

Multi-Domain Sketch Recognition

Lecture #11: Sketch Understanding
Joseph J. LaViola Jr.
Fall 2008

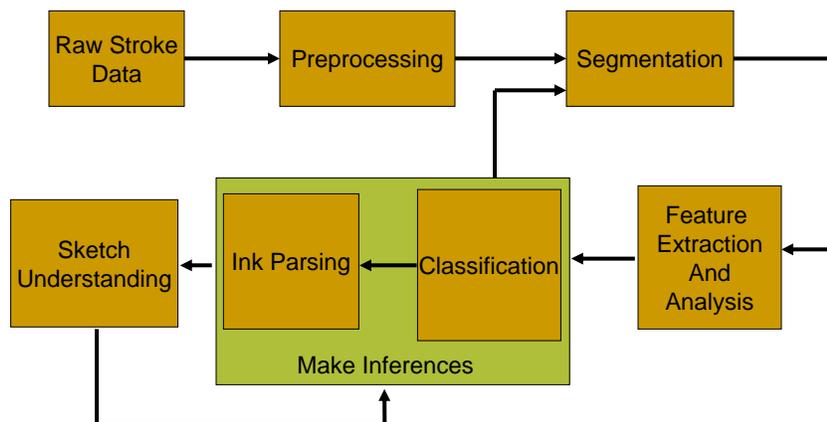
Slides adapted from Alvarado, Multi-Domain Sketch Understanding, SIGGRAPH course #3, 2007.

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Recall Pen-Based Interface Dataflow

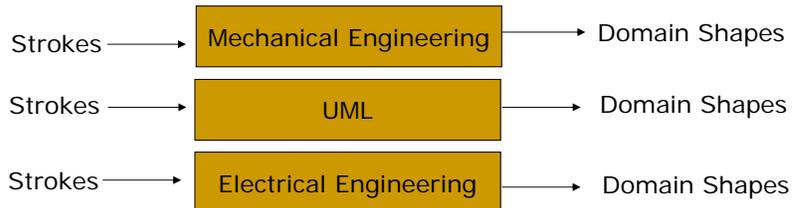


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Building Recognition Systems



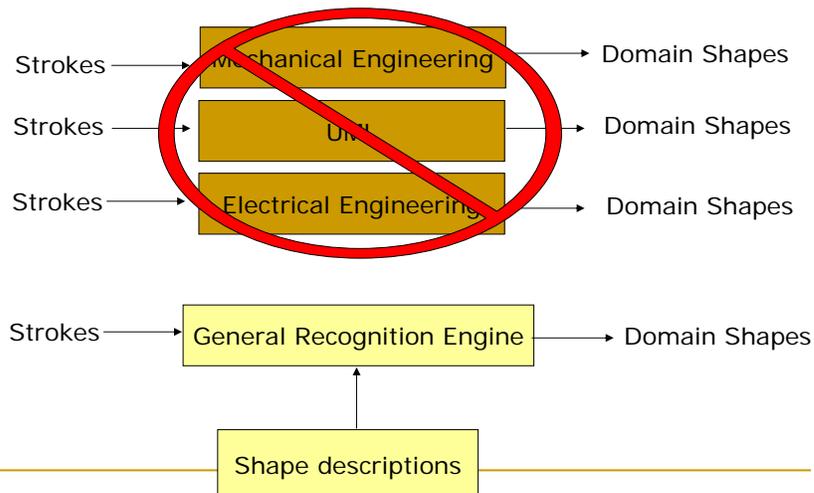
- Building each system requires:
 - sketch recognition expertise
 - a lot of time (2-5 person years!)
 - built in domain assumptions to improve recognition

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A Multi-Domain Sketch Recognition Engine



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Enabling Natural Interaction

- Goal:
 - recognition engines for multiple domains
- Core challenge:
 - multi-domain recognition

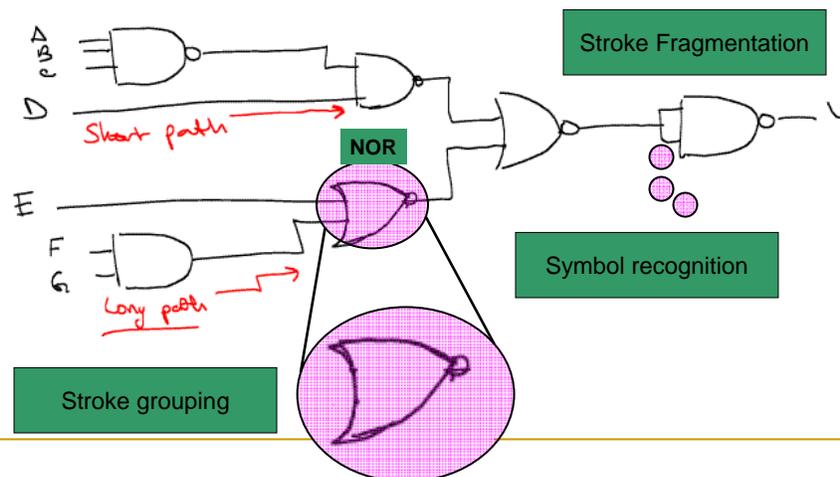
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Sketch Recognition Subtasks

- Need a multi-domain solution!

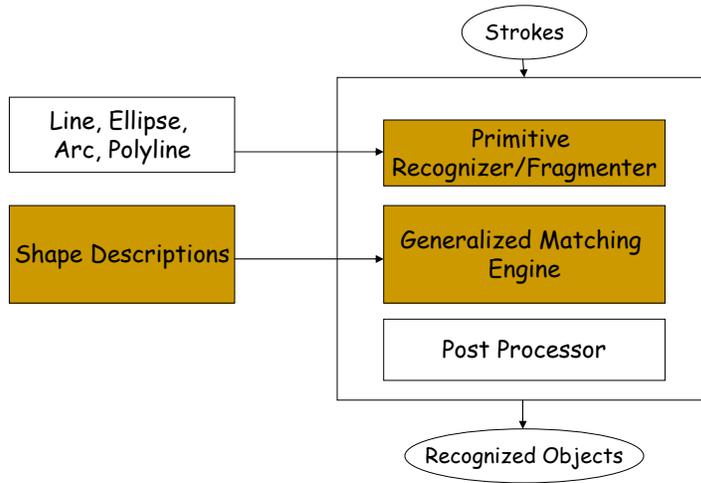


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Multi-Domain Sketch Recognition Architecture

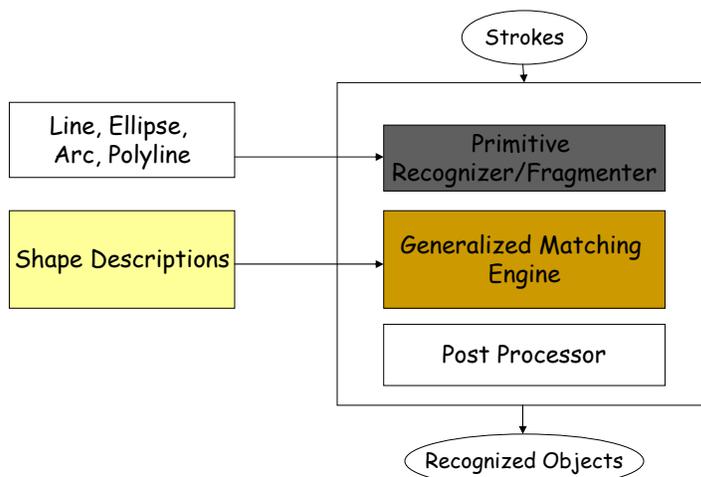


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Multi-Domain Sketch Recognition Architecture



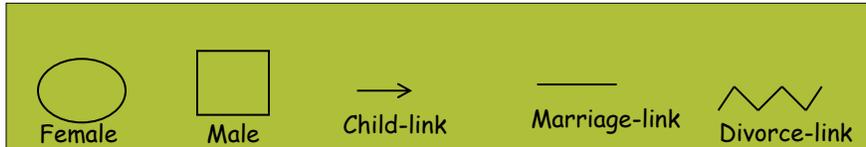
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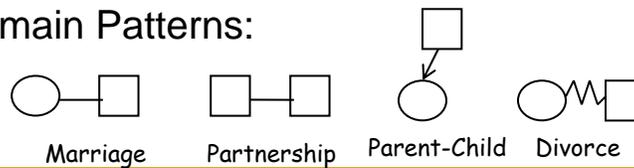
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Family Tree Domain

- Compound:  → Arrow
- Domain:  Quadrilateral



- Domain Patterns:

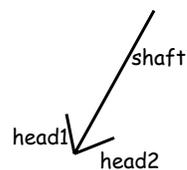


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Knowledge Representation (LADDER [Hammond03])



Shape defined by

Subshapes
Constraints

(Define **Arrow**

(Subshapes (Line shaft)
(Line head1)
(Line head2))

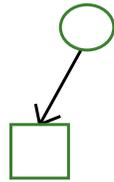
(Constraints
(coincident shaft.p1 head1.p1)
(coincident shaft.p1 head2.p1)
(equalLength head1 head2)
(smaller head1 shaft)
(acuteAngle head1 shaft)
(acuteAngle head2 shaft)))

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Knowledge Representation



```
(Define Child-link  
  (Subshapes (Arrow a)))
```



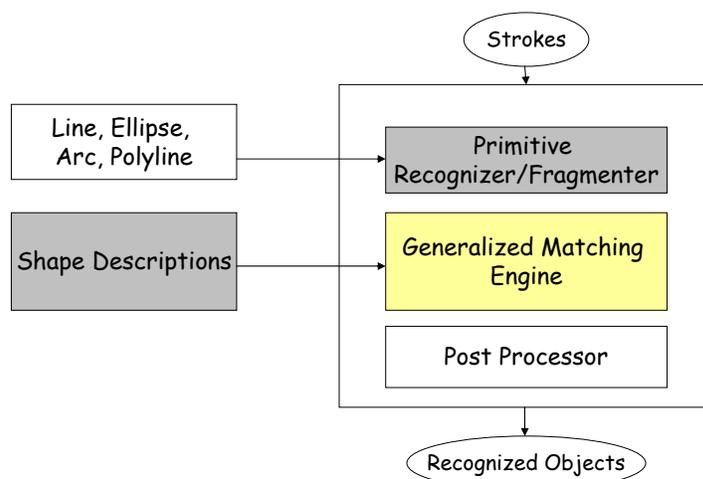
```
(Define Current-Source  
  (Subshapes (Arrow a)  
            (Ellipse e))  
  (Constraints  
    (contains e a)))
```

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Multi-Domain Sketch Recognition Architecture



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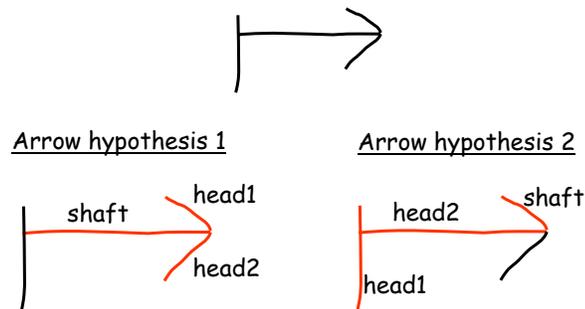
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Recognition overview

- Task: Simultaneous fragmentation, grouping and symbol identification
- Constraint-based approach
- Generate and test

Definition

- Hypothesis: A shape description with associated mapping from subshapes to user's strokes.



Hypothesis-based recognition

- Given a hypothesis, determine if it matches a shape description by testing constraints



```
(Define Arrow
  (Subshapes ✓Line shaft)
             ✓Line head1)
             ✓Line head2))
(Constraints
  ✓coincident shaft.p1 head1.p1)
  ✓coincident shaft.p1 head2.p1)
  ✓equalLength head1 head2)
  ✓smaller head1 shaft)
  ✓acuteAngle head1 shaft)
  ✓acuteAngle head2 shaft)))
```

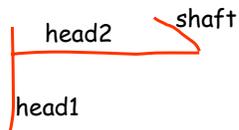
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Hypothesis-based recognition

- Given a hypothesis, determine if it matches a shape description by testing constraints



```
(Define Arrow
  (Subshapes ✓Line shaft)
             ✓Line head1)
             ✓Line head2))
(Constraints
  ✗coincident shaft.p1 head1.p1)
  ✓coincident shaft.p1 head2.p1)
  ✗equalLength head1 head2)
  ✗smaller head1 shaft)
  ✓acuteAngle head1 shaft)
  ✓acuteAngle head2 shaft)))
```

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Hypothesis-based recognition: Issues

- Too many hypotheses to try them all

$$\sum_{i \in S} \binom{n}{k_i} (k_i!)$$

n = number of strokes;
 S = set of shapes;
 k_i = subcomponents in shape S_i

- Constraints depend on context

And this only considers shapes *independently!*



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Definition

- Partial Hypothesis: A hypothesis with unbound subshapes

Quadrilateral partial hypothesis



L4 is unbound

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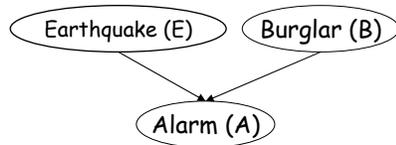
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Recognition Using Partial Hypotheses

- **Generating Hypotheses (rule-based)**
 - generate partial hypotheses (PHs) based on easily recognizable low-level shapes
 - fill in strong PHs with unrecognized strokes
 - prune weak PHs
- **Evaluating Hypotheses (probabilistic)**
 - how well do user's strokes fit low level shapes?
 - how well are constraints satisfied?

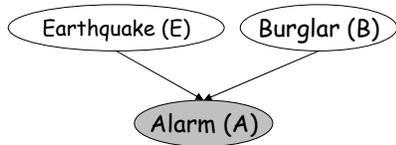
Bayesian Networks [Pearl88]



Use Bayes Rule to reason about the certainty of each variable

- Reason about events/entities
- Two parts
 - directed Acyclic Graph:
 - assign meaning to nodes
 - specify which variables influence one another
 - conditional Probability Tables
 - specify *how* variables influence one another

Bayesian Networks [Pearl88]



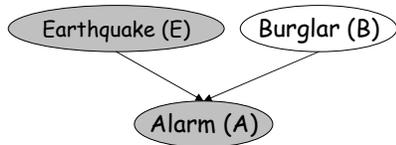
- Observations give evidence for other variables

Say we observe $A=t$, then

$$P(E|A)=0.0056$$

$$P(B|A)=0.49$$

Bayesian Networks [Pearl88]



- Observations give evidence for other variables

Say we observe $A=t$, then

$$P(E|A)=0.0056$$

$$P(B|A)=0.49$$

- Important Phenomenon:
Explaining away

If we *also* hear there has been an earthquake (i.e., $E=t$), then

$$P(B|A,E) = 0.001$$

Shape Fragments

(Define **Arrow**)

(Subshapes

L₁: (Line shaft)

L₂: (Line head1)

L₃: (Line head2))

(Constraints

C₁: (coincident shaft.p1 head1.p1)

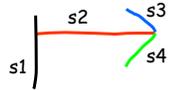
C₂: (coincident shaft.p1 head2.p1)

C₃: (equalLength head1 head2)

C₄: (smaller head1 shaft)

C₅: (acuteAngle head1 shaft)

C₆: (acuteAngle head2 shaft)))



Arrow Hypothesis

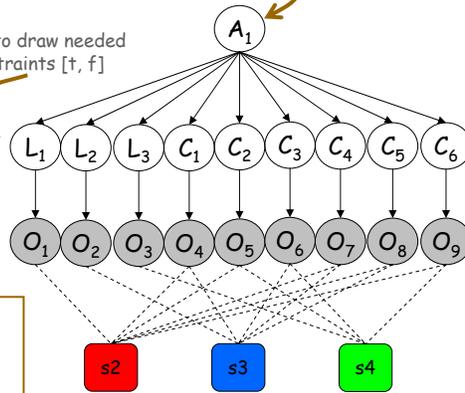
shaft = s2

head1 = s3

head2 = s4

User's intention to draw an Arrow [t, f]

User's intention to draw needed lines and constraints [t, f]



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Shape Fragments: Measurement Nodes

(Define **Arrow**)

(Subshapes

L₁: (Line shaft)

L₂: (Line head1)

L₃: (Line head2))

(Constraints

C₁: (coincident shaft.p1 head1.p1)

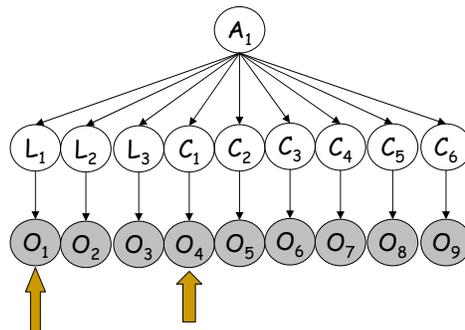
C₂: (coincident shaft.p1 head2.p1)

C₃: (equalLength head1 head2)

C₄: (smaller head1 shaft)

C₅: (acuteAngle head1 shaft)

C₆: (acuteAngle head2 shaft)))



Squared error between stroke and best fit line

Distance between shaft.p1 head.p1

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Shape Fragments

(Define **Arrow**

(**Subshapes**

L₁: (Line shaft)

L₂: (Line head1)

L₃: (Line head2))

(**Constraints**

C₁: (coincident shaft.p1 head1.p1)

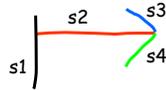
C₂: (coincident shaft.p1 head2.p1)

C₃: (equalLength head1 head2)

C₄: (smaller head1 shaft)

C₅: (acuteAngle head1 shaft)

C₆: (acuteAngle head2 shaft)))

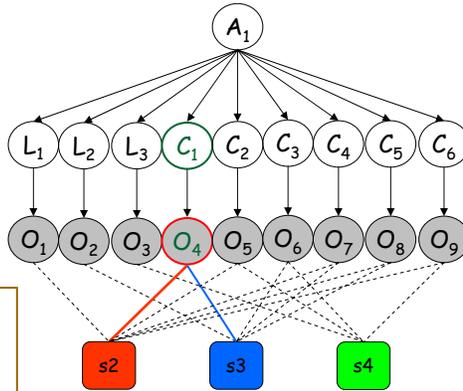


Arrow Hypothesis

shaft = s2

head1 = s3

head2 = s4



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Shape Fragments: Another Hypothesis

(Define **Arrow**

(**Subshapes**

L₁: (Line shaft)

L₂: (Line head1)

L₃: (Line head2))

(**Constraints**

C₁: (coincident shaft.p1 head1.p1)

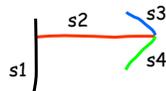
C₂: (coincident shaft.p1 head2.p1)

C₃: (equalLength head1 head2)

C₄: (smaller head1 shaft)

C₅: (acuteAngle head1 shaft)

C₆: (acuteAngle head2 shaft)))

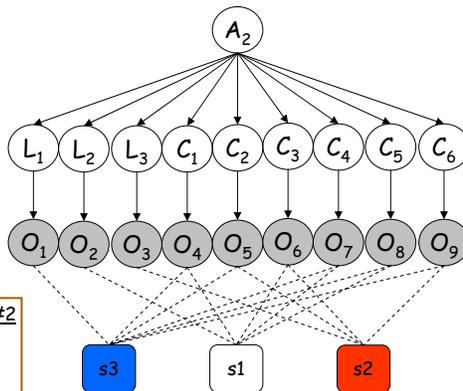


Arrow Hypothesis #2

shaft = s3

head1 = s1

head2 = s2



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Shape Fragments: Partial Hypothesis

(Define **Arrow**

(**Subshapes**

L₁: (Line shaft)

L₂: (Line head1)

L₃: (Line head2))

(**Constraints**

C₁: (coincident shaft.p1 head1.p1)

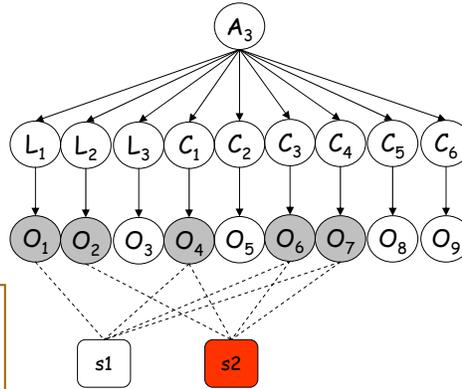
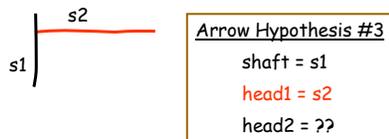
C₂: (coincident shaft.p1 head2.p1)

C₃: (equalLength head1 head2)

C₄: (smaller head1 shaft)

C₅: (acuteAngle head1 shaft)

C₆: (acuteAngle head2 shaft)))

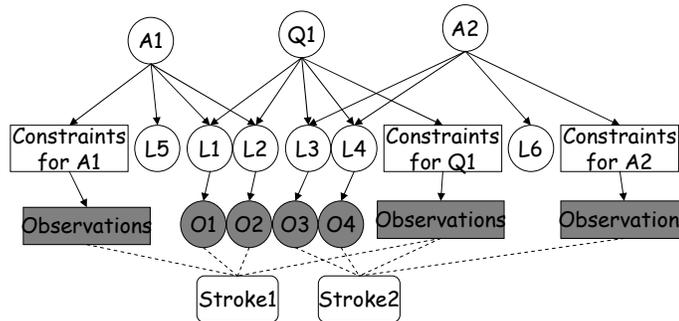
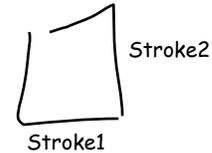


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Composing Shape Fragments



Each node represents a hypothesis

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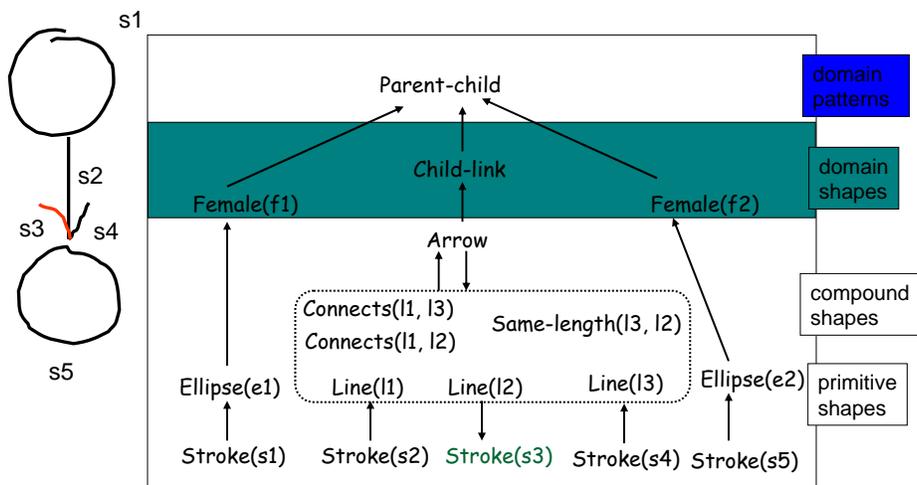
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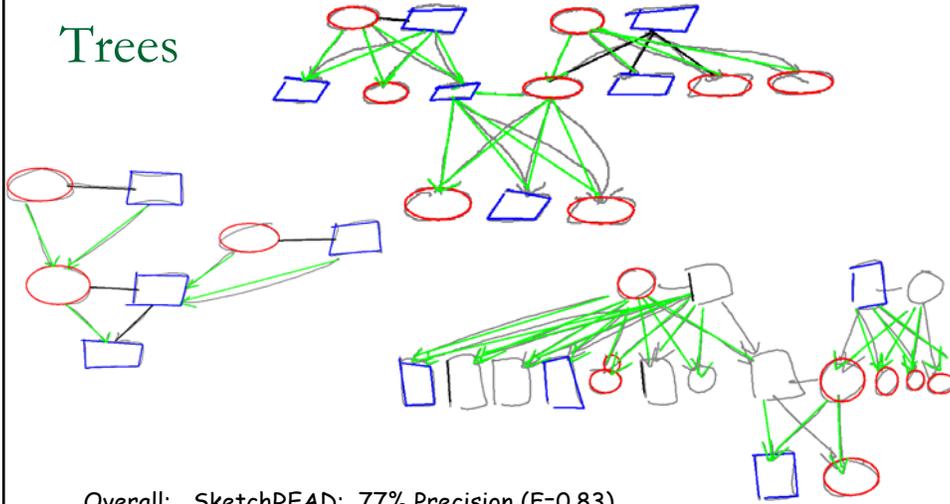
Hypothesis Generation

- Bottom Up
 - partial hypotheses generated based on rough classification for objects and constraints
- Top Down
 - strokes possibly reclassified to fit into PHs
- Pruning
 - keep number of hypotheses manageable

An Illustration



Results: Trees



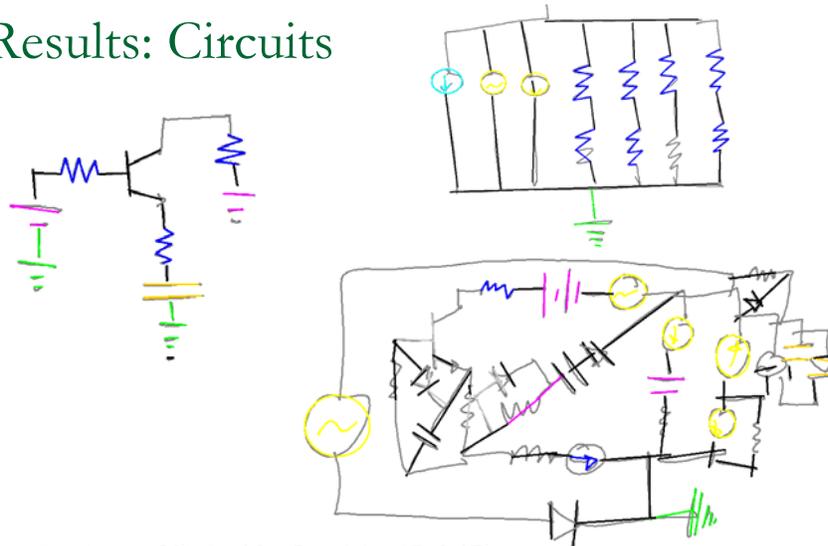
Overall: SketchREAD: 77% Precision (F=0.83)
Baseline: 50% Precision (F=0.65)

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Results: Circuits



Overall: SketchREAD: 62% Precision (F=0.65)
Baseline: 54% Precision (F=0.57)

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Readings

- LaViola, J. and Zeleznik, R. MathPad²: A System for the Creation and Exploration of Mathematical Sketches" *ACM Transactions on Graphics (Proceedings of SIGGRAPH 2004)*, 23(3):432-440, August 2004.
- Christine Alvarado and Randall Davis. SketchREAD: A Multi-Domain Sketch Recognition Engine. In *Proceedings of UIST 2004*, pp.23-32. New York, New York, October 24-27 2004.
- Lockwood, K., Lovett, A., Forbus, K., Dehghani, M., and Usher, J. Automatic Interpretation of Depiction Conventions in Sketched Diagrams. *Proceedings of the Eurographics Workshop on Sketch-Based Interfaces and Modeling*, 167-174, 2008.
- Hammond, T., and R. Davis. Ladder: A Sketching Language for User Interface Developers, *Computers and Graphics* 29, 518-532, 2005.