Multi-Domain Sketch Recognition

Lecture #11: Sketch Understanding
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Slides adapted from Alvarado, Multi-Domain Sketch Understanding, SIGGRAPH course #3, 2007.

Recall Pen-Based Interface Dataflow
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

A Multi-Domain Sketch Recognition Engine

- Strokes to General Recognition Engine
- General Recognition Engine to Shape descriptions
Enabling Natural Interaction

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

Sketch Recognition Subtasks

- Need a multi-domain solution!

Diagram showing:
- Stroke Fragmentation
- Symbol recognition
- Stroke grouping

NOR gate with connections and labels.
Multi-Domain Sketch Recognition Architecture

- Strokes
  - Line, Ellipse, Arc, Polyline
  - Shape Descriptions
    - Primitive Recognizer/Fragmenter
    - Generalized Matching Engine
    - Post Processor

Recognized Objects
Family Tree Domain

- **Compound:**
- **Domain:** Quadrilateral

**Domain Patterns:**
- Marriage
- Partnership
- Parent-Child
- Divorce

Knowledge Representation

(LADDER [Hammond03])

(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)))
**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**

- **Strokes**
  - Line, Ellipse, Arc, Polyline
  - Shape Descriptions

- **Primitive Recognizer/Fragmenter**
  - Generalized Matching Engine
  - Post Processor

- **Recognized Objects**
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.

![Diagram](image)
Hypothesis-based recognition

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

\begin{align*}
(\text{Define } \text{Arrow} & \\
\text{Subshapes} & \text{Line shaft, Line head1, Line head2}) \\
\text{Constraints} & \text{Coincident shaft.p1 head1.p1, Coincident shaft.p1 head2.p1, EqualLength head1 head2, Smaller head1 shaft, AcuteAngle head1 shaft, AcuteAngle head2 shaft})
\end{align*}
Hypothesis-based recognition: Issues

- Too many hypotheses to try them all
  \[ \sum_{i \in S} \binom{n}{k_i!} \]
  - \( n \) = number of strokes;
  - \( S \) = set of shapes;
  - \( k_i \) = subcomponents in shape \( S_i \)
- Constraints depend on context
  And this only considers shapes independently!

Definition

- Partial Hypothesis: A hypothesis with unbound subshapes

  Quadrilateral partial hypothesis

  L1 \( \rightarrow \) L2

  L3

  L4 is unbound
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]

- 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

Use Bayes Rule to reason about the certainty of each variable
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)))

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

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

Squared error between stroke and best fit line

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)))

Distance between shaft.p1 head.p1

Squared error between stroke and best fit line
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)))

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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)))

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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)))

Composing Shape Fragments

Each node represents a hypothesis
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

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An Illustration

- **Parent-child**
  - Female(f1)
  - Female(f2)

- **Child-link**
  - Connects(l1, l3)
  - Connects(l1, l2)
  - Same-length(l3, l2)
  - Arrow

- **Domain patterns**
  - Domain shapes

- **Compound shapes**
  - Primitive shapes

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Stroke(s1) Stroke(s2) Stroke(s3) Stroke(s4) Stroke(s5)
Results: Trees

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

Results: Circuits

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