A Graphical Memory Architecture

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5/20/2010

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Memory Architecture

- **Nature of memories used w/in decision cycle**
- **Short-term/working and long-term memories**
  - Soar 1-8: working memory + production memory
  - ACT-R: buffers + production memory, semantic memory
  - Soar 9: working memory, ST visual imagery + production memory, semantic memory, episodic memory, LT visual memory
- **Focus here is on representation and access**
  - Haven't yet got to learning

Goals

- **Broadly functional memory architecture**
  - Both procedural and declarative knowledge
  - *Hybrid*: Continuous/signal + discrete/symbolic
  - *Mixed*: Probabilistic/uncertain + discrete/symbolic
- **Uniform implementation**
- **Provide core for development of full hybrid mixed architecture**
  - Melding scope with simplicity and elegance

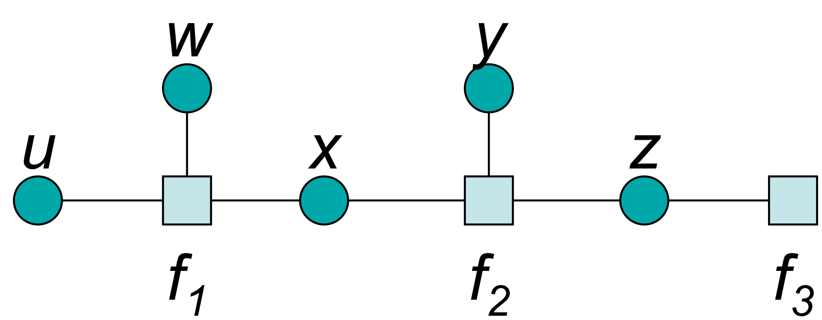
Approach

- **Base roughly on Soar 9 and ACT-R**
  - Working memory
  - Procedural LT Memory
    - Productions
  - Declarative LT Memory
    - Semantic: Predict unspecified attributes of objects based on specified ones (cues)
    - Episodic: Retrieve best episode based on recency and match to cues
  - Eventually imagery as well, but not yet
- **Implement via *graphical models***
  - Layered approach: *graph* and *memory* layers

Graph Layer: Factor Graphs w/ Summary Product

- **Factor graphs are undirected bipartite graphs**
  - Decompose functions: e.g., $f(u,w,x,y,z) = f_1(u,w,x) f_2(x,y,z) f_3(z)$
  - Map to variable & factor nodes (with functions in factor nodes)
- **Summary product algorithm does message passing**
  - Compute values of variables (marginals) by sum-product
  - Compute best overall (max. a posteriori) by max-product

Complete reimplementation from last year with improved functionality, generality, efficiency



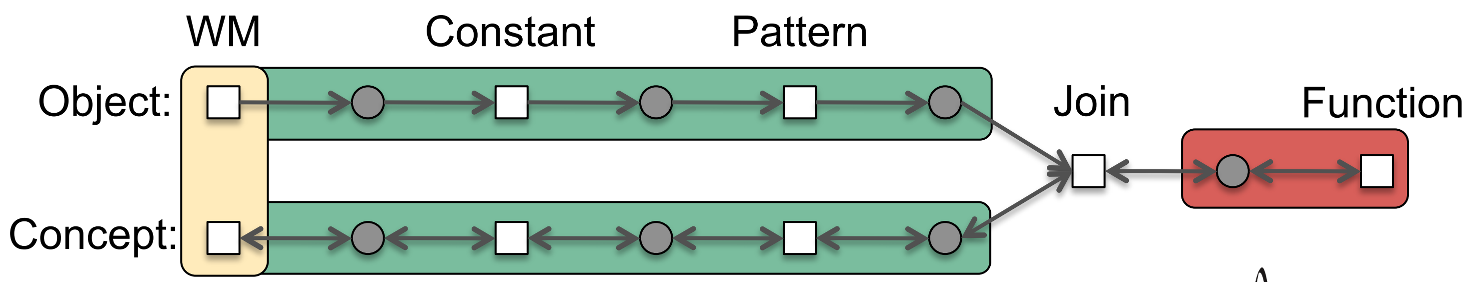
Generalized Function/Message Representation

- **N dimensional continuous functions**
  - Approximated as piecewise linear functions over rectilinear regions
- **Span (continuous) signals, (continuous and discrete) probability distributions, symbols**
  - *Discretize domain* for discrete distributions & symbolic
    - [0,1>, [1,2>, [2,3>, …
  - *Booleanize range* (and add symbol table) for symbolic
    - E.g., [0,1>=1 ➔ RED true; [1,2>=0 ➔ GREEN false

*y**x*	[0,10>	[10,25>	[25,50>
[0,5>	0	.2*y*	0
[5,15>	.5*x*	1	.1+.2*x*+.4*y*

Memory Layer: Distinguish WM and LTM

- **Representation is predicate based**
  - E.g., `Object(`*s*`,O1)`, `Concept(O1,`*c*`)`
  - Arguments may be constants, or variables (in LTM)
- **Long-term memories compile into graphs**
  - LTM is composed of *conditionals* (generalized rules)
  - Each conditional is a set of predicate patterns and a function
- **WM compiles into functions in peripheral factor nodes**
  - It is just an N dimensional continuous function where normal symbolic wmes correspond to unit regions with Boolean values



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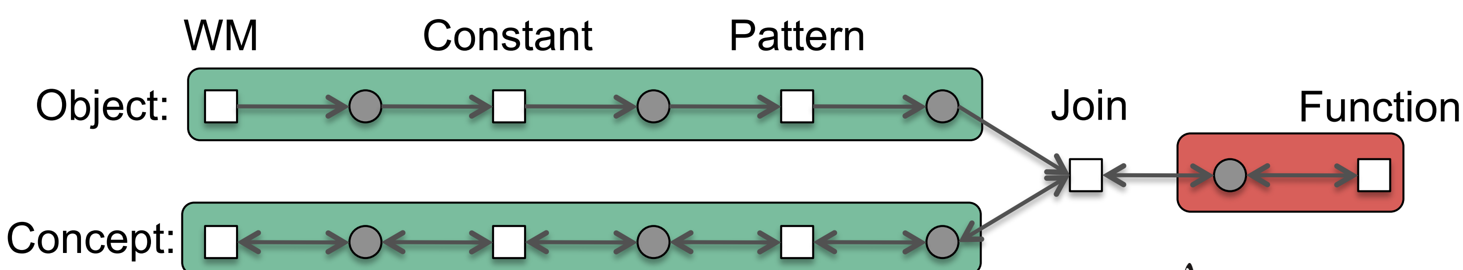
Conditionals

```
CONDITIONAL ConceptPrior
   Condition: Object(s,O1)
   Condact: Concept(O1,c)
```

Walker	Table	Dog	Human
.1	.3	.5	.1

- **Patterns can be *conditions*, *actions* or *condacts***
  - Conditions and actions embody normal rule semantics
    - Conditions: Messages flow from WM
    - Actions: Messages flow towards WM
  - Condacts embody (bidirectional) constraint/probability semantics
    - Messages flow in both directions: local match + global influence
  - Encoded as (generalized) linear *alpha networks*
- **Pattern networks joined via bidirectional *beta network***
- **Functions are defined over condact variables**



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Additional Details

- **Link directionality is set independently for each link**
  - Determines which messages are sent
- **Whether to use *sum* or *max* is specified on an individual variable/node basis**
  - Overall algorithm thus mixes sum-product and max-product
- **Variables can be specified as *unique* or *multiple***
  - Unique variables sum to 1 and use *sum* for marginals: [.1 .5 .4]
  - Multiple variables can have any or all elements valued at 1 and use *max* for marginals: [1 1 0 0 1]
- **Predicates can be declared as *open world* or *closed world* with respect to matching WM**
- ***Pattern variables* cause sharing of graph structure**
  - May be within a single conditional or across multiple conditionals

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Memories

Production Memory

- Just conditions and actions
  - Although may also have a function
- CWA and multiple variables

```
CONDITIONAL Transitive
    Condition: Next(a,b)
               Next(b,c)
    Action: Next(a,c)
```

Semantic Memory

- Just condacts (in pure form)
- OWA and unique variables
- Naïve Bayes (prior on concept + conditionals on attributes)

```
CONDITIONAL ConceptWeight
    Condact: Concept(O1,c)[α1]
             Weight(O1,w)
```

w\c	Walker	Table	…
[1,10>	.01w	.001w	…
[10,20>	.2-.01w	"	…
[20,50>	0	.025-.00025w	…
[50,100>	"	"	…

```
CONDITIONAL ConceptPrior
    Condition: Object(s,O1)
    Condact: Concept(O1,c)[α1]
```

Walker	Table	Dog	Human
.1	.3	.5	.1

Memories (cont.)

Episodic Memory

- Just condacts (in pure form)
- OWA and unique variables
- Exponential prior on time + conditionals on episode attributes

```
Conditional TimeConcept
     Condact: Time(t)[α3]
              Concept(O1,c)
```

t\c	Walker	Table	Dog	Human
1	1	0	0	0
2	0	0	0	1
3	0	0	0	1
4	0	0	1	0

Constraint Memory

- Just condacts (in pure form)
- OWA and multiple variables

```
CONDITIONAL TwoColorConstraint12
   Condact: Color(R1,c1)[α7]
            Color(R2,c2)[α8]
```

c1\c2	Red	Blue
Red	0	1
Blue	1	0

```
CONDITIONAL TimePrior
     Condact: Time(t)[α3]
```

0	1	2	3	4
0	.032	.087	.237	.644

Key Similarities and Differences

Similarities

- All based on WM and LTM
- All LTM based on conditionals
- All conditionals map to graph
- Processing by summary product

Is analogy vs. generalization driven by max vs. sum over instance-based memory?

Differences

- Procedural vs. declarative
  - Conditions/actions vs. condacts
    - Directionality of message flow
  - Closed vs. open world
  - Multiple vs. unique variables
- Semantic vs. episodic
  - Marginal/sum vs. MAP/max
  - Condition on concept vs. time
  - General probs. vs. instances

Constraints are actually hybrid: condacts, OWA, multiple
Other variations and hybrids are also possible

Summary

Gold

- Uniform implementation of four distinct LTMs
- Reveals subtle underlying differences among the LTMs
- An important step towards a full hybrid mixed architecture
  - Working on decisions
  - Then subgoaling & learning
  - Proposal on imagery
    - Leverage continuous functions at core and known facility of graphical models for perception

Coal

- Subtle incompatibilities imply less uniformity in details
  - They have also proven quite difficult to resolve cleanly
- Progress can be slow & difficult
  - With occasional bursts of insight
- Not full memory implementations
  - And no learning
- Still far from full architecture
  - And from showing that there is a significant functional gain from this approach