NOVAMENTE

A Practical Architecture for Artificial General Intelligence

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Biomind LLC
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Virginia Tech, Applied Research Lab for National and Homeland Security

The Novamente Project

- **Long-term goal**:
  - creating "artificial general intelligence" approaching and then exceeding the human level
  - to be approached via a series of incremental phases
    - Learning programme inspired by human developmental psychology
    - The system is taught via its embodiment in a 3D simulation world
- **Novamente AI Engine:** an integrative AI architecture
  - Overall architecture inspired by cognitive science
  - a "weighted labeled hypergraph" knowledge representation
    - smoothly spans perception, cognition and action
    - Aspects in common with semantic nets and attractor neural nets
  - Learning via computer science algorithms:
    - **evolutionary programming** (a special kind of EDA)
    - **probabilistic inference** (Probabilistic Logic Networks)
  - efficient, scalable C++/Linux implementation
- Currently parts of the Novamente codebase are being **used for commercial projects**
  - natural language processing
  - biological data analysis

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Overview Papers

- *The Novamente AI Engine*
  - – IJCAI Workshop on Intelligent Control of Agents, Acapulco, August 2003
- *Novamente: An Integrative Architecture for Artificial General Intelligence*
  - – AAAI Symposium on Achieving Human-Level Intelligence Through Integrated Systems and Research, Washington DC, October 2004
- *Patterns, Hypergraphs and General Intelligence*
  - – World Congress on Computational Intelligence, Vancover CA, July 2006
- Chapter on Novamente in
  - – *Artificial General Intelligence* volume, Springer Verlag, 2006

Novamente-Related Books-in-Progress

- *The Hidden Pattern*
  - *Related philosophy of mind*
  - *In press; to appear 2006*
- *Probabilistic Term Logic*
  - *In final editing stage; to be submitted 2006*
- *Engineering General Intelligence*
  - *In final editing stage*
  - *Reviews the overall NM design*
  - *May or may not be submitted (AI Safety concerns)*
- *Artificial Cognitive Development*
  - *Developmental psychology for Novamente and other AGIs*
  - *In preparation*

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The Grand Vision

- Conceptual Background
- Teaching Approach
- Knowledge Representation
- Software Architecture
- Learning Dynamics

The Current Reality

- Implemented Components
- AGISim Experiments
- NLP Experiments

The Path Ahead

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Novamente:
The Grand Vision

Conceptual Background: Probabilistic Patternism

- Founded on a “patternist philosophy of mind”
- An intelligent system is conceived as a system for recognizing patterns in the world and in itself
- Probability theory is used as a language for quantifying and relating patterns
- Logic (term, predicate, combinatory) is used as a base-level language for expressing patterns
- Self-analysis allows the system to recognize and utilize patterns existing emergently among numerous logical expressions

Conceptual Background: Novamente Learning Dynamics

- Evolutionary learning is used to generate speculative new patterns
- Logical inference is used to systematically extrapolate known patterns
  - Accounting appropriately for uncertainty in inference is critical
- Simpler, statistical pattern mining algorithms are also incorporated

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Conceptual Background: Definition of Intelligence

- Intelligence is considered as the ability to achieve complex goals in a complex environment
- Goals are achieved via recognizing probabilistic patterns of the form “Carrying out procedure P in context C will achieve goal G.”

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The Structure of Intelligence, Springer-Verlag, 1993

The Evolving Mind, Gordon and Breach, 2003

Chaotic Logic, Plenum Press, 1994

From Complexity to Creativity, Plenum Press, 1997

Creating Internet Intelligence, Kluwer Academic, 2001

The Hidden Pattern, Brown Walker Press, 2006

Page Count = 472; Spine = 0.951 "

The Hidden Pattern presents a novel philosophy of mind, intended to form a coherent conceptual framework within which it is possible to understand the diverse aspects of mind and intelligence in a unified way. The central concept of the philosophy presented is the concept of "pattern": minds and the world they live in and co-create are viewed as patterned systems of patterns, evolving over time, and various aspects of subjective experience and individual and social intelligence are analyzed in detail in this light.

Many of the ideas presented are motivated by recent research in artificial intelligence and cognitive science, and the author's own AI research is discussed in moderate detail in one chapter. However, the scope of the book is broader than this, incorporating insights from sources as diverse as Vedantic philosophy, psychedelic psychotherapy, Nietzschean and Peircean metaphysics and quantum theory. One of the unique aspects of the patternist approach is the way it seamlessly fuses the mechanistic, engineering-oriented approach to intelligence and the introspective, experiential approach to intelligence.

ISBN 1-58112-989-0
52995
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THE HIDDEN PATTERN
A Patternist Philosophy of Mind
GOERTZEL

THE HIDDEN PATTERN

A Patternist Philosophy of Mind

BEN GOERTZEL

The Hidden Pattern:

Contents

AI Teaching Methodology

- Embodiment
- Post-embodiment
- Developmental Stages

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The Power of Embodiment

Embodiment (real or virtual) provides a would-be AGI with

- Symbol grounding
  - Most crucially: grounding of subtle words like prepositions
- An effective medium for learning complex cognitive skills
  - attention allocation
  - procedure-learning
  - inference control
- A sense of self
  - Critical for cognition as well as mental health
- Empathy with humans

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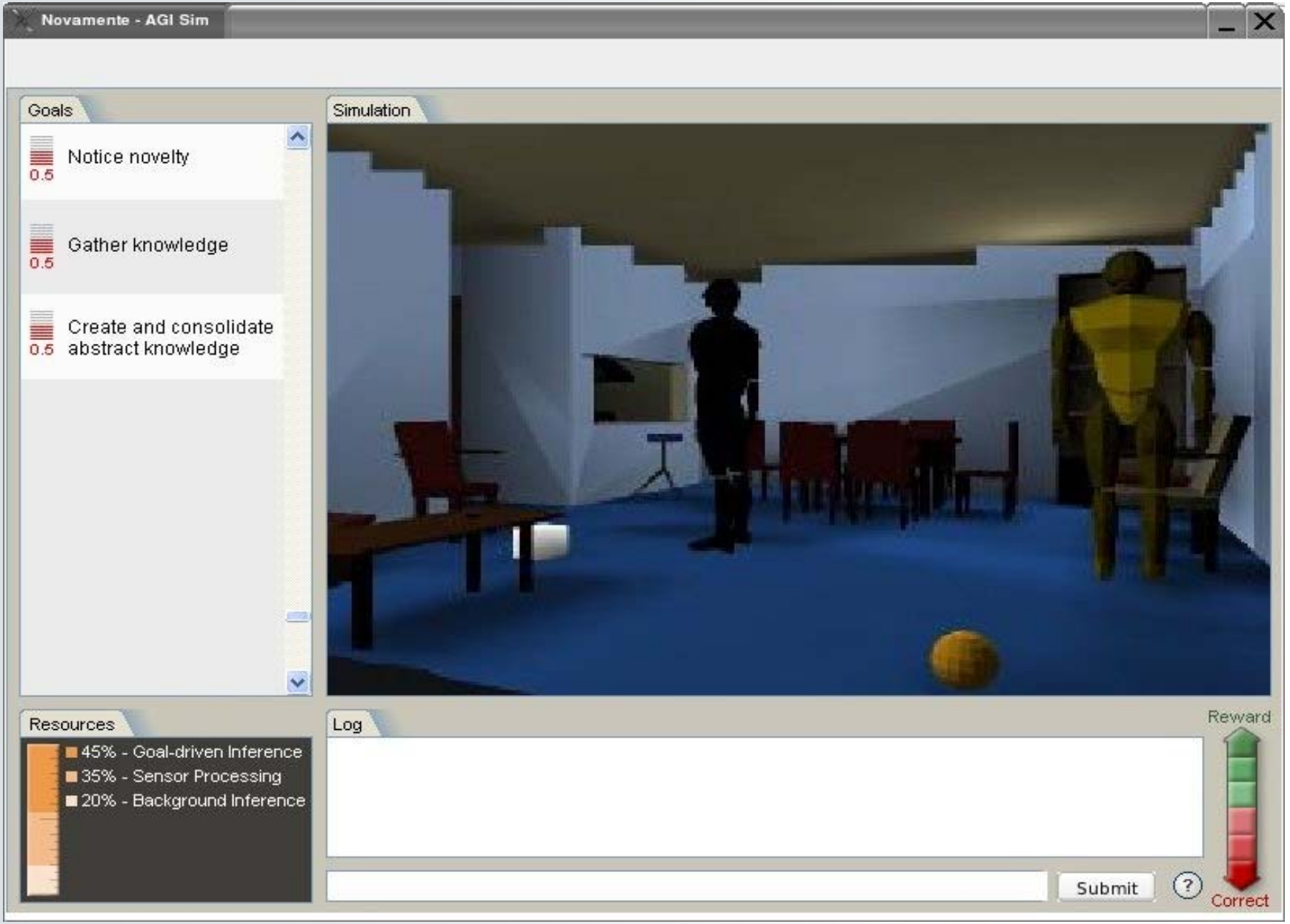
AGISim:

An Open-Source Simulation Environment for AGI

- AI systems can sense and act in real-time via embodiment in a 3D virtual world
- Uses CrystalSpace (open-source game engine) for visualization
- Provides AI systems with multisensory inputs
  - visual inputs at varying levels of granularity: pixels, polygons or objects
  - hearing, touch, proprioception, …
- Integration with natural language interface for fluid, situated communication
- Suitable for teaching/learning based on a developmental-psychology-based methodology
- Compatible with Novamente but usable by any AI system via a simple sockets-based protocol


Crystal Space Application


Novamente - AGI Sim
Goals
Notice novelty
0.5
Gather knowledge
0.5
Create and consolidate abstract knowledge
0.5
Simulation
Resources
45% - Goal-driven Inference
35% - Sensor Processing
20% - Background Inference
Log
Submit
Reward
Correct

Post-Embodied AI

AI systems may viably synthesize knowledge gained via various means

- virtually embodied experience
  - AGISim
- physically embodied experience
  - Robotics
- explicit encoding of knowledge in natural language
- ingestion of databases
  - WordNet, FrameNet, Cyc, etc.
  - quantitative scientific data

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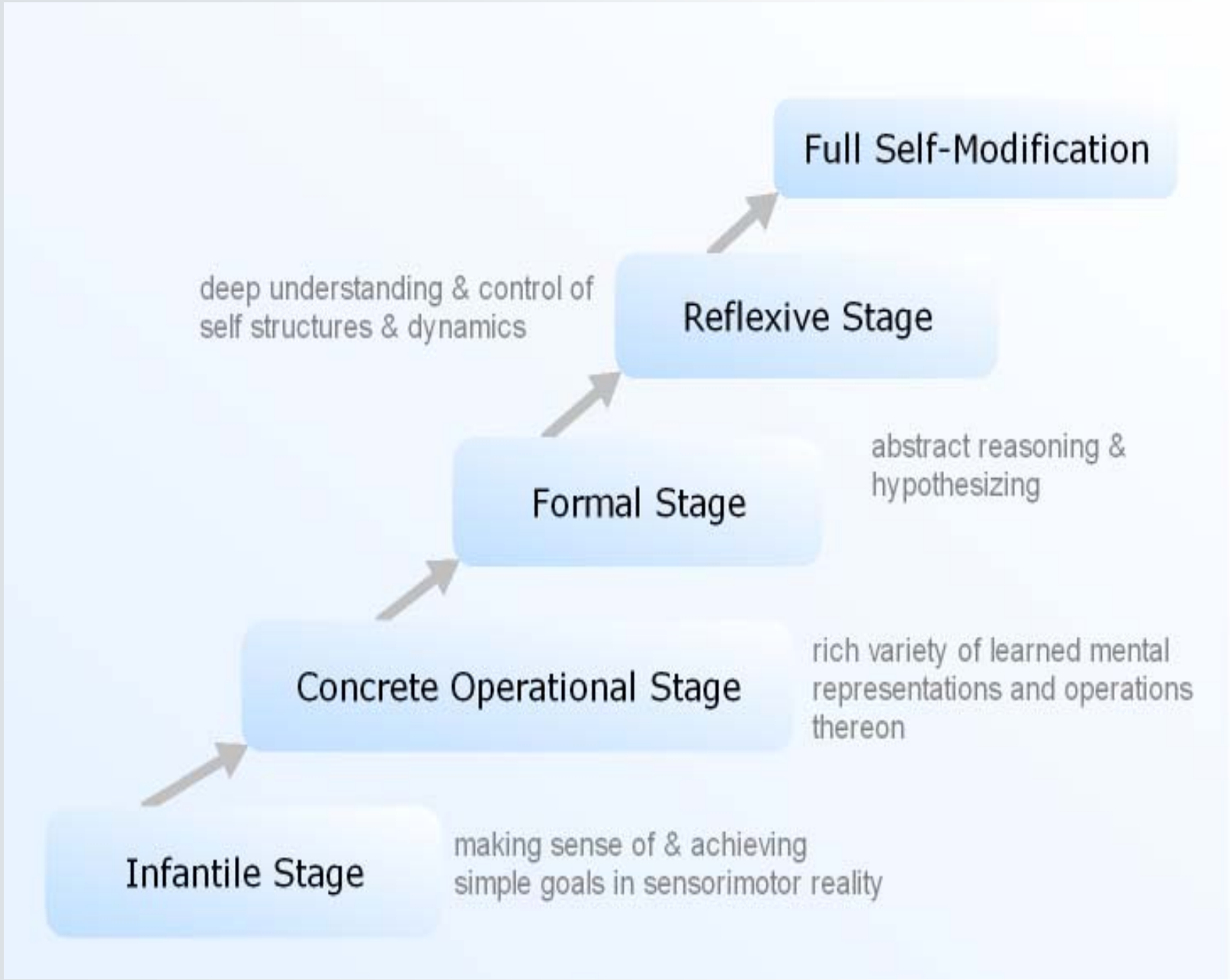
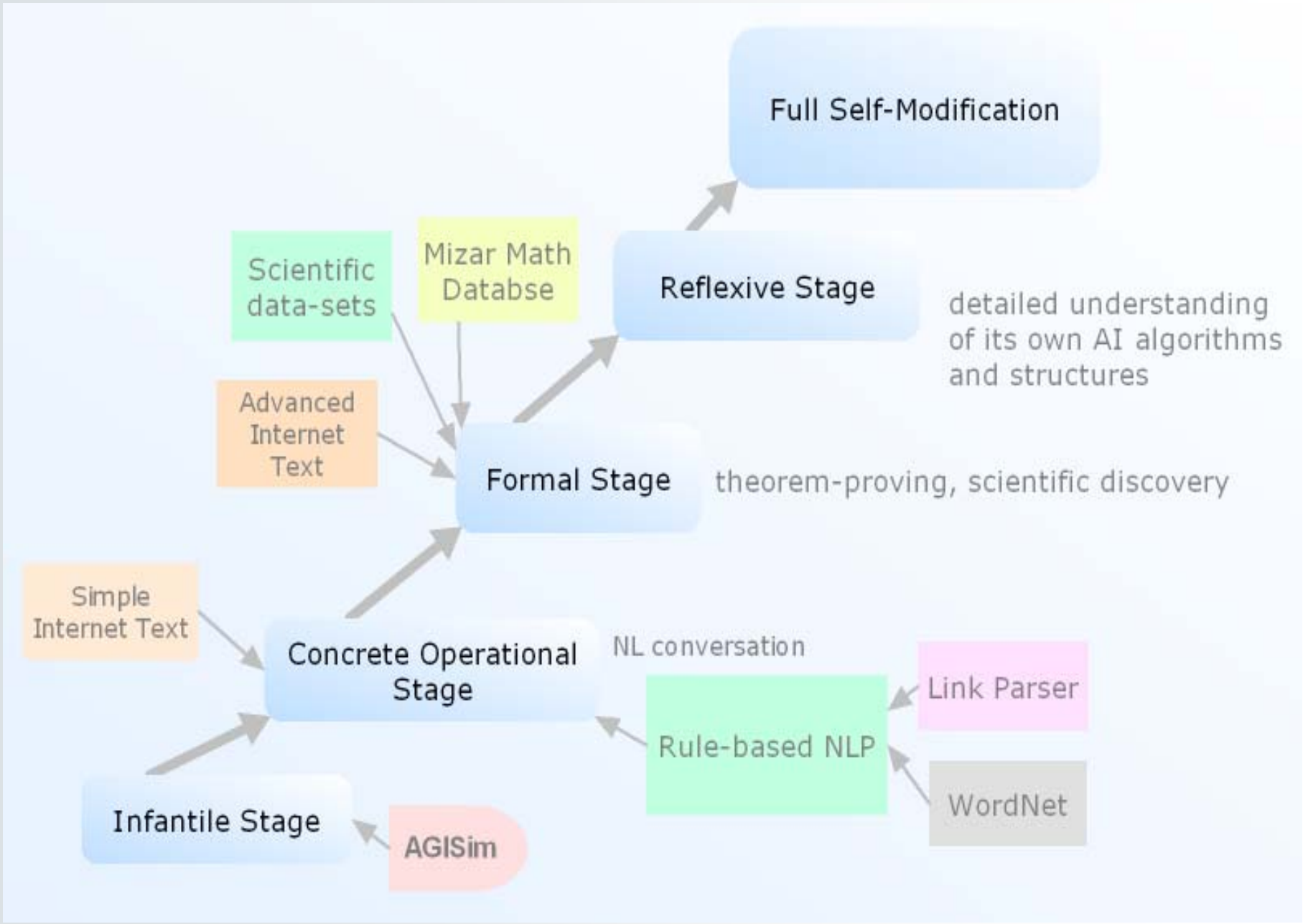

Full Self-Modification
deep understanding & control of self structures & dynamics
Reflexive Stage
Formal Stage
abstract reasoning & hypothesizing
Concrete Operational Stage
rich variety of learned mental representations and operations thereon
Infantile Stage
making sense of & achieving simple goals in sensorimotor reality


Full Self-Modification
Scientific data-sets
Mizar Math Databse
Reflexive Stage
detailed understanding of its own AI algorithms and structures
Advanced Internet Text
Formal Stage
theorem-proving, scientific discovery
Simple Internet Text
Concrete Operational Stage
NL conversation
Link Parser
Rule-based NLP
WordNet
Infantile Stage
AGISim

Artificial Cognitive Development :

Contents

(with Stephan Vladimir Bugaj, Ari Heljakka. ??)

1. Cognitive Development from a Systems Theory Perspective
2. Human versus Artificial Developmental Psychology
3. Object Recognition and Object Permanence
4. Grounding Semantic Primitives
5. Building the Phenomenal Self
6. Experiential Language Learning
7. Learning “Theory of Mind”
8. Learning Conservation Laws
9. Learning Ethical Behavior

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Knowledge Representation

Novamente's "Atom Space"

- Atoms = Nodes or Links
- Atoms have
  - Truth values (probability + weight of evidence)
  - Attention values (short and long term importance)
- The Atomspace is a weighted, labeled hypergraph

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Novamente's "Atom Space"

- Not a neural net
  - No activation values, no attempt at low-level brain modeling
- Not a semantic net
  - Atoms may represent percepts, procedures, or parts of concepts
  - Most Nodes do not correspond to any simple English label

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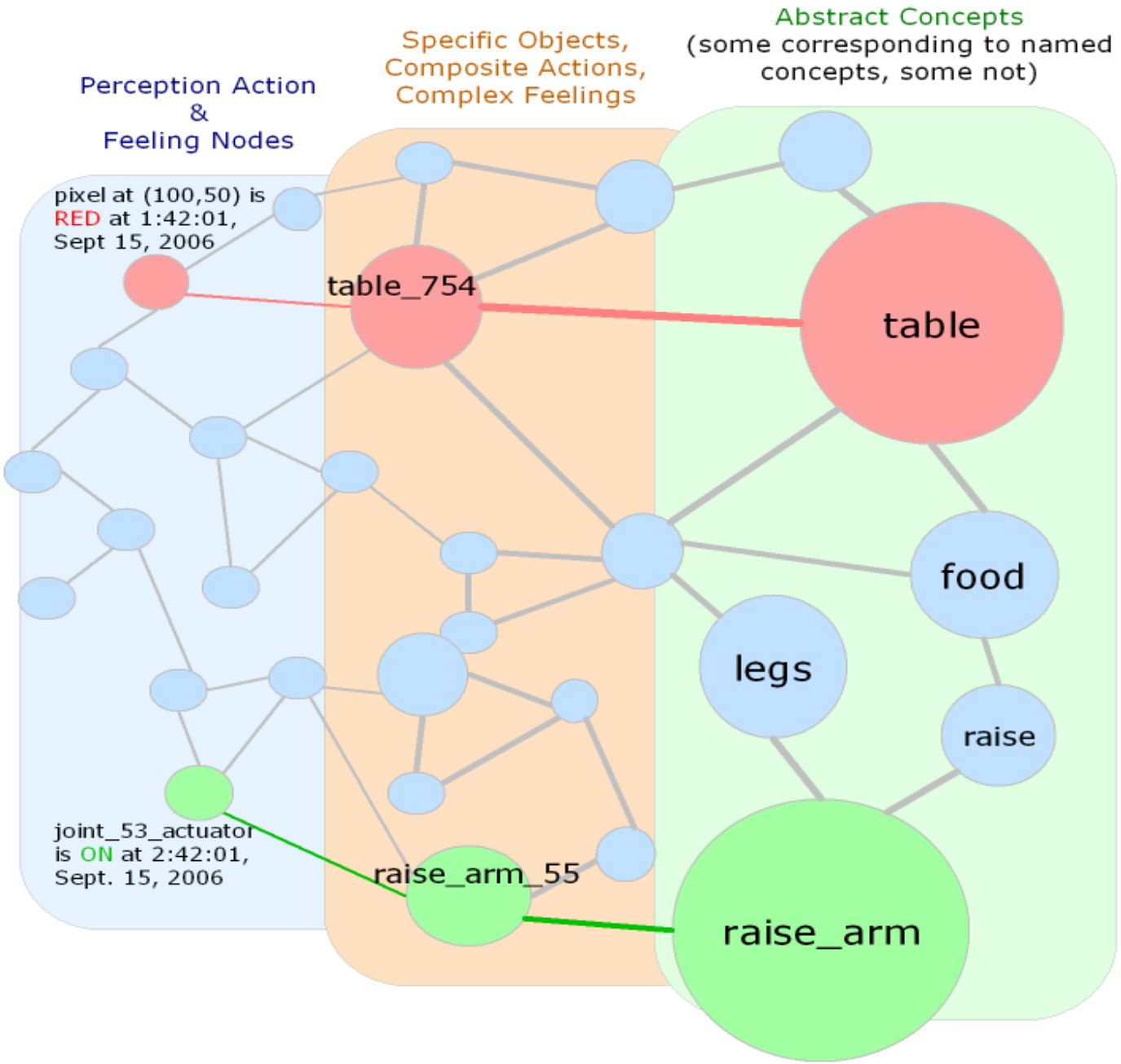
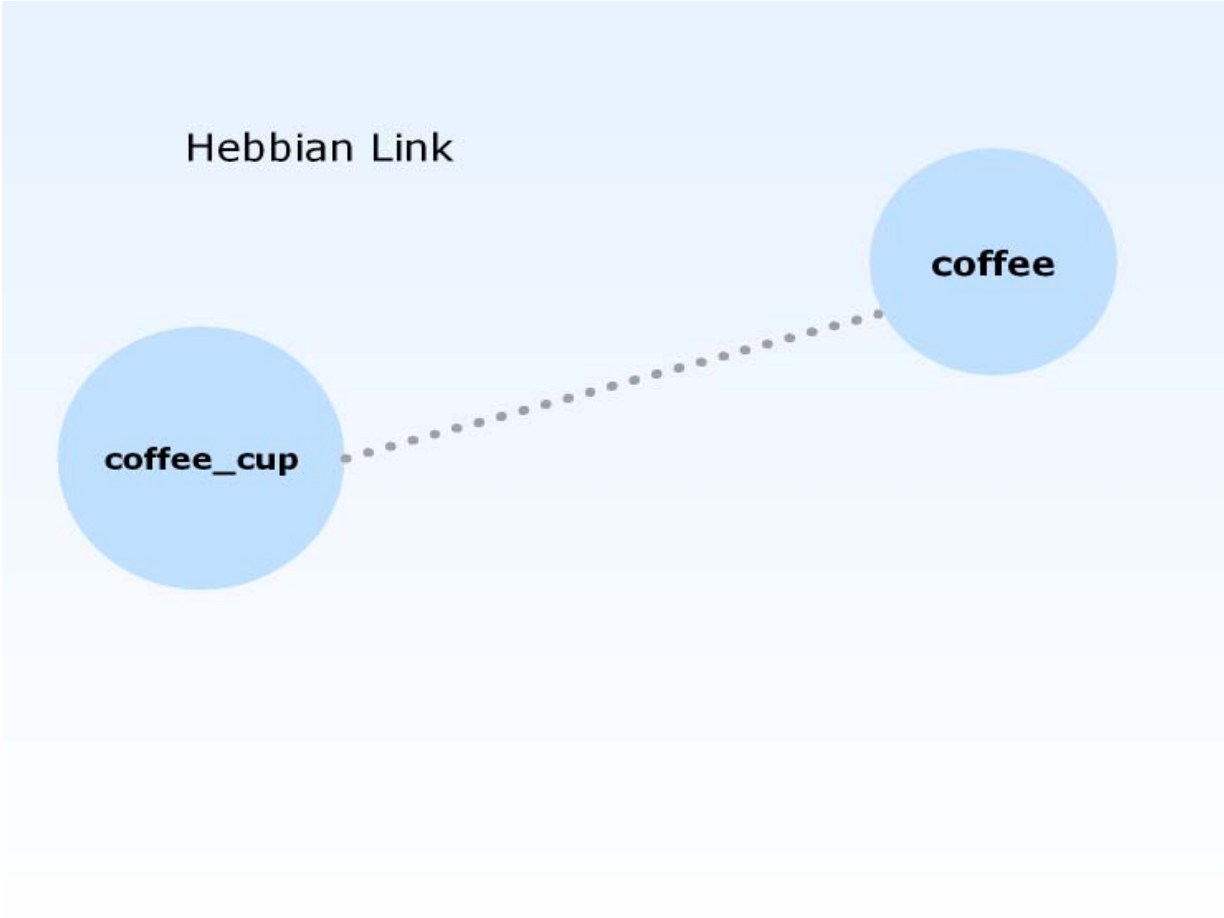

Perception Action
&
Feeling Nodes
Specific Objects,
Composite Actions,
Complex Feelings
Abstract Concepts
(some corresponding to named
concepts, some not)
pixel at (100,50) is
RED at 1:42:01,
Sept 15, 2006
table_754
table
food
legs
raise
joint_53_actuator
is ON at 2:42:01,
Sept. 15, 2006
raise_arm_55
raise_arm

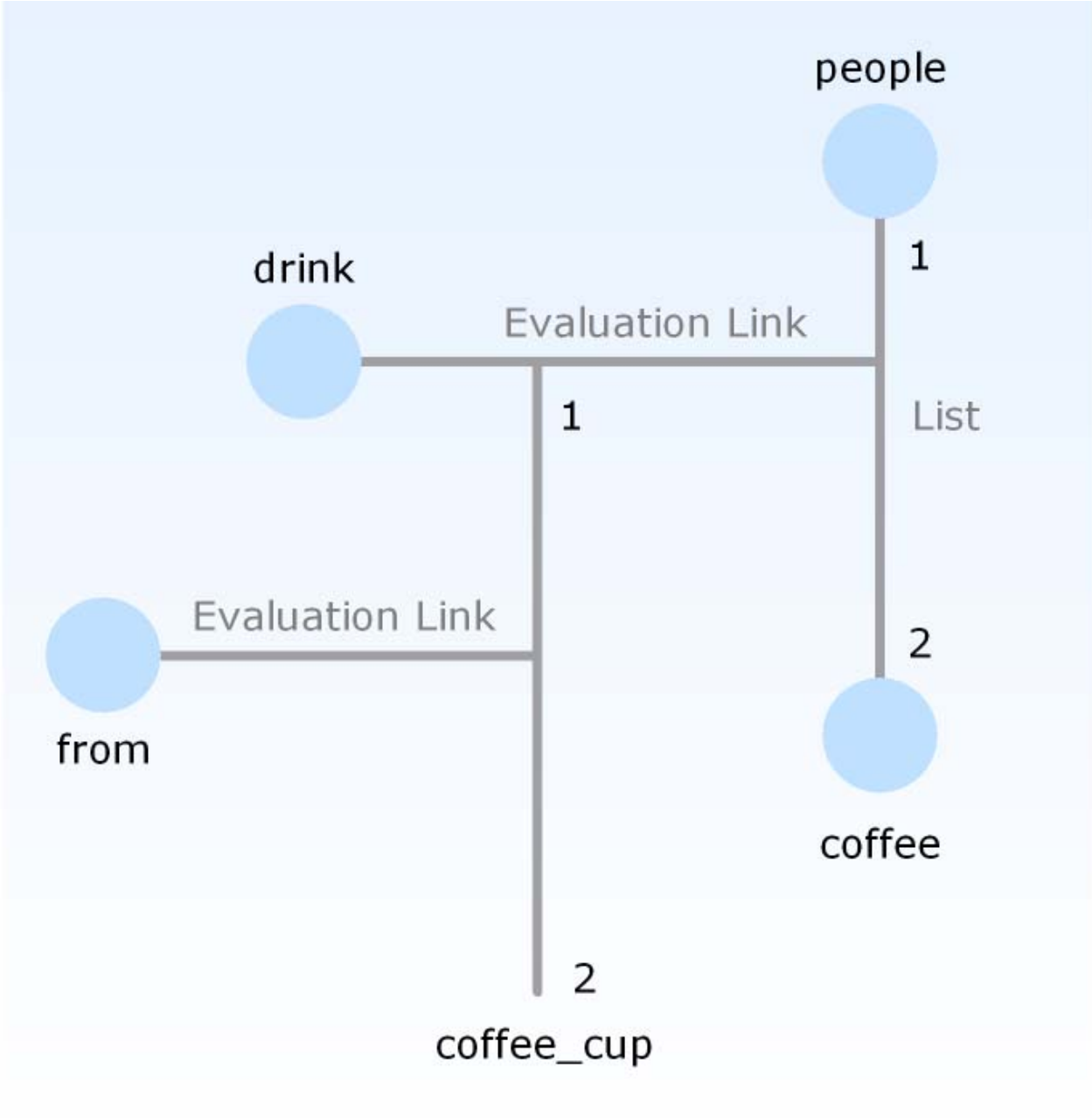
Node Variety	Description
Perceptual Nodes	These correspond to perceived items, like WordInstanceNode, CharacterInstanceNode, NumberInstanceNode, PixelInstanceNode
Procedure Nodes	These contain small programs called "schema," and are called SchemaNodes. Action Nodes that carry out logical evaluations are called PredicateNodes.
ConceptNodes	This is a "generic Node" used for two purposes. An individual ConceptNode may represent a category of Nodes. Or, a Map of ConceptNodes may represent a concept.
Psyche Nodes	These are GoalNodes and FeelingNodes, which are special PredicateNodes that play a special role in overall system control, in terms of monitoring system health, and orienting overall system behavior.

Link Variety	Description
Logical links	These represent symmetric or asymmetric logical relationships , either among Nodes (InheritanceLink, SimilarityLink), or among links and PredicateNodes (e.g. ImplicationLink, EquivalenceLink) .
MemberLink	These denote fuzzy set membership .
Associative links	These denote generic relatedness, including HebbianLink learned via Hebbian learning, and a simple AssociativeLink representing relationships derived from natural language or from databases.
ExecutionOutput Link	These indicate input-output relationships among SchemaNodes and PredicateNodes and their arguments.
Action-Concept links	Called ExecutionLinks and EvaluationLinks, these form a conceptual record of the actions taken by SchemaNodes or PredicateNodes .
ListLink and concatListLink	These represent internally-created or externally-observed lists, respectively .

Links may denote generic association …



…or precisely specified relationships


people
1
drink
Evaluation Link
1
List
Evaluation Link
2
from
coffee
2
coffee_cup

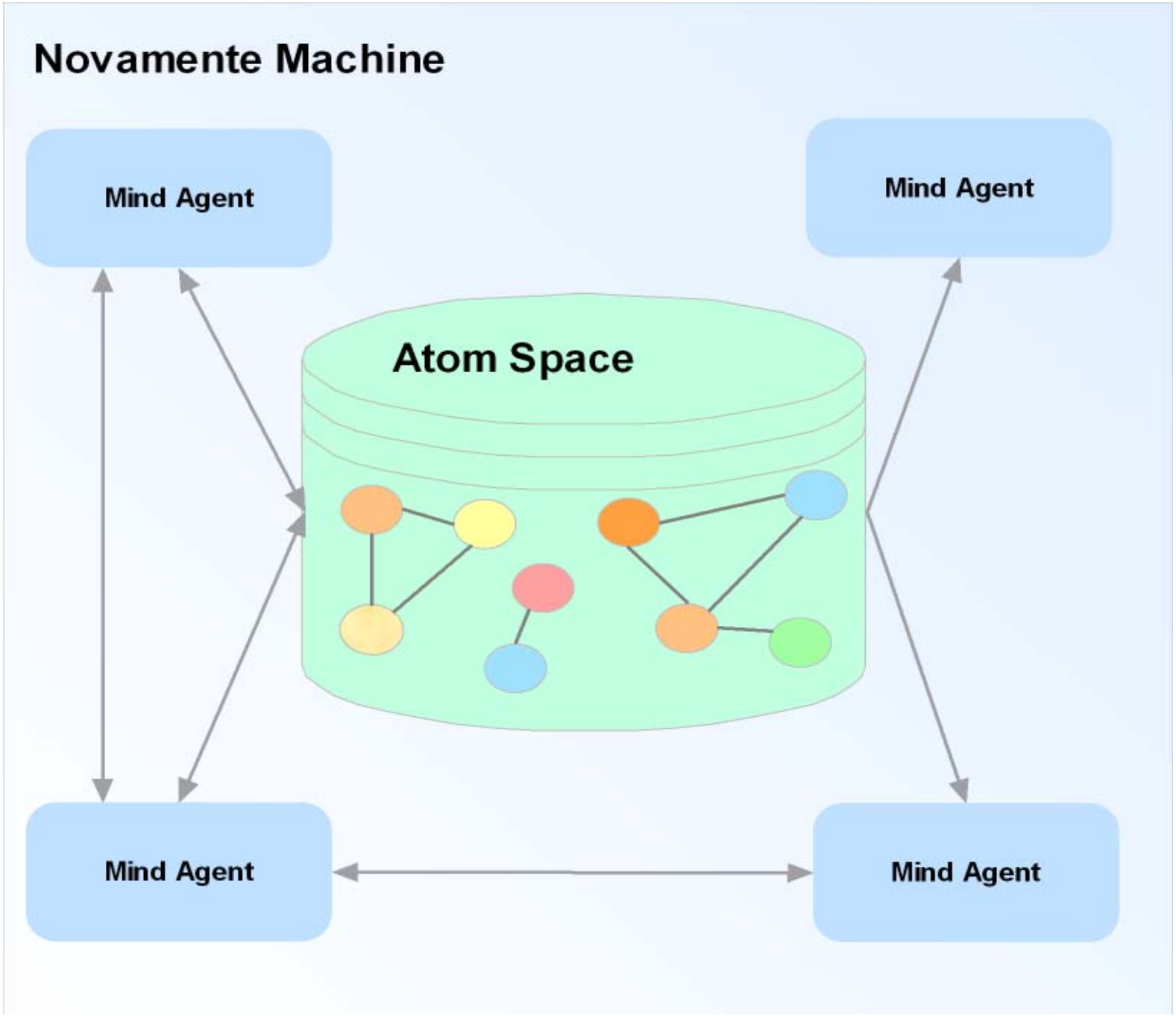
Attention Values

	Low Long-term Importance	High Long-term Importance
Low Short-term Importance	Useless	Remembered but not currently used (e.g. mother's phone #)
High Short-term Importance	Used then forgotten (e.g. most precepts)	Used and remembered

Truth Values

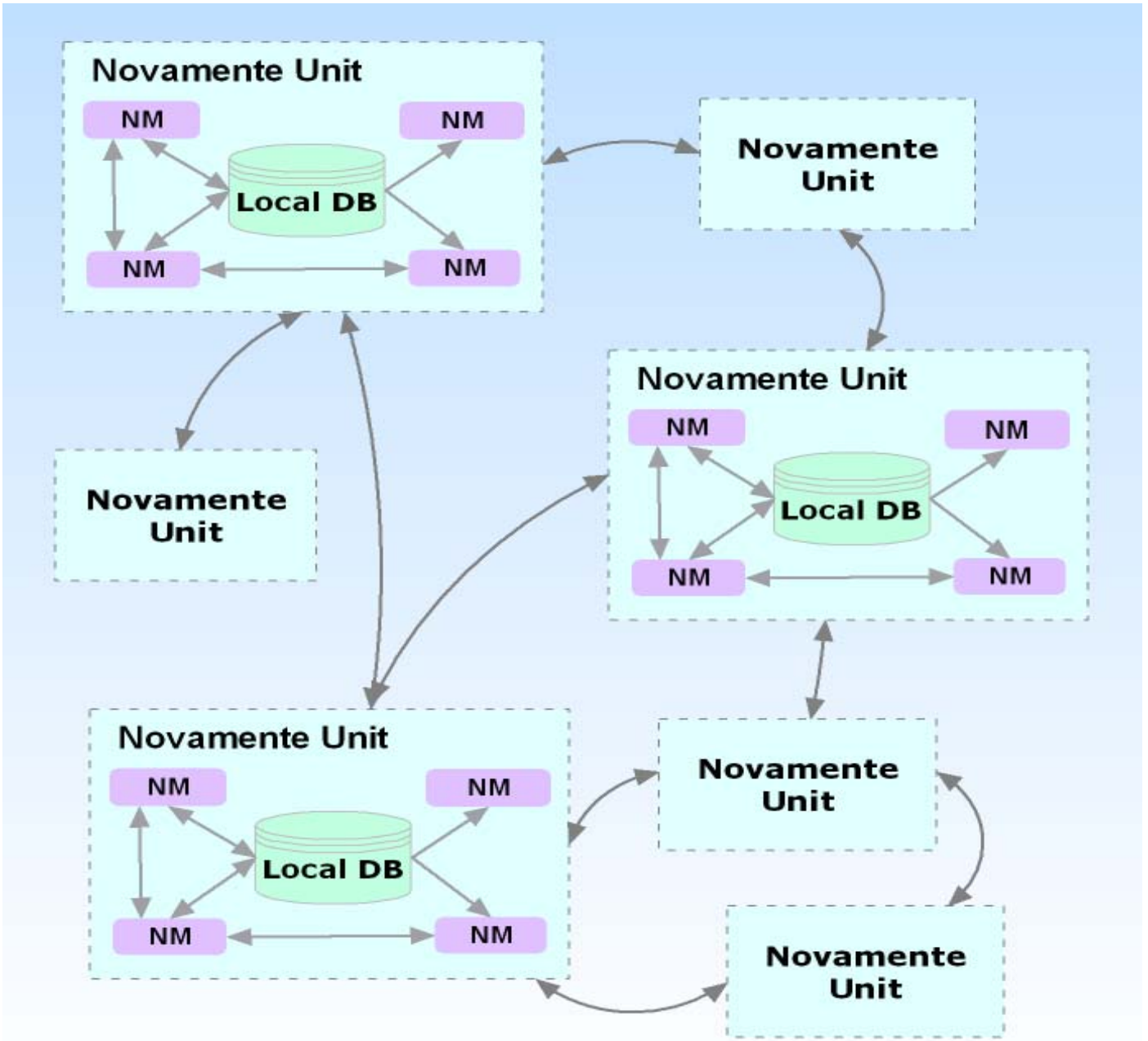
	Strength low	Strength high
Weight of evidence low	Weakly suspected to be false	Weakly suspected to be true
Weight of evidence high	Firmly known to be false	Firmly known to be true

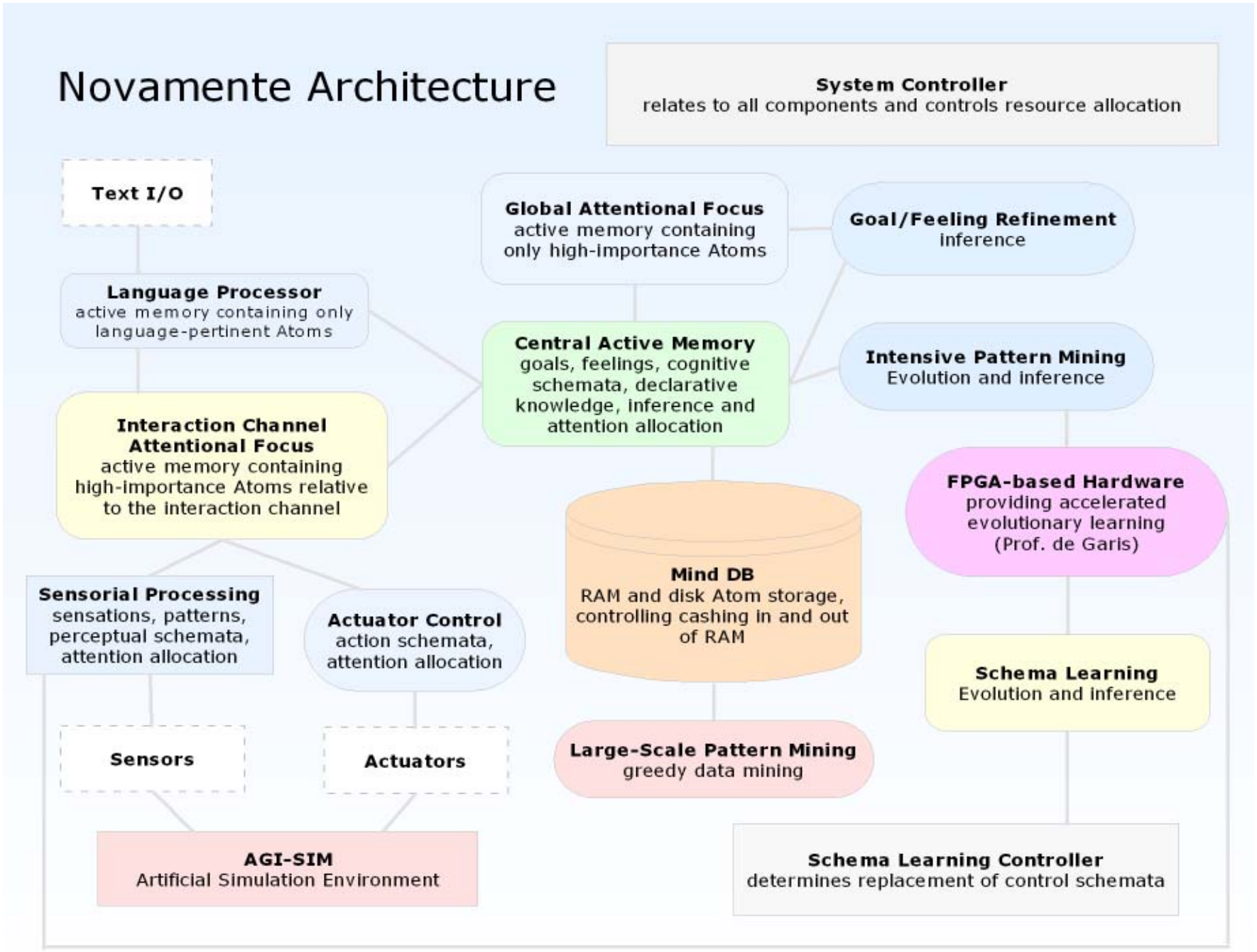
Software Architecture

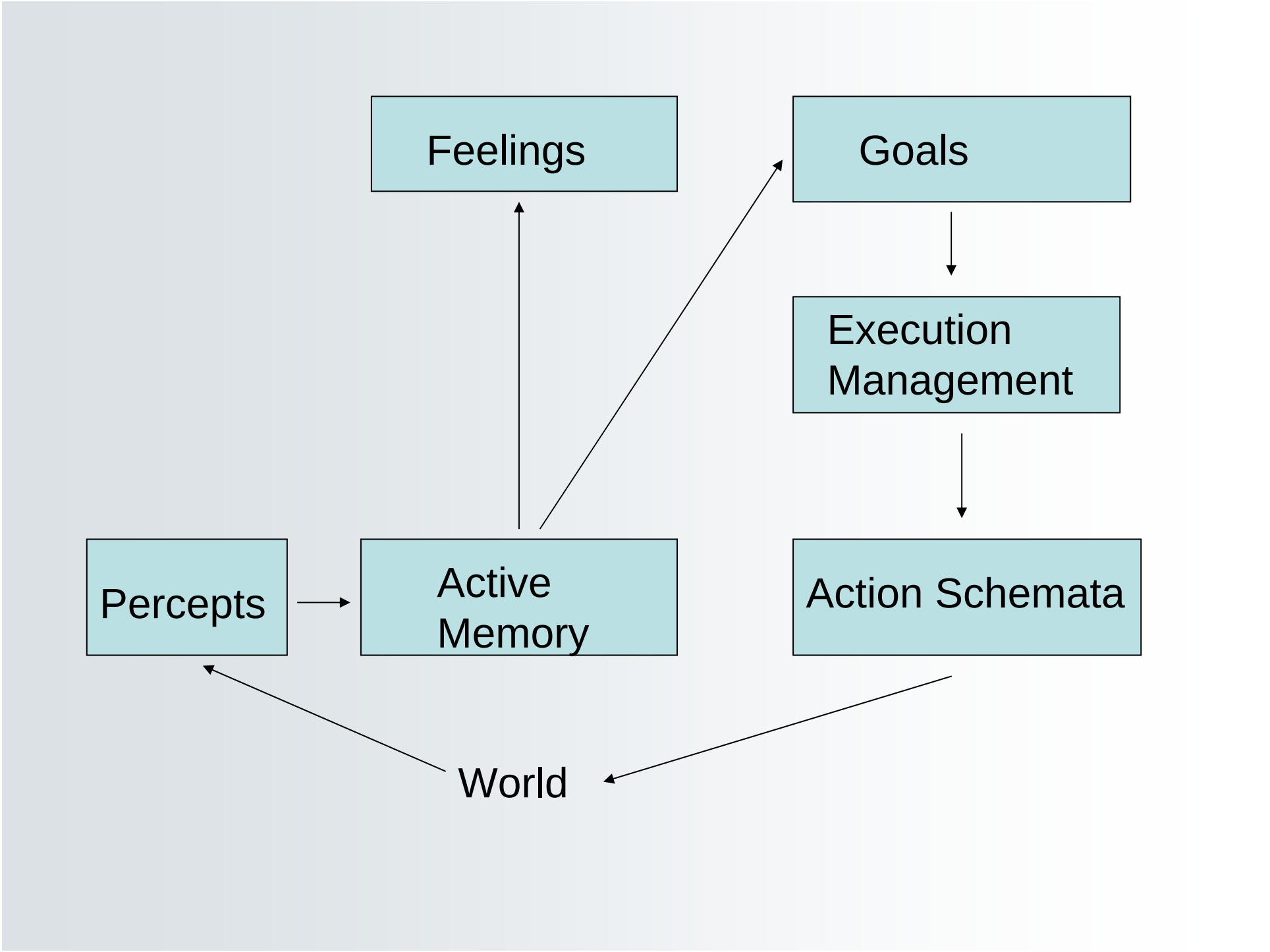

Novamente Machine
Mind Agent
Mind Agent
Atom Space
Mind Agent
Mind Agent

MindAgent	Function
Spontaneous Inference	Uses PLN inference to infer new links from existing ones, driven by a general "fitness function" that aims to create surprising or useful information
Goal-Directed Inference	Uses PLN inference to figure out ho w to achieve current goals
Goal Refinement	Uses PLN inference and heuristics to create new goals refining existing ones
Predicate Schematization	Transforms logical knowledge regarding goal achievement into schemata that can be executed to achieve goals
LogicalLinkMining	Creates logical links out of nonlogical links (a form of pattern recognition)
Evolutionary Predicate Learning	Creates PredicateNodes containing predicates that predict membership in ConceptNodes
Clustering	Creates ConceptNodes represent ing clusters of existing ConceptNodes
Importance Updating	Updates Atom "importance" variables and other related quantities
Hebbian Association Formation	Builds and modifies HebbianLinks between Atoms, based on a PLN-derived Hebbian reinforcement learning rule
Evolutionary Schema Learning	Creates SchemaNodes that fulfill criteria, e.g. that are expected to satisfy given GoalNodes
Concept Formation	Creates speculative, potentially interesting new ConceptNodes via blending existing ones

MindAgent	Function (Table Continued)
Predicate/Schema Formation	Creates speculative, potentially interesting new SchemaNodes and PredicateNodes by blending existing ones
Schema Execution	Enacts active SchemaNodes, allowing the system to carry out coordi nated trains of action
Map Encapsulation	Scans the AtomTable for patterns and creates new Atoms embodying these patterns
Map Expansion	Takes schemata and predicates embodied in nodes, and expands them into multiple Nodes and links in the AtomTable (thus transforming complex Atoms into Maps of simple Atoms)
Homeostatic Parameter Adaptation	Applies evolutionary programming to adaptively tune the parameters of the system


Novamente Unit
NM
NM
Local DB
NM
NM
Novamente Unit
Novamente Unit
Novamente Unit
NM
NM
Local DB
NM
NM
Novamente Unit
Novamente Unit
Novamente Unit
NM
NM
Local DB
NM
NM
Novamente Unit
Novamente Unit


Novamente Architecture
System Controller
relates to all components and controls resource allocation
Text I/O
Global Attentional Focus
active memory containing only high-importance Atoms
Goal/Feeling Refinement
inference
Language Processor
active memory containing only language-pertinent Atoms
Central Active Memory
goals, feelings, cognitive schemata, declarative knowledge, inference and attention allocation
Intensive Pattern Mining
Evolution and inference
Interaction Channel Attentional Focus
active memory containing high-importance Atoms relative to the interaction channel
FPGA-based Hardware
providing accelerated evolutionary learning (Prof. de Garis)
Mind DB
RAM and disk Atom storage, controlling cashing in and out of RAM
Sensorial Processing
sensations, patterns, perceptual schemata, attention allocation
Actuator Control
action schemata, attention allocation
Schema Learning
Evolution and inference
Sensors
Actuators
Large-Scale Pattern Mining
greedy data mining
AGI-SIM
Artificial Simulation Environment
Schema Learning Controller
determines replacement of control schemata


Feelings
Goals
Execution Management
Percepts
Active Memory
Action Schemata
World

Learning Dynamics

Engineering General Intelligence:

Contents

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Probabilistic Logic Networks:

Contents

(with Matt Ikle', Izabela Freire Goertzel, Ari Heljakka)

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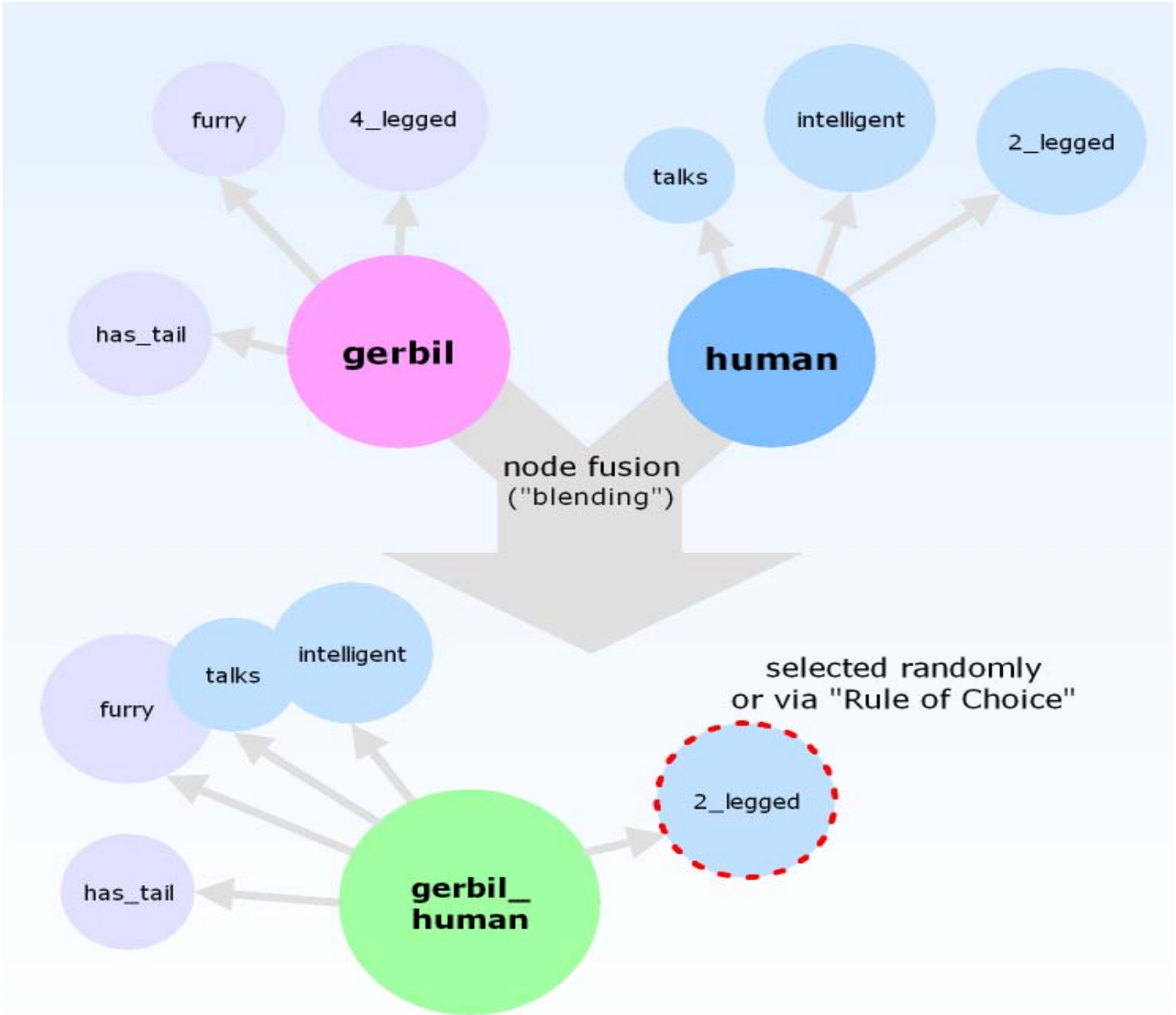
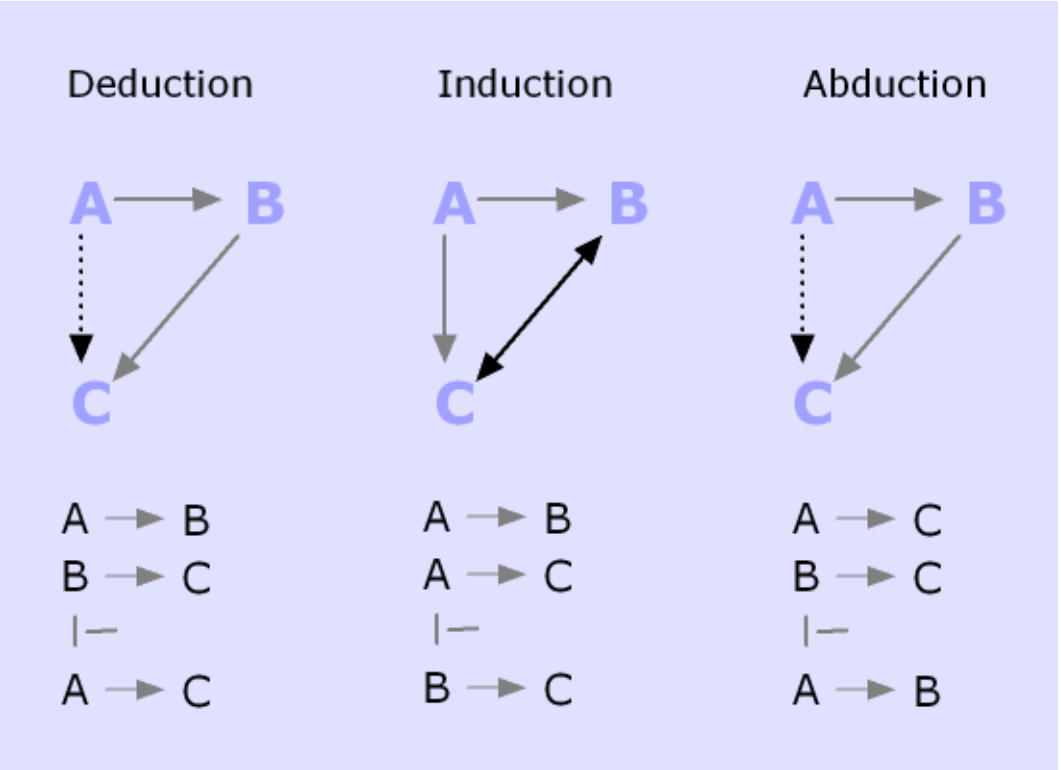
Novamente contains multiple heuristics for Atom creation, including "blending" of existing Atoms



Example PLN Rules Acting on ExtensionalInheritanceLinks



Unification:

```
  Imp <1.00, 0.95>
     AND
        Inh($t,toy)
        Inh($b,bucket)
        Eval placed_under($t,$b)
     Eval found_under($t,$b)
  Inh (toy_6,toy)
  Inh (red_bucket_6,bucket)
  Eval placed_under(toy_6,red_bucket_6)
  AND <1.00, 0.98>
     Inh (toy_6,toy)
     Inh (red_bucket_6,bucket)
     Eval placed_under(toy_6,red_bucket_6)

|-

Imp <1.00, 0.95>
  AND <1.00, 0.98>
     Inh (toy_6,toy)
     Inh (red_bucket_6,bucket)
     Eval placed_under(toy_6,red_bucket_6)
  Eval found_under(toy_6,red_bucket_6)
```

Higher-order PLN inference handles complex inferences with variables, quantifiers, etc.

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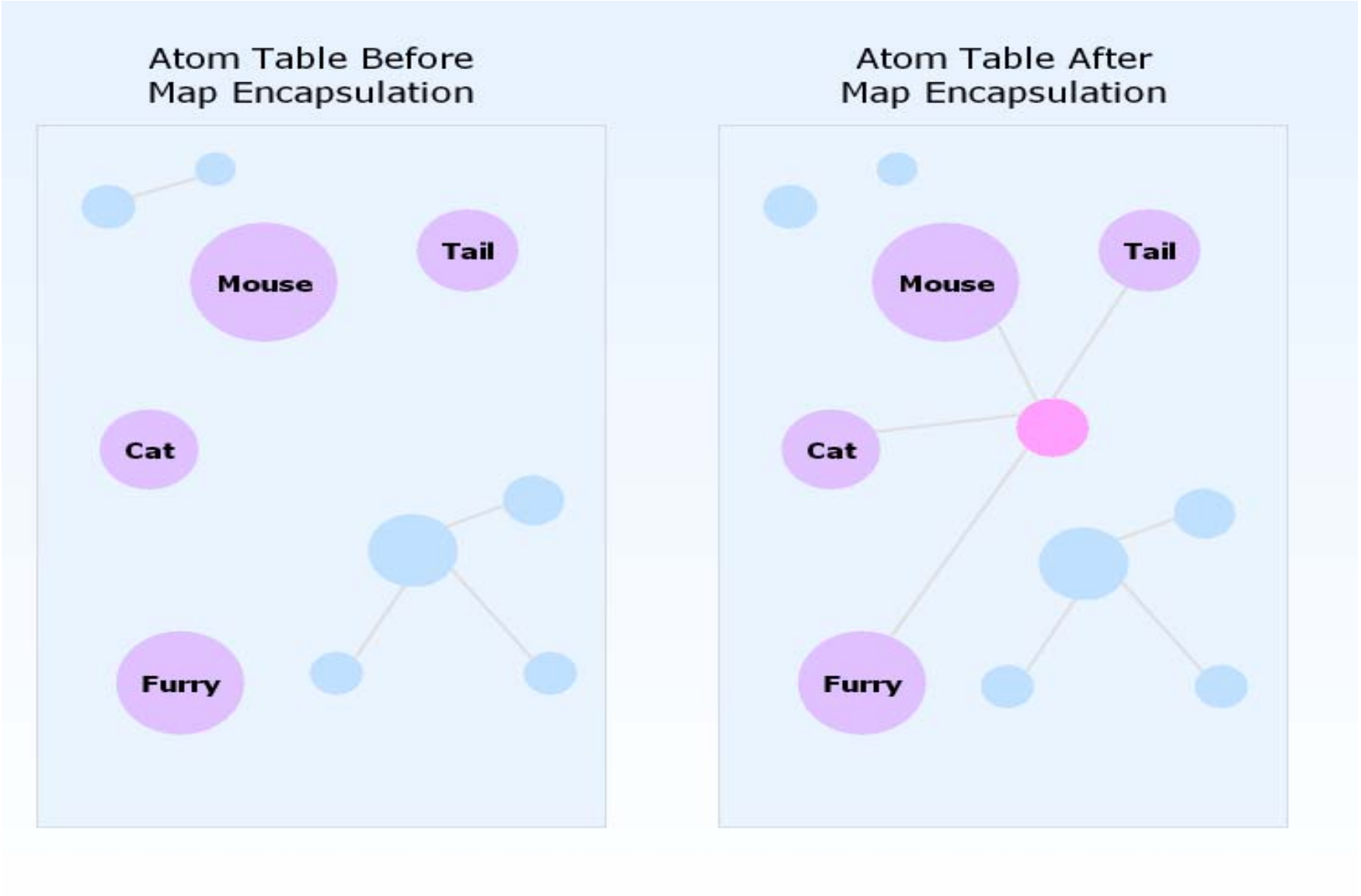
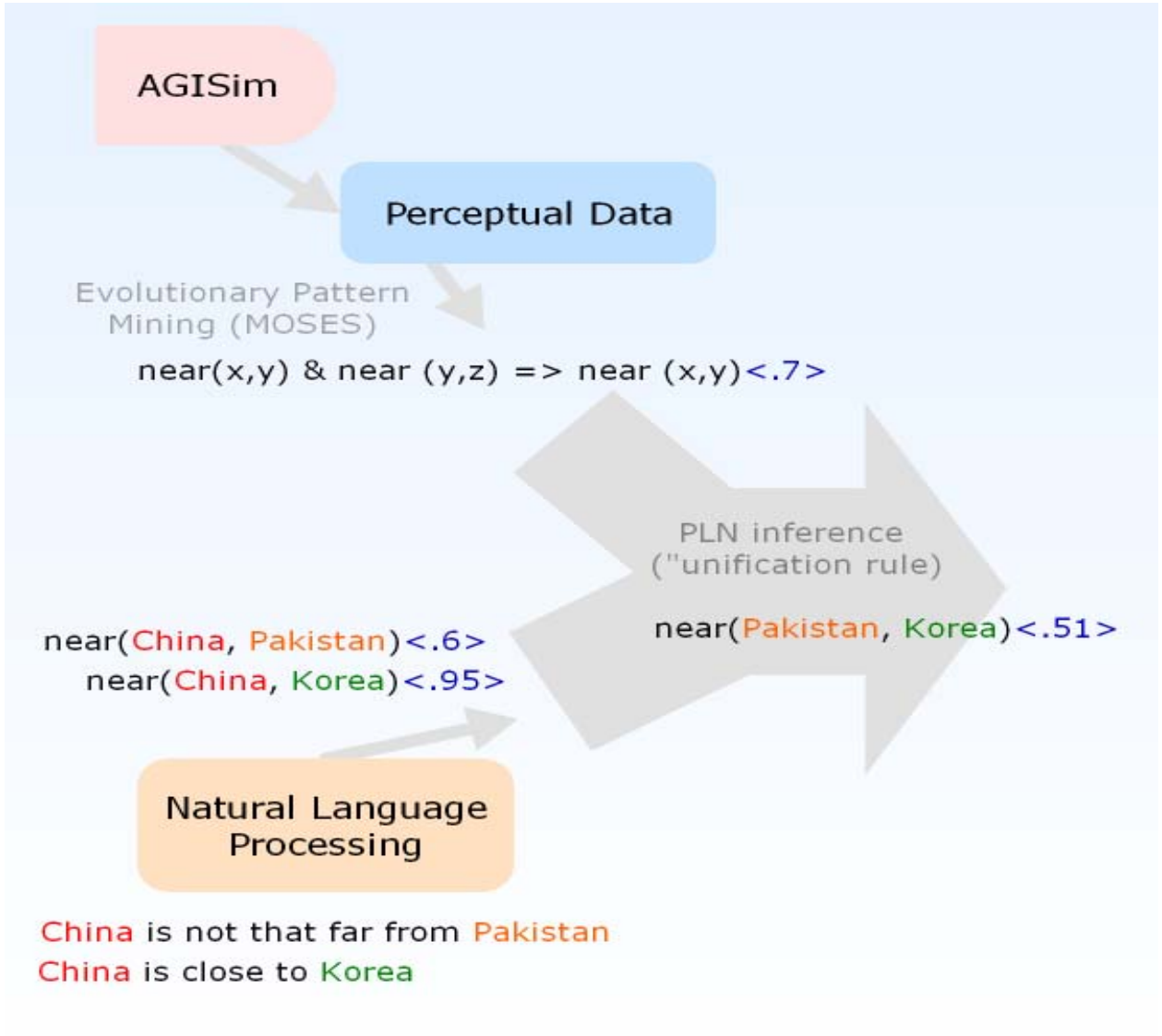
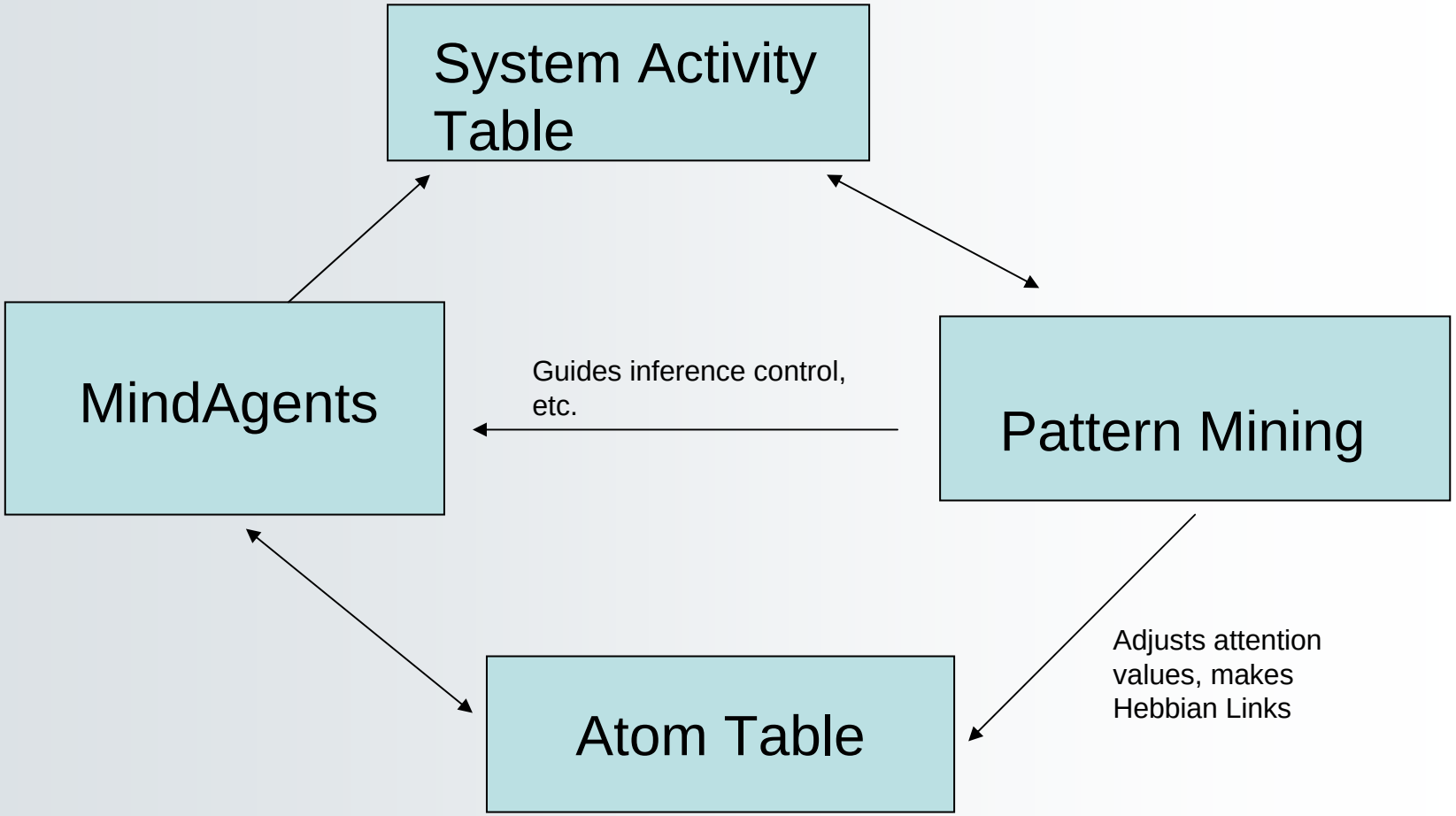
Atoms associated in a dynamic “map” may be grouped to form new Atoms: the Atomspace hence *explicitly representing patterns in itself*



Grounding of natural language constructs is provided via inferential integration of data gathered from linguistic and perceptual inputs



Attention Allocation

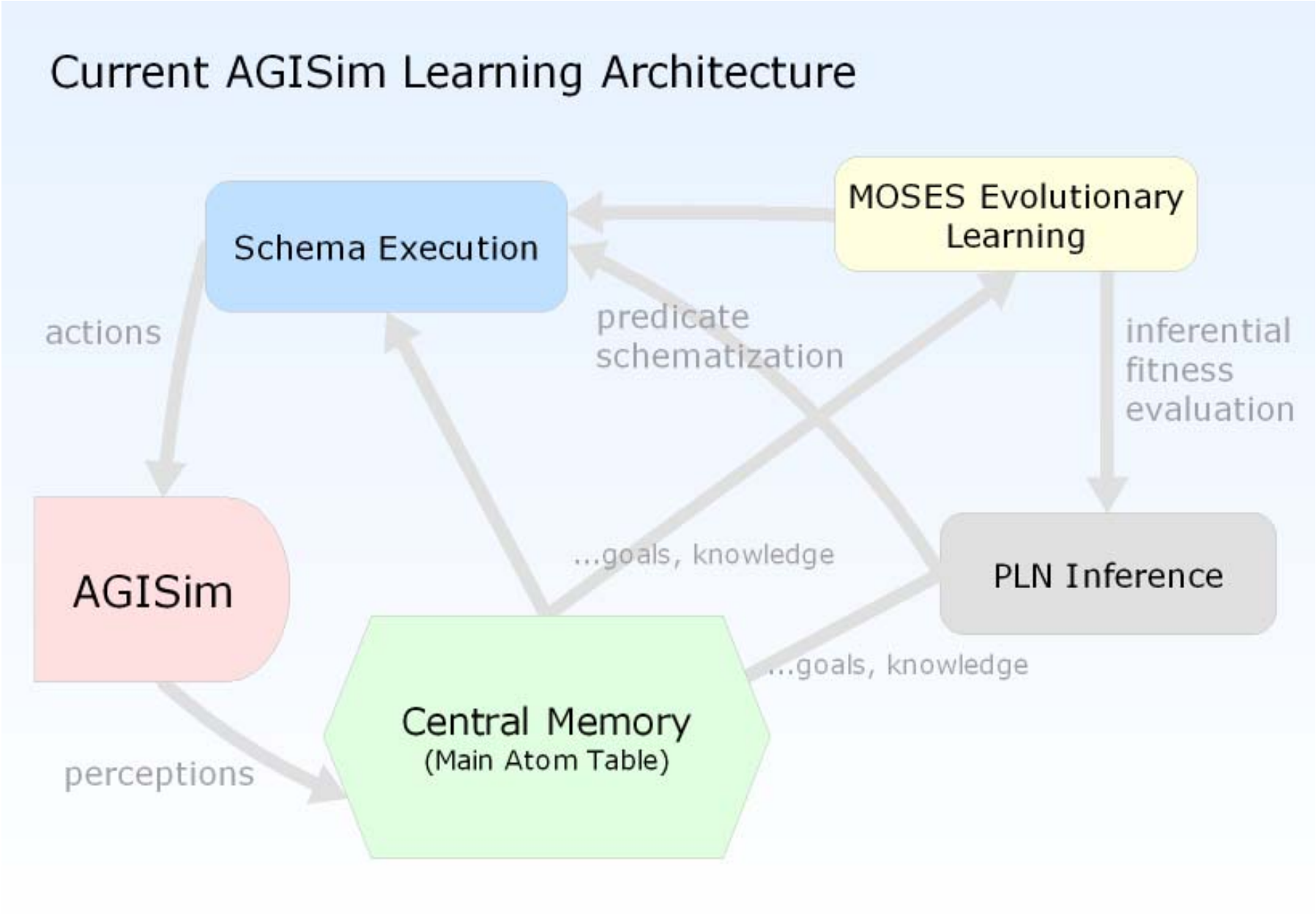


Novamente:

The Current Reality

Implemented Components

- **Novamente core system**
  - AtomTable, MindAgents, Scheduler, etc.
  - Now runs on one machine; designed for distributed processing
- **PLN**
  - Relatively crude inference control heuristics
  - Simplistic predicate schematization
- **MOSES**
  - Little experimentation has been done evolving procedures with complex control structures
- **Schema execution framework**
  - Enacts learned procedures
- **AGISim**
  - And proxy for communication with NM core
- **NLP front end**
  - External NLP system for “cheating” style knowledge ingestion


Current AGISim Learning Architecture
Schema Execution
MOSES Evolutionary Learning
actions
predicate schematization
inferential fitness evaluation
AGISim
...goals, knowledge
PLN Inference
...goals, knowledge
Central Memory
(Main Atom Table)
perceptions

Simple, Initial AGISim Experiments

- Fetch
- Tag
- Piagetan A-not-B experiment
- Word-object association

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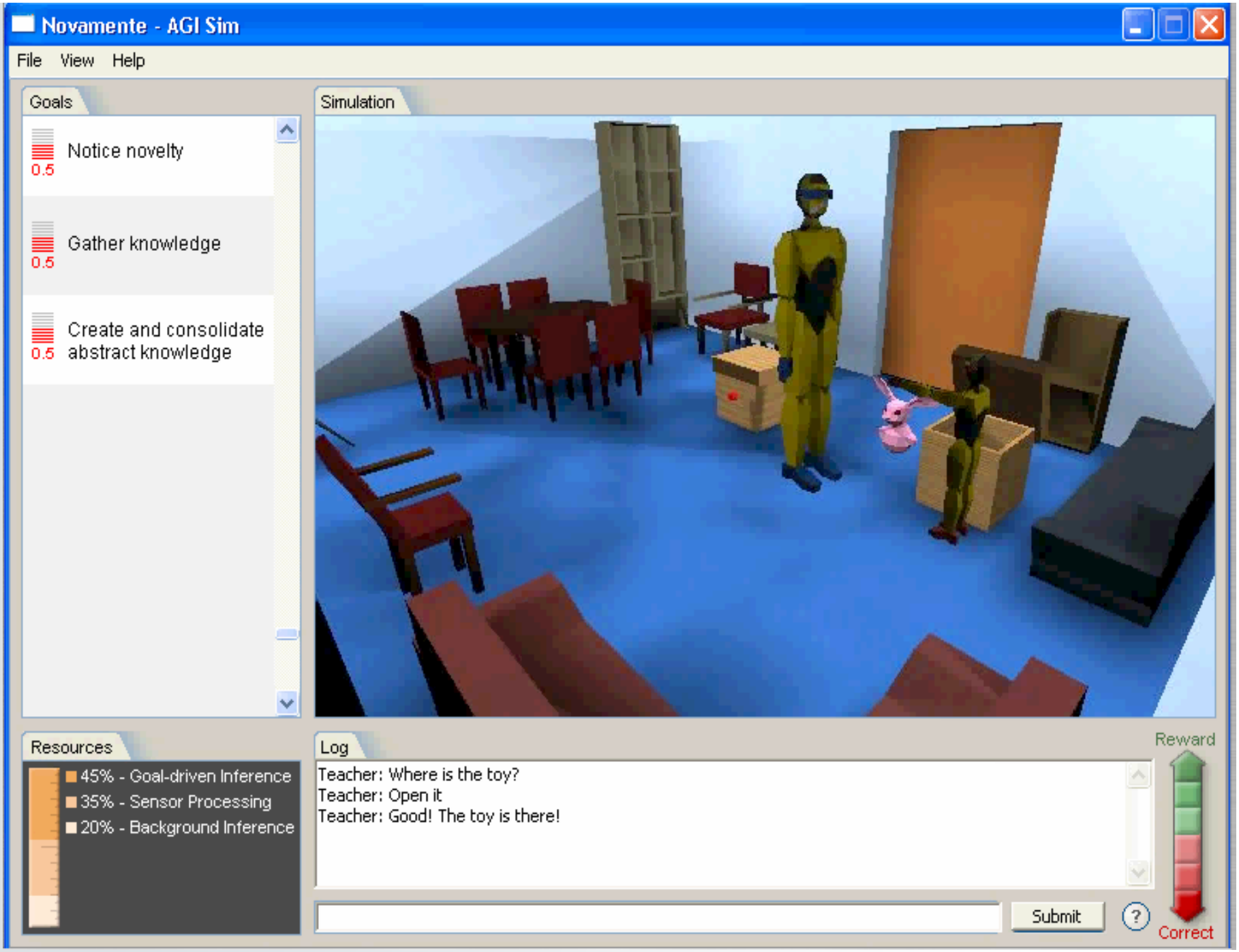

Novamente - AGI Sim
File
View
Help
Goals
Notice novelty
0.5
Gather knowledge
0.5
Create and consolidate abstract knowledge
0.5
Simulation
Resources
45% - Goal-driven Inference
35% - Sensor Processing
20% - Background Inference
Log
Teacher: Where is the toy?
Teacher: Open it
Teacher: Good! The toy is there!
Submit
Reward
Correct

Inference Trajectory for A-not-B

Target:

Eval found_under(toy_6,$1)

Step 1

ANDRule:

Inh (toy_6,toy)
Inh (red_bucket_6,bucket)
Eval placed_under(toy_6,red_bucket_6)
|-
AND <1.00, 0.98>
Inh (toy_6,toy)
Inh (red_bucket_6,bucket)
Eval placed_under(toy_6,red_bucket_6)

Step 2

Unification:

Imp <1.00, 0.95>
AND
Inh($t,toy)
Inh($b,bucket)
Eval placed_under($t,$b)
Eval found_under($t,$b)
AND
Inh (toy_6,toy)
Inh (red_bucket_6,bucket)
Eval placed_under(toy_6,red_bucket_6)
|-
Imp <1.00, 0.94>
AND
Inh (toy_6,toy)
Inh (red_bucket_6,bucket)
Eval placed_under(toy_6,red_bucket_6)
Eval found_under(toy_6,red_bucket_6)

Step 3

Modus Ponens

Imp <1.00, 0.94>
AND
Inh (toy_6,toy)
Inh (red_bucket_6,bucket)
Eval placed_under(toy_6,red_bucket_6)
Eval found_under(toy_6, red_bucket_6)
AND <1.00, 0.98>
Inh (toy_6,toy)
Inh (red_bucket_6,bucket)
Eval placed_under(toy_6,red_bucket_6)
|-
Eval found_under(toy_6, red_bucket_6) <1.00, 0.93>

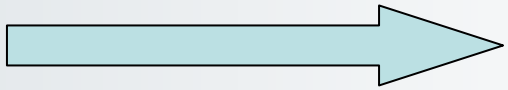
Predicate Schematization

Logical knowledge

EvPredImp <0.95, 0.3>
    Execution try(goto box)
    Eval near box

SimultaneousImplication
    Eval near box
    Eval can_do(push box)

EvPredImp <0.6,0.4>
  And
    Eval can_do(push box)
    Execution try(push box)
  Evaluation Reward



Predicate schematization

Executable procedure

repeat
  goto box
  near box
repeat
  push box
  Reward

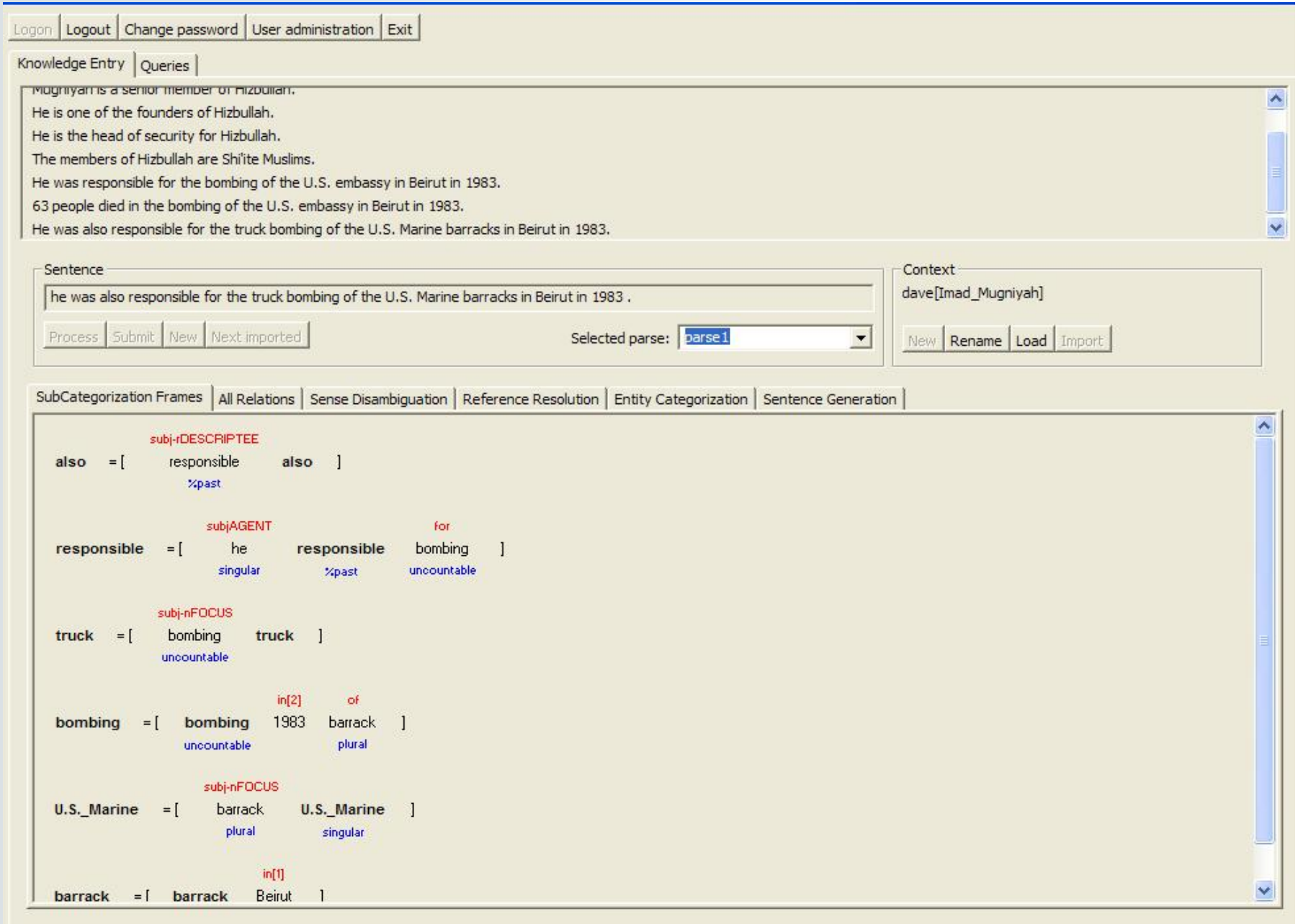
NLP Subsystem

- RelEx (Relationship Extractor)
  - Developed under subcontract to INSCOM
  - Based on Carnegie-Mellon link parser
  - Add hand-crafted semantic mapping rules
  - Add statistical methods for disambiguation and reference resolution
  - Designed to allow easy feeding of NL knowledge into Novamente
  - Can be modified to enable simple language generation
- INLINK
  - Interactive system for NL knowledge entry
  - Allows user to correct RelEx's mistakes prior to submission of knowledge into Novamente

NLP Subsystem

Viewed as “scaffolding” from an AGI perspective

Using it, we may feed Novamente semantic information that will help guide its experiential, embodied language learning process


Logon
Logout
Change password
User administration
Exit
Knowledge Entry
Queries
He is one of the founders of Hizbullah.
He is the head of security for Hizbullah.
The members of Hizbullah are Shi'ite Muslims.
He was responsible for the bombing of the U.S. embassy in Beirut in 1983.
63 people died in the bombing of the U.S. embassy in Beirut in 1983.
He was also responsible for the truck bombing of the U.S. Marine barracks in Beirut in 1983.
Sentence
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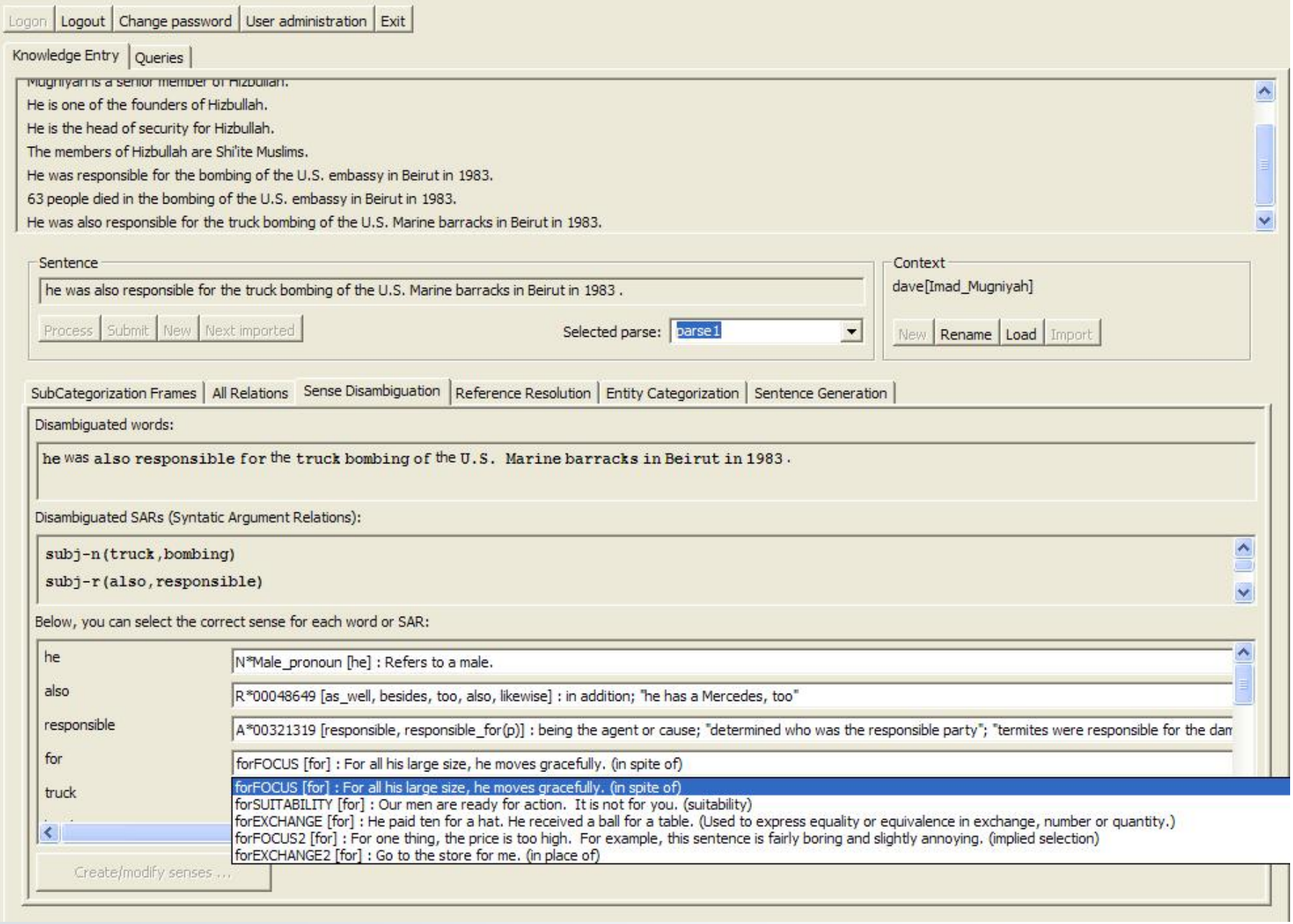
Process
Submit
New
Next imported
Selected parse:
parse1
Context
dave[Imad_Mugniyah]
New
Rename
Load
Import
SubCategorization Frames
All Relations
Sense Disambiguation
Reference Resolution
Entity Categorization
Sentence Generation
subj-rDESCRIPTEE
also = [responsible also]
%past
subjAGENT for
responsible = [he responsible bombing]
singular %past uncountable
subj-nFOCUS
truck = [bombing truck]
uncountable
in[2] of
bombing = [bombing 1983 barrack]
uncountable plural
subj-nFOCUS
U.S._Marine = [barrack U.S._Marine]
plural singular
in[1]
barrack = [barrack Beirut]


Logon
Logout
Change password
User administration
Exit
Knowledge Entry
Queries
Mughniyah is a senior member of Hizbullah.
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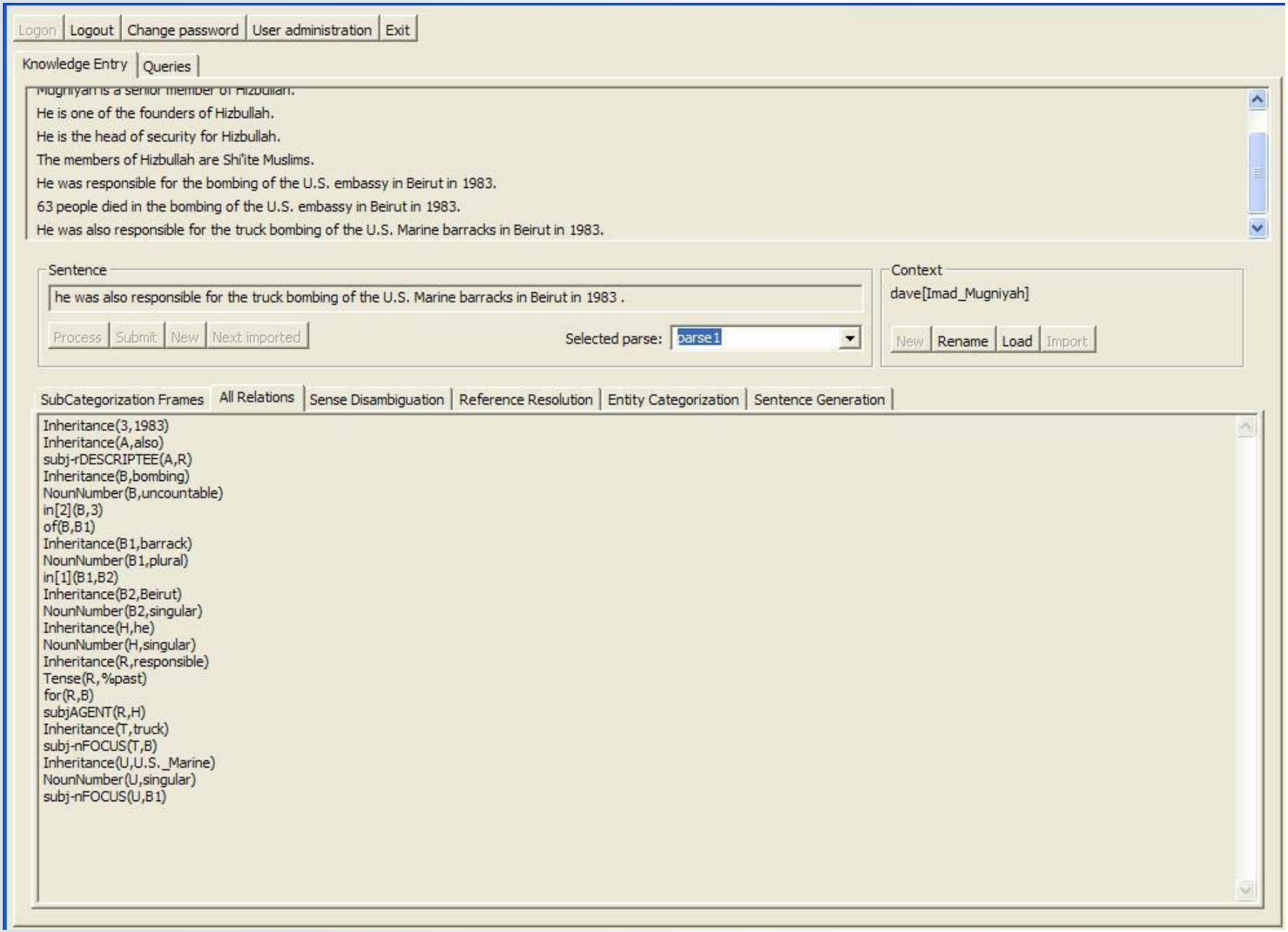
Sentence Generation
Disambiguated words:
he was also responsible for the truck bombing of the U.S. Marine barracks in Beirut in 1983 .
Disambiguated SARs (Syntatic Argument Relations):
subj-n(truck,bombing)
subj-r(also,responsible)
Below, you can select the correct sense for each word or SAR:
he
N*Male_pronoun [he] : Refers to a male.
also
R*00048649 [as_well, besides, too, also, likewise] : in addition; "he has a Mercedes, too"
responsible
A*00321319 [responsible, responsible_for(p)] : being the agent or cause; "determined who was the responsible party"; "termites were responsible for the dam
for
forFOCUS [for] : For all his large size, he moves gracefully. (in spite of)
truck
forFOCUS [for] : For all his large size, he moves gracefully. (in spite of)
forSUITABILITY [for] : Our men are ready for action. It is not for you. (suitability)
forEXCHANGE [for] : He paid ten for a hat. He received a ball for a table. (Used to express equality or equivalence in exchange, number or quantity.)
forFOCUS2 [for] : For one thing, the price is too high. For example, this sentence is fairly boring and slightly annoying. (implied selection)
forEXCHANGE2 [for] : Go to the store for me. (in place of)
Create/modify senses ...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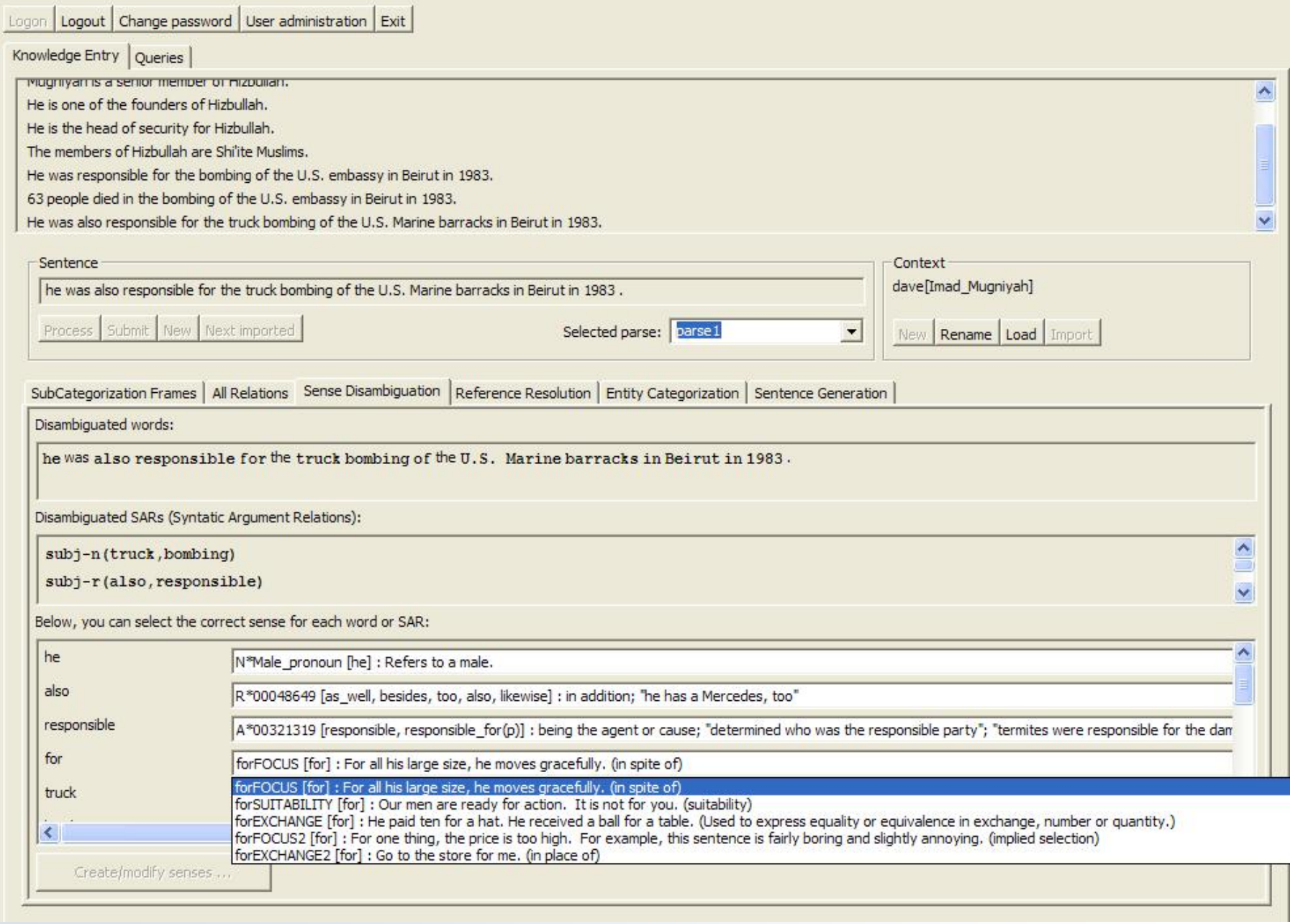
Reference Resolution
Entity Categorization
Sentence Generation
Inheritance(3,1983)
Inheritance(A,also)
subj-rDESCRIPTEE(A,R)
Inheritance(B,bombing)
NounNumber(B,uncountable)
in[2](B,3)
of(B,B1)
Inheritance(B1,barrack)
NounNumber(B1,plural)
in[1](B1,B2)
Inheritance(B2,Beirut)
NounNumber(B2,singular)
Inheritance(H,he)
NounNumber(H,singular)
Inheritance(R,responsible)
Tense(R,%past)
for(R,B)
subjAGENT(R,H)
Inheritance(T,truck)
subj-nFOCUS(T,B)
Inheritance(U,U.S._Marine)
NounNumber(U,singular)
subj-nFOCUS(U,B1)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Create/modify senses ...

Novamente:

The Path Ahead

Hypothetical Timeline

2006-2007:

- –Complete “infantile” stage behaviors in AGISim
- –Initial integration of existing NLP system

2007-2019:

- –Enter concrete-operational stage
- –Integration of NLP code with learning mechanisms
- –Implement distributed processing infrastructure

2008-2012:

- –Powerful natural-language question-answering
- –Focus on embodied language learning

2009-2014:

- –Formal stage?
- –Integration of Mizar DB?

NOVAMENTE LLC
ARTIFICIAL GENERAL INTELLIGENCE

Credits

Novamente:

- Cassio Pennachin
- Moshe Looks
- Ari Heljakka
- Andre Senna
- Izabela Freire Goertzel
- Welter Silva
- Michael Ross
- Hugo Pinto

AGISim:

- Ari Heljakka
- Welter Silva