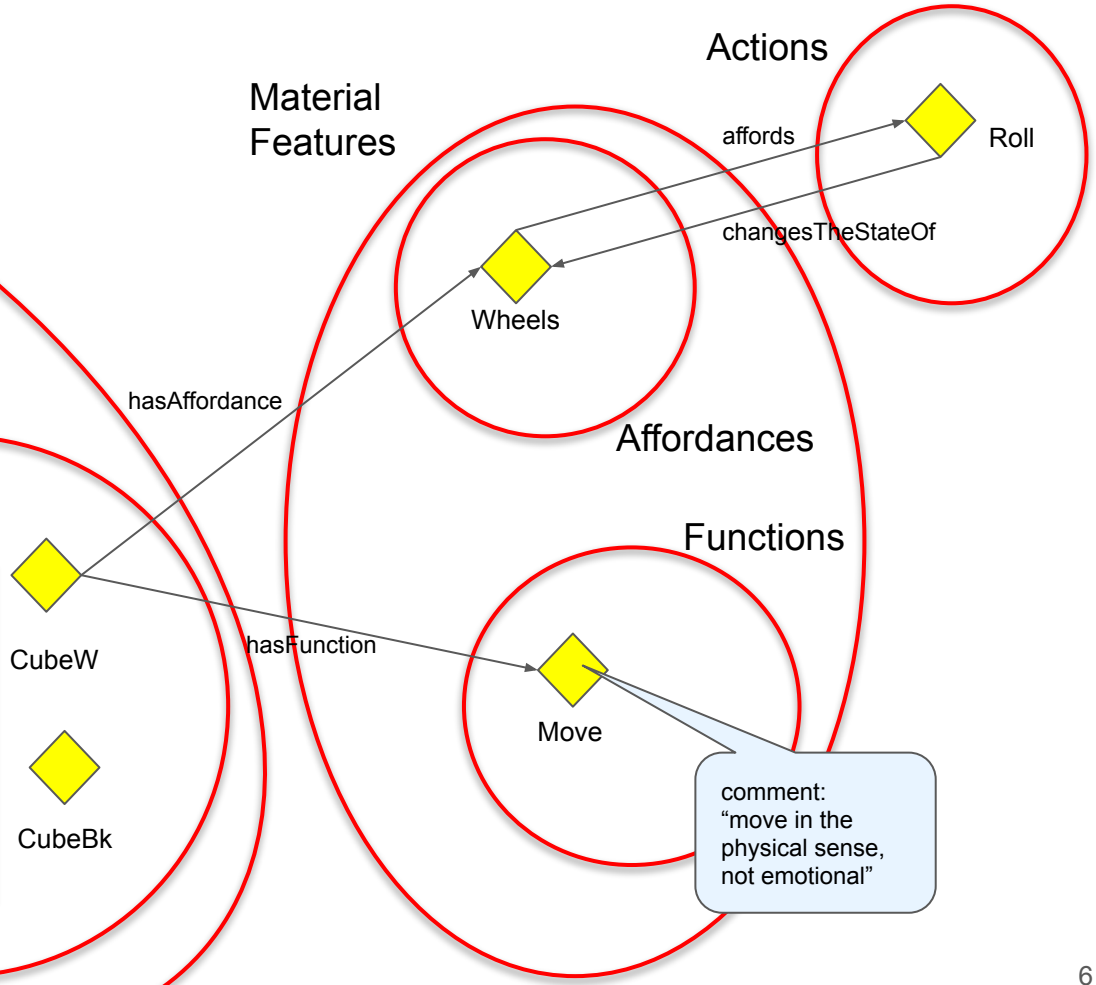
Romero et al, 2016

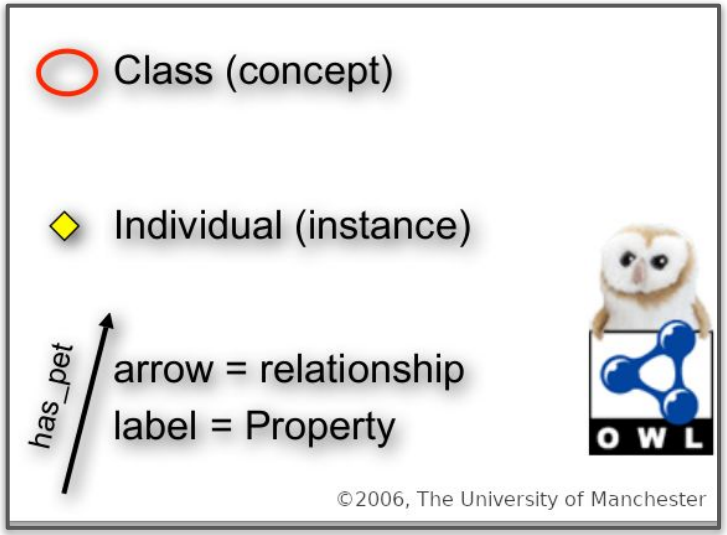
Specifying the task material

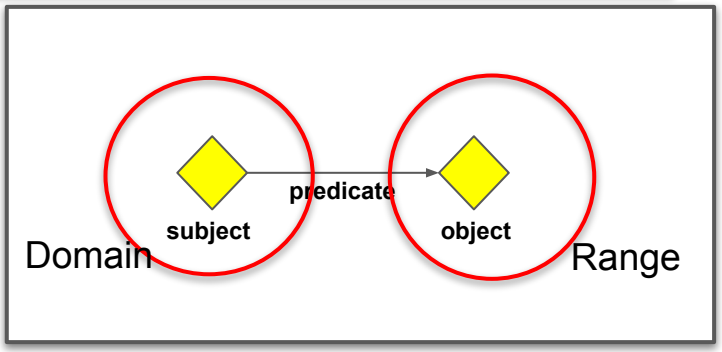



Class (concept)
Individual (instance)
has_pet
arrow = relationship
label = Property
OWL
©2006, The University of Manchester


predicate
subject
object
Domain
Range


Actions
Material Features
affords
Roll
changesTheStateOf
Wheels
hasAffordance
Affordances
Functions
CubeW
hasFunction
Move
CubeBk
comment:
“move in the physical sense, not emotional”





RDF(S) + OWL
Resource Description Framework (Schema)
Web Ontology Language

```
:hasAFeature rdf:type owl:ObjectProperty ;
             rdfs:domain :MaterialObject ;
             rdfs:range :MaterialFeature .

:Cube rdf:type owl:MaterialObject .

:Wheel rdf:type owl:MaterialFeature .

:WhiteCube rdf:type :Cube ;
              :hasAffordance :Wheel ;
              :hasFunction :Move .

:Move rdfs:comment " move in the physical sense, not emotional"
.
```

`subject predicate object .`

RDF triple

An ontology: what for?

A structured semantic network...

- to share and reuse knowledge
  - between humans, esp. between different fields of expertise: education/learning sciences, computer science, cognitive neuroscience
  - between machines
- to specify the task process at two levels:
  - the material (from designing specifications)
  - the learner behavior (as described in the literature)

⇨ an epistemological tool

Specifying the learner behavior

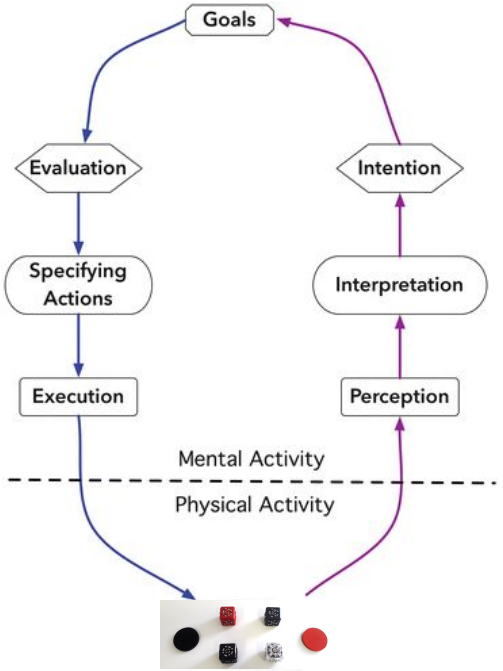
- Mental representation of the environment:

  knowledge construction through a **hypothetico-deductive process**
  ➔ model knowledge interdependencies

- Attentional focus and action selection:

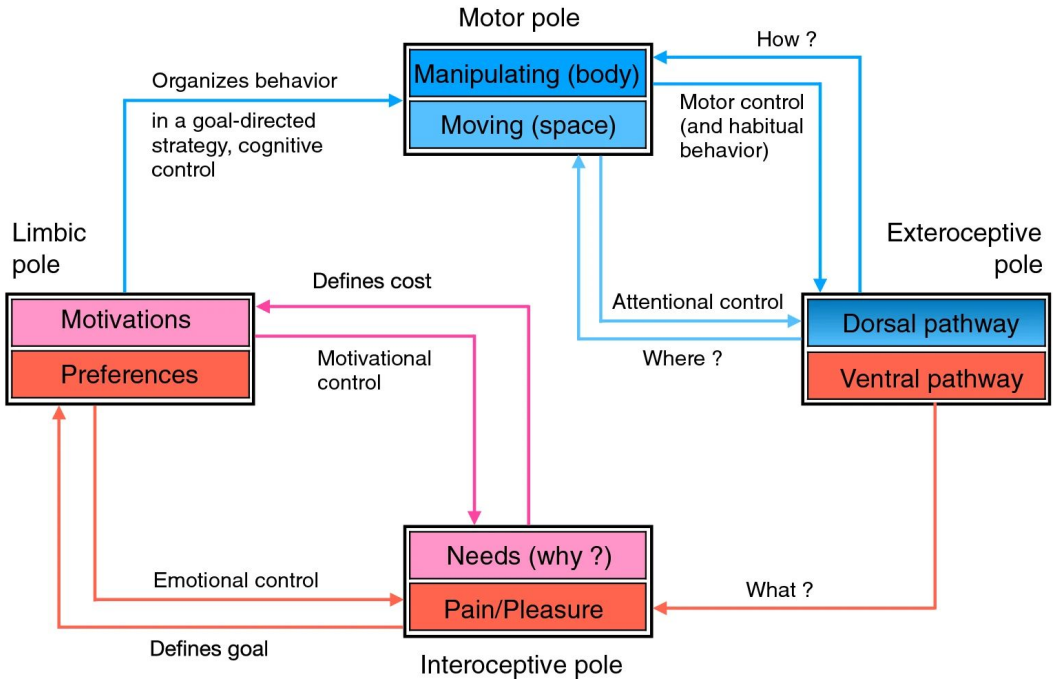
  goal-driven vs **stimulus-driven** behavior (top-down / bottom-up)

\+ concurrent goals (mastery vs performance)

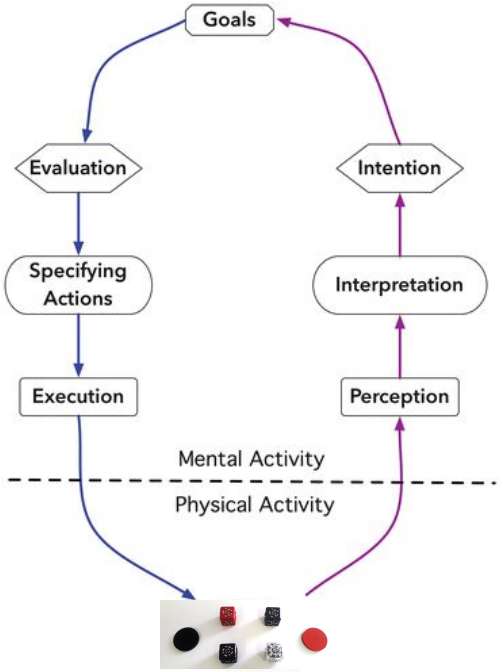


Romero et al, 2016

Specifying the learner behavior

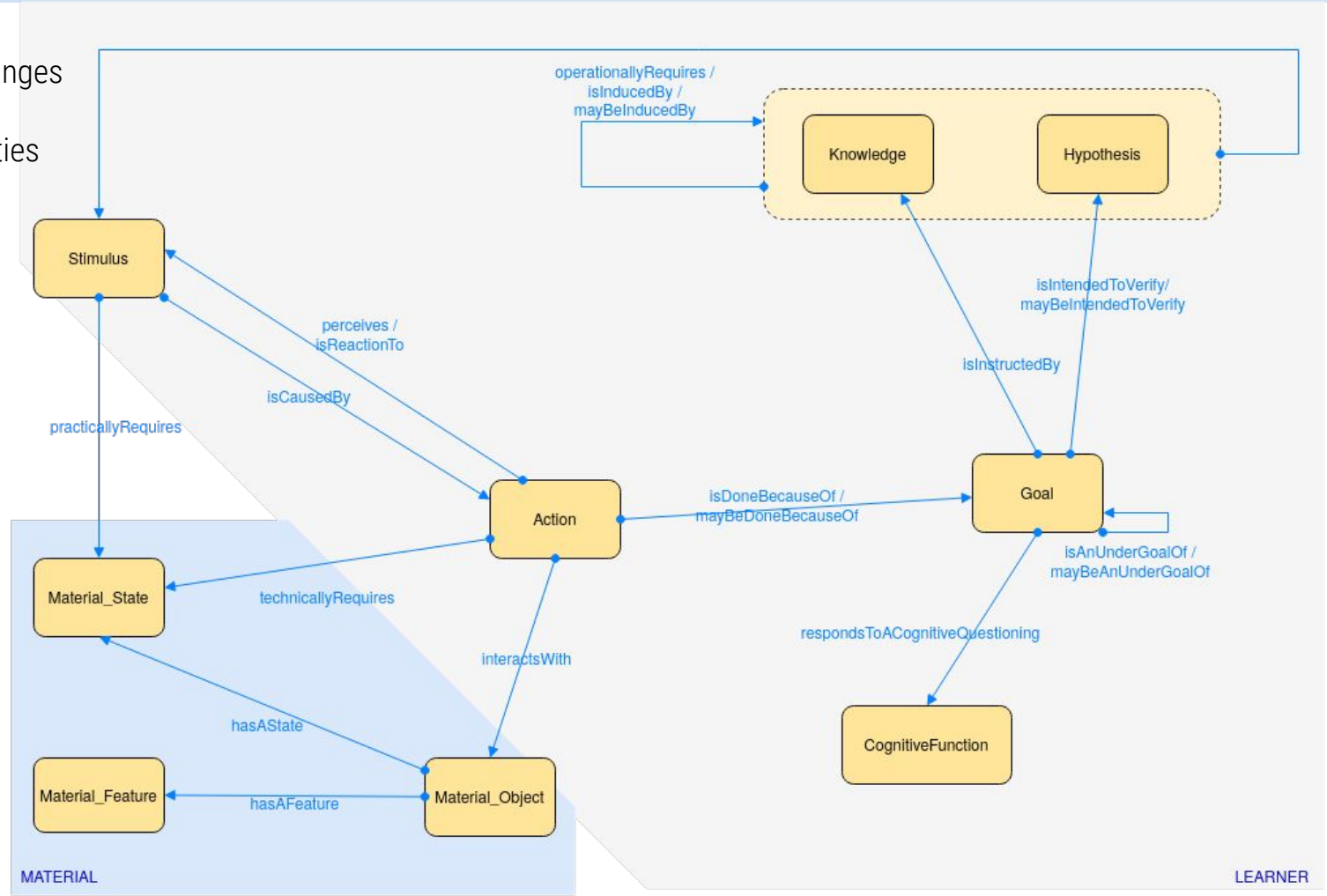


Alexandre et al, 2021

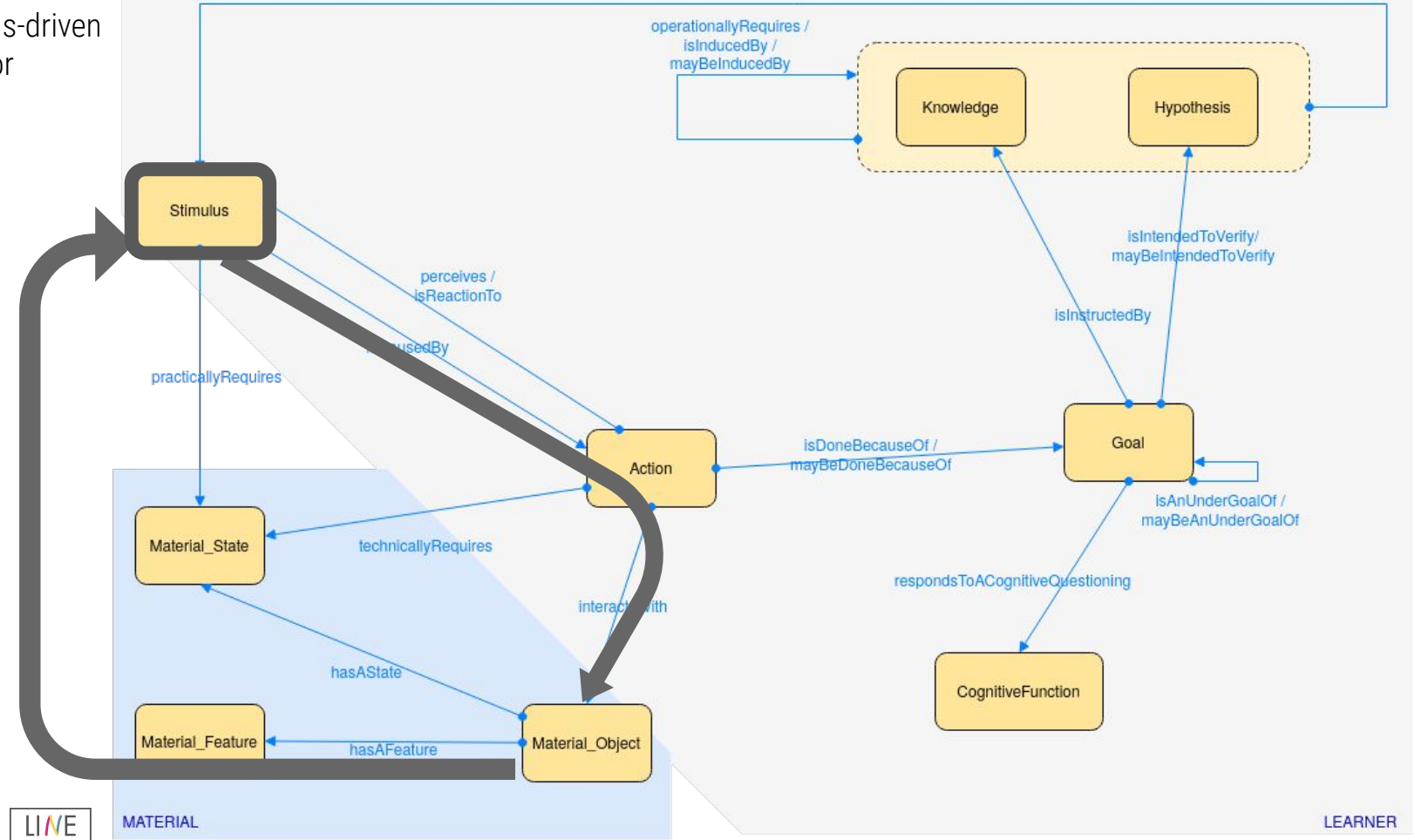


Romero et al, 2016

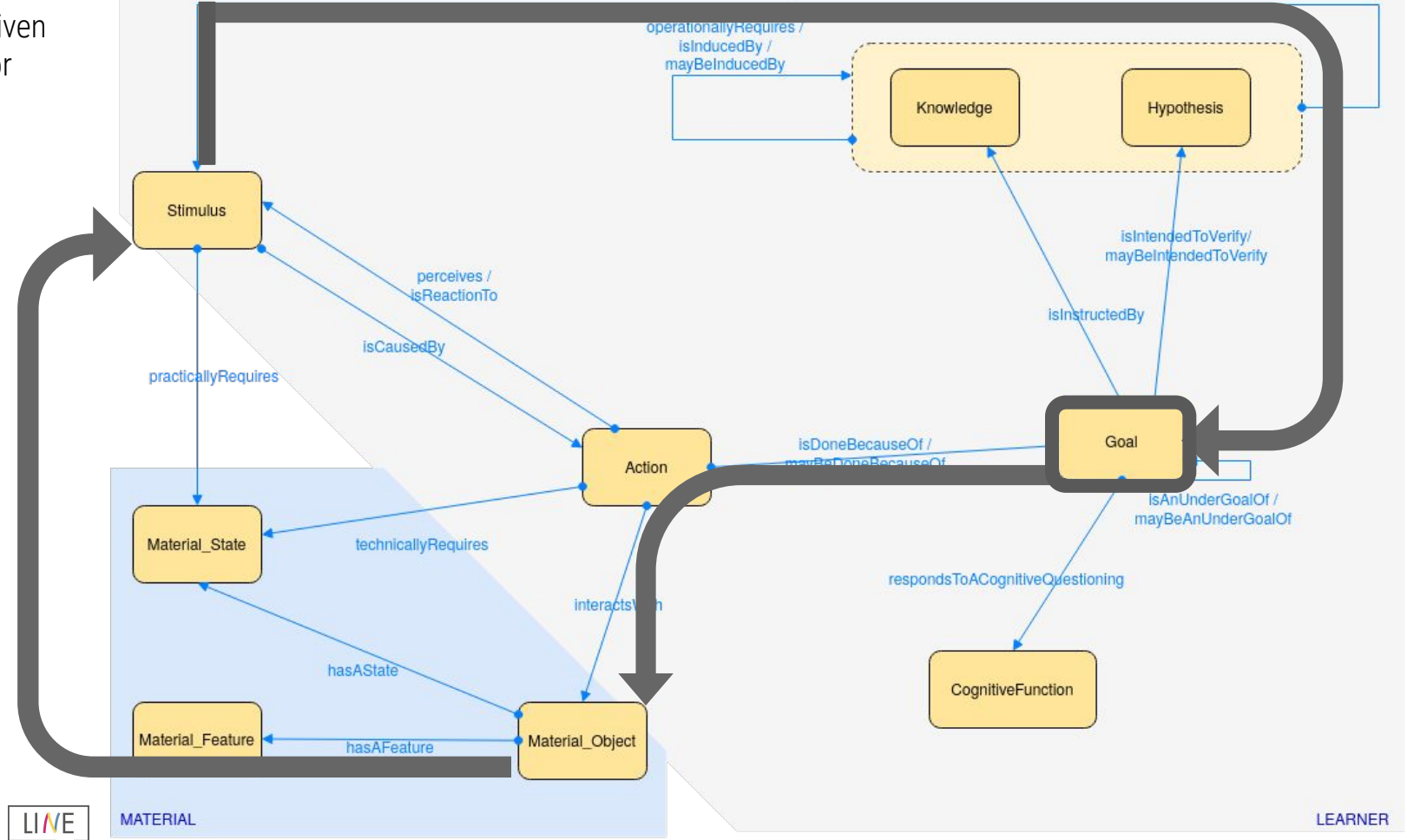
Domains and ranges for the main classes/properties



Stimulus-driven behavior



Goal-driven behavior



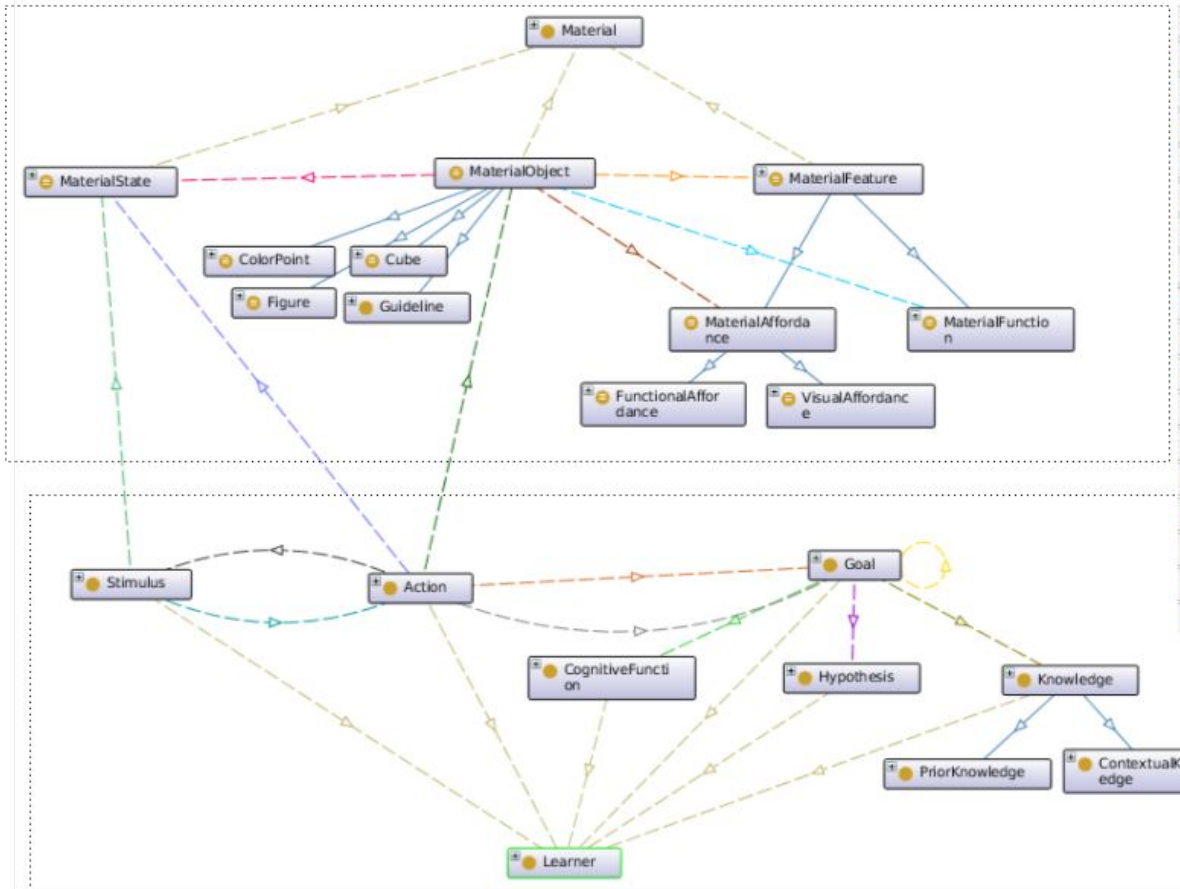
The ontology at a glance...

The ontology and its documentation are available at
https://line.gitlabpages.inria.fr/aide-group/creaonto/

model of the task material

Complete version:
75 classes
40 properties
396 individuals

model of the learner behavior



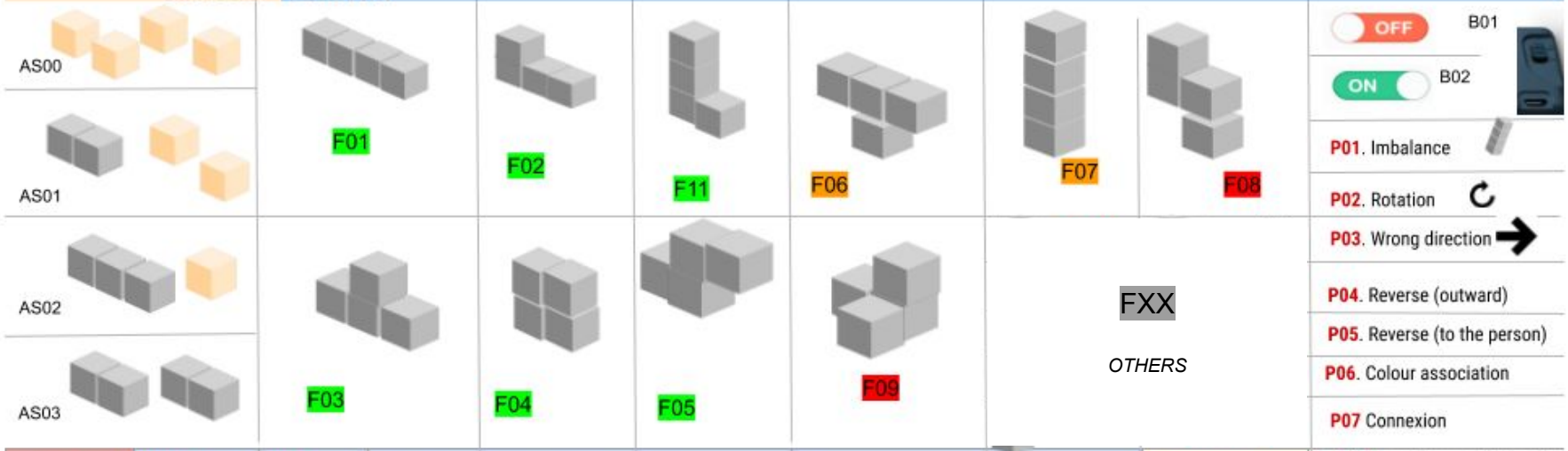
Roux et al, 2020
edited in
Mercier et al, 2021

An ontology: what for?

A structured semantic network...

- to share and reuse knowledge
  - among humans, esp. between different fields of expertise: education/learning sciences, computer science, cognitive neuroscience
  - between machines
- to specify the task process at two levels:
  - the material (from designing specifications)
  - the learner behavior (as described in the literature)
    ⇨ an epistemological tool
- to make sense of the collected data
  - inference on the learner's cognition based on the observables, using a reasoner (eg Hermit, Pellet)
  - detecting possible inconsistencies in the model
    ⇨ an operational tool?

CREACUBE | **2. Activity**



FL01 Turn cube wo reloc **FL02** Repositi onner cube même forme	**U00**. Play instructio **U01**. Stop intrusctions	**U02**. Questionn ing instructio ns	U03. No cubes in hand (no manipulati on)	U04. Hands up with **1 cube**	U05. Hands up with **2 cubes**	U06. Hands up with **3 cubes**	U07. Hands up with **4 cubes**	**T01**. No test **T02**. Drop Out / Abandon **T03**. Succeed	**P08** Doesn't move (wheels) **P09** Doesn't move (on/off) **P10** Doesn't move (capteur) **P11** Doesn't move (invers)
	B01. Trial/error	B02. Analytical /systemic	B03. Hypothesi zing	B04. Ego preservation	B05. Complaining	**E01**. Ecstasy/Joy/Serenity	**E02**. Admiration/Trus t/Acceptance	**E03**. Terror/Fear/Appr ehension	**E04**. Amazement/Surprise/Distrac tion
START	AF01. Wheels	AF02. Magnets	AF03.Butt on on/off	AF04.Two eyes	AF05. Sensors UNDO	**E05**. Grief/Sadness/Pensi veness	**E06**. Loathing/Disgus t/Boredom	**E07**. Rage/Anger/Ann oyance	**E08**. Vigilance/Anticipation/Intere st

CREACUBE | **2. Activity**

AS00 AS01 AS02 AS03

F01 F02 F11 F06 F07 F08

F03 F04 F05 F09

FXX

OTHERS

B01 OFF

B02 ON

P01. Imbalance

P02. Rotation

P03. Wrong direction

P04. Reverse (outward)

P05. Reverse (to the person)

P06. Colour association

P07 Connexion

P08 Doesn't move (wheels)

P09 Doesn't move (on/off)

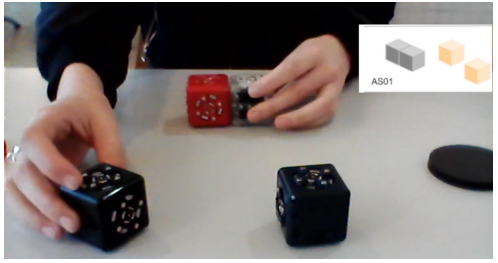
P10 Doesn't move (capteur)

P11 Doesn't move (invers)

FL01 Turn cube wo reloc **FL02** Repositionner cube même forme	**U00**. Play instructio **U01**. Stop intrusctions	**U02**. Questionning instructions	U03. No cubes in hand (no manipulation)	U04. Hands up with **1 cube**	U05. Hands up with **2 cubes**	U06. Hands up with **3 cubes**	U07. Hands up with **4 cubes**	**T01**. No test **T02**. Drop Out / Abandon **T03**. Succeed
	B01. Trial/error	B02. Analytical /systemic	B03. Hypothesizing	B04. Ego preservation	B05. Complaining			
START	AF01. Wheels	AF02. Magnets	AF03.Button on/off	AF04.Two eyes	AF05. Sensors			

UNDO

Example:



Encoding each video as a **sequence of observables** in JSON (JavaScript Object Notation) format:


```
{
    "clicks": [
      {
        "time": 0,
        "tclicks": [
          "START"
        ]
      },
      {
        "time": 2,
        "tclicks": [
          "U00"
        ]
      },
      {
        "time": 9,
        "tclicks": [
          "U01"
        ]
      },
      {
        "time": 17,
        "tclicks": [
          "U04"
        ]
      },
      {
        "time": 21,
        "tclicks": [
          "AS01"
        ]
      },
      {
        "time": 22,
        "tclicks": [
          "AS02"
        ]
      },
[...]
```

```
[...]
      {
        "time": 3664,
        "tclicks": [
          "AS02"
        ]
      },
      {
        "time": 3665,
        "tclicks": [
          "AS03"
        ]
      },
      {
        "time": 3807,
        "tclicks": [
          "F000"
        ]
      },
      {
        "time": 3811,
        "tclicks": [
          "P03"
        ]
      },
      {
        "time": 3812,
        "tclicks": [
          "P03"
        ]
      },
      {
        "time": 3860,
        "tclicks": [
          "T03"
        ]
      }
    ],
    "idParticipant": "p0136",
    "age": "12",
    "ageCategory": "enf",
    "gender": "M",
    "diversity": "dys",
    "leftHanded": "",
    "cubeletsPriorKnowledge": "null",
    "participationOK": true,
    "results": {
      "_warning": "",
      "_first_time": 0,
      "_last_time": 3860
    }
  ],
  "dateJMA": "25-01-2019"
},
```


age category	nb of participants
preschoolers (3-6 yo)	21
children/pre-teens (7-12)	**263**
teenagers (13-17)	55
young adults (18-29)	147
adults (30-60)	162
seniors (>60)	15

A queryable knowledge base

Using the query language SPARQL

Snap SPARQL Query:

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX : <http://www.semanticweb.org/mnemosyne-line/aide/creacube#>

SELECT ?action ?stimulus ?goal ?supergoal ?knowledge ?hypothesis ?x
        WHERE {
                ?action :changesTheStateOf :Switch .
                OPTIONAL{
                        ?action :mayBeAReactionTo ?s .
                        ?s :refersTo ?stimulus
                }
                OPTIONAL{
                        ?action :mayBeDoneBecauseOf ?goal .
                        OPTIONAL {
                                ?goal :mayBeAnUnderGoalOf ?supergoal .
                        }
                        OPTIONAL {
                                ?goal :isInstructedBy ?k .
                                ?k :refersTo ?knowledge .
                        }
                        OPTIONAL {
                                ?goal :mayBeIntendedToVerify ?h .
                                ?h :refersTo ?hypothesis .

                        }
                }
        }
```

Execute

?action	?stimulus	?goal	?supergoal	?knowledge	?hypothesis
:SwitchOnF		:G_SwitchOnF	:G_MakeFigureMoveAutonomously	Switches are used to activate an electronic device	
:SwitchOnF		:G_SwitchOnF	:G_MakeFigureMoveAutonomously	The blue cube has a switch	
:SwitchOnF		:G_SwitchOnF	:G_MakeFigureMoveAutonomously	Switches must be switched on to activate an electronic device	
:SwitchOnF		:G_SwitchOnF	:G_MakeFigureMoveAutonomously	The vehicle must move autonomously	
:Try_toFlipSwitch	The switch of the blue cube is visible	:G_FlipSwitch	:G_FindFunctionCubeBe	Switches must be switched on to activate an electronic device	The blue cube is a switch and permits to activate the vehicle

Discussion

- An original approach, despite being only a preliminary study
  - Ontology use in education mostly focuses on modelling learning resources and/or learning assistants*.
    - LUDO ontology for serious games (based on Tang et al, 2011)
  - Few formal models of ill-defined problems
    - some work available on ontological descriptions of general problem-solving methods (eg Chandrasekaran 1997, Crubezy and Musen 2004)

- Further work needed to:
  - Bridge the remaining gap between the ontology and the experiment observables
    (eg. emotional states, positions of the cubes in the configurations)
  - To be considered:
    - Confront the inferred interpretations to post-task interviews with the participants
    - Link this ontology to an existing foundational ontology (eg Dolce)

*See a recent review in Stancin et al, 2020.

Thank you for your attention!

Mercier, Chloé, Lisa Roux, Margarida Romero, Frederic Alexandre, and Thierry Viéville. “Formalizing Problem-Solving in Computational Thinking : An Ontology Approach.” In *ICDL ’2021*. Beijing, China, 2021.

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More about the AIDE (*Artificial Intelligence Devoted to Education)* project: https://team.inria.fr/mnemosyne/aide/

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Inria LINE Laboratoire d’Innovation et Numérique pour l’Education Mnemosyne UNIVERSITÉ CÔTE D’AZUR OTESIA Alde

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