CogSketch Tutorial

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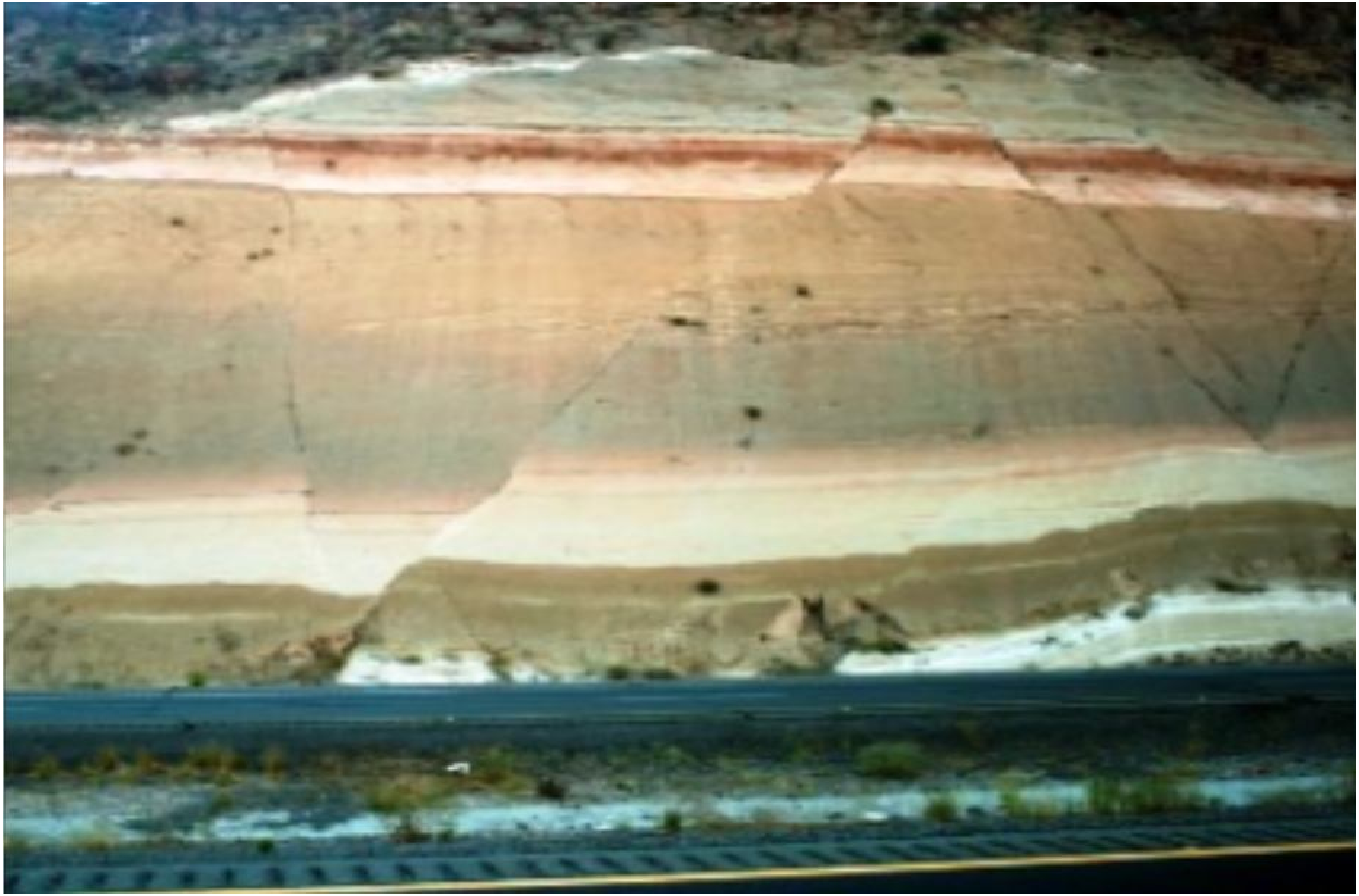
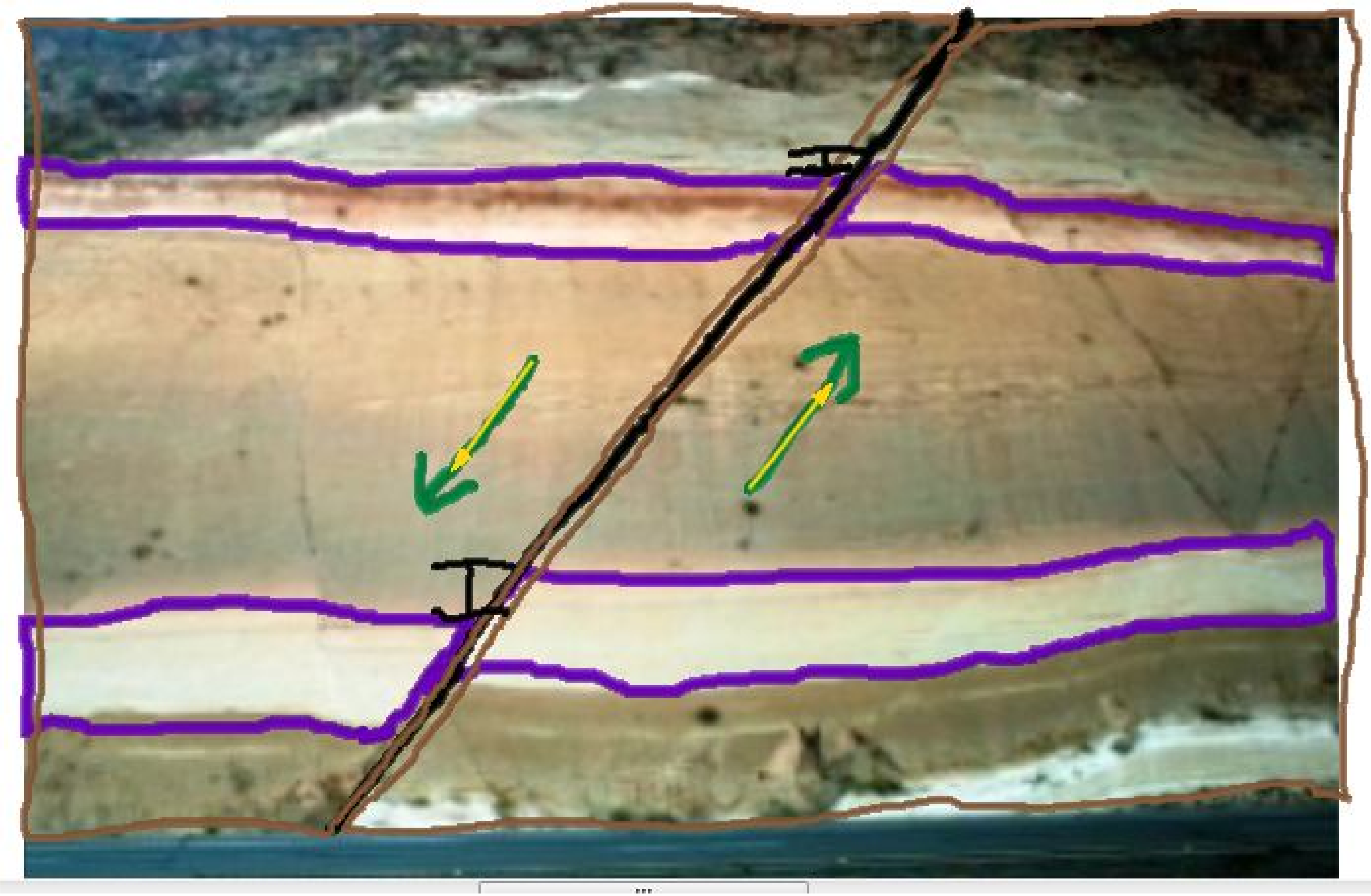
Welcome

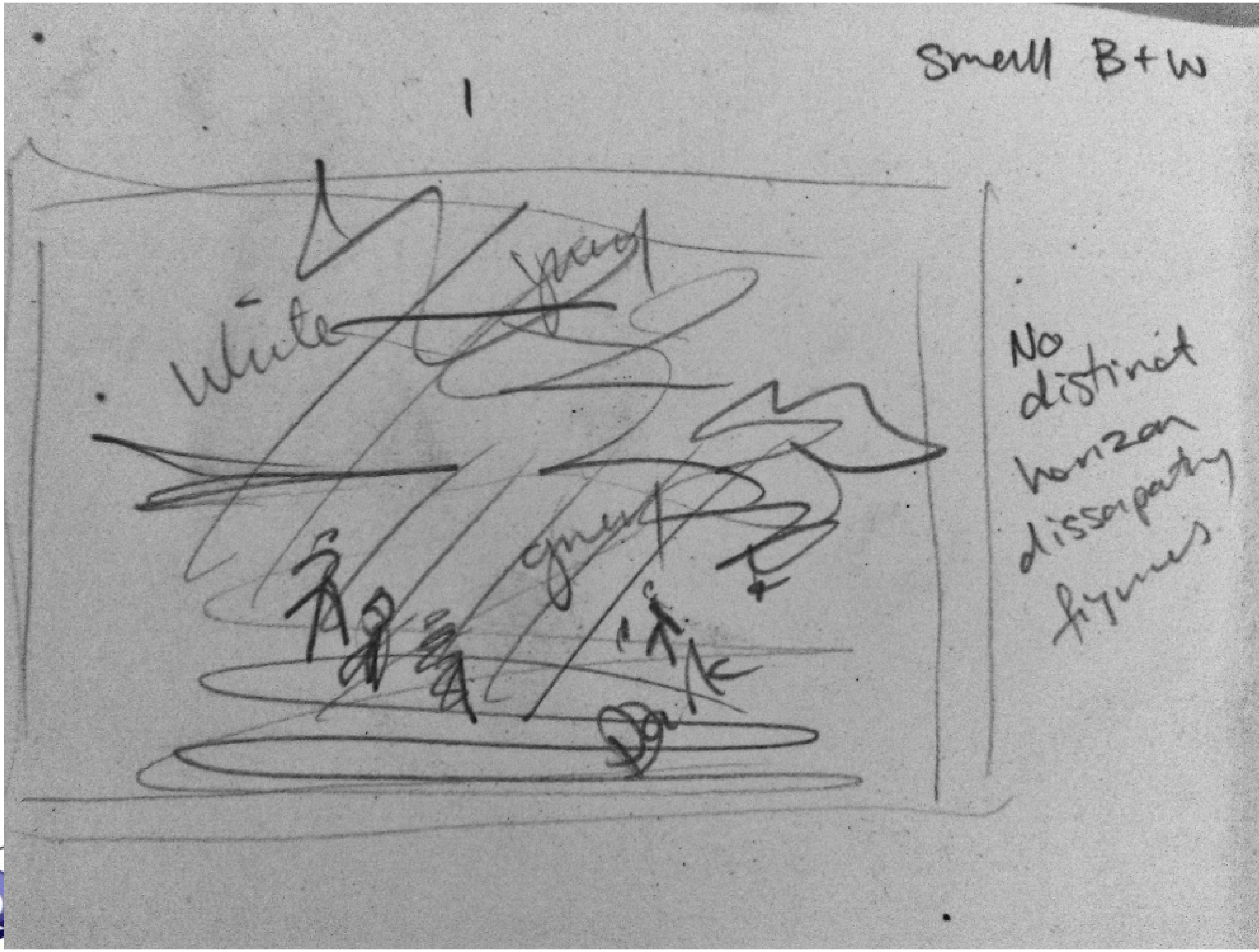
Sketching is a Form of Communication



Sketching is a Form of Communication

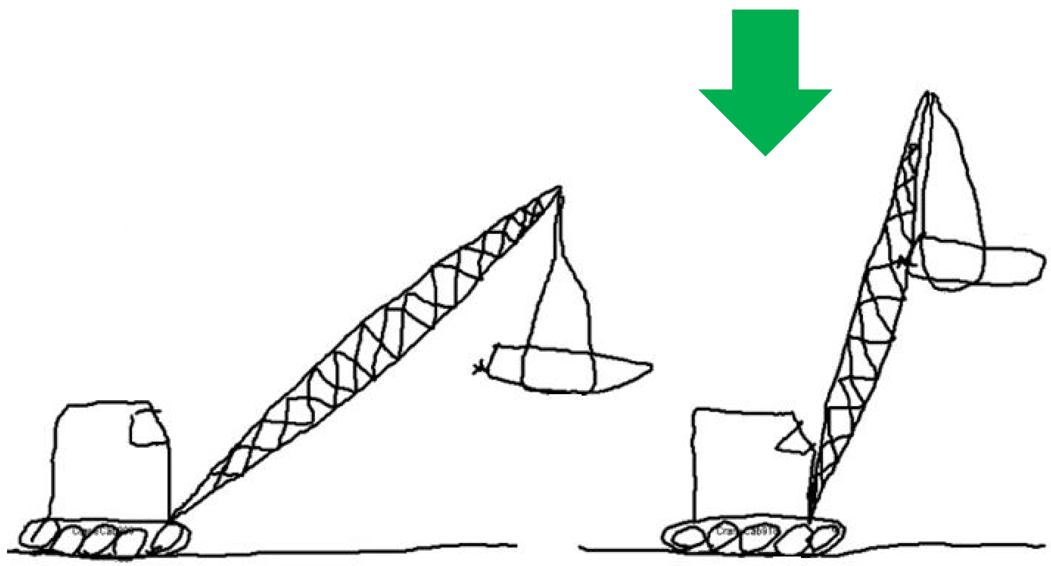


Sketching is an Aid to Thinking

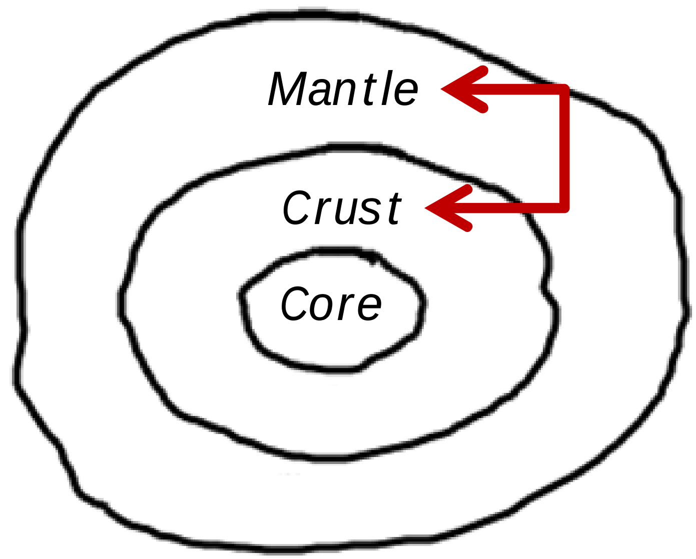


Sketching is an Aid to Thinking

Understanding Sketches is a Deep Scientific Problem



Which crane is more stable?



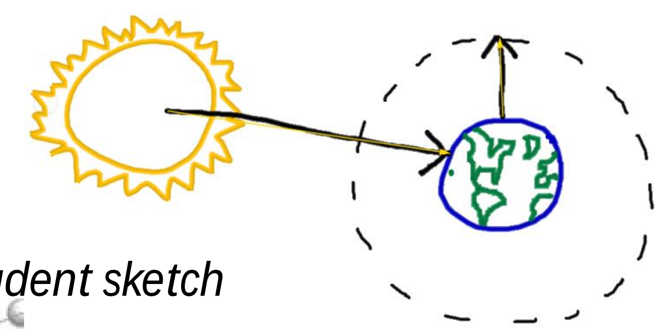
Does this accurately depict the insides of the Earth?

CogSketch Goal 1: Cognitive Science Research Instrument

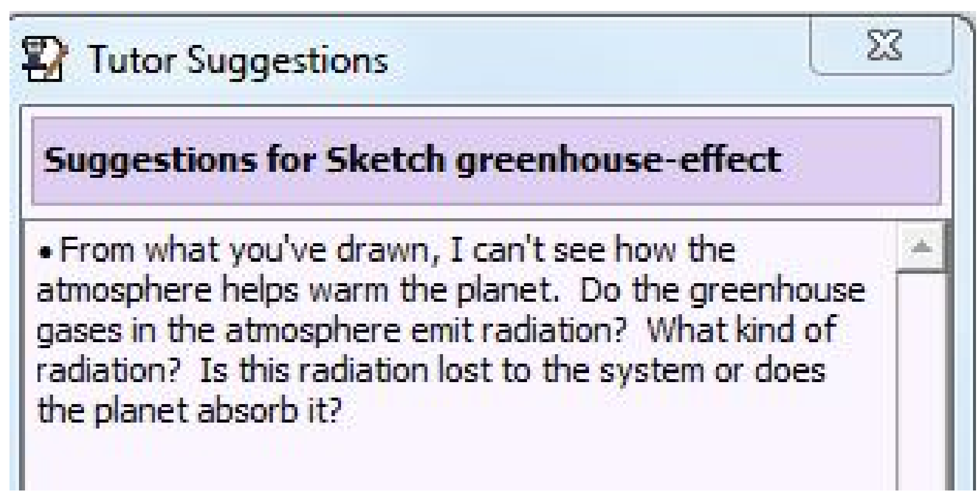
- Modeling human spatial reasoning and learning
  - Cognitive simulations provide new insights into human processing
  - Support AI research
- Gathering and analyzing data in laboratory and classroom studies
  - Digital ink provides time-stamped data
  - Human-like visual processing could support automated data analysis

Computer Tutors Need Spatial Capabilities

- Intelligent tutoring systems have provided valuable benefits for education (e.g. Cognitive Tutors)
  - Immediate feedback, potentially any time, anywhere
  - Potential for large-scale assessment
- But not in spatially rich STEM subjects
  - e.g., geoscience, engineering
- Sketch understanding software could change this



Student sketch



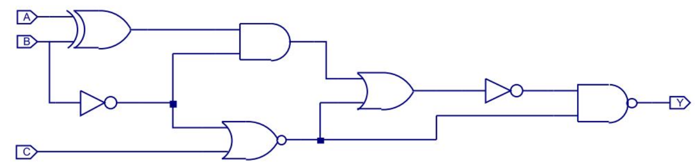
CogSketch Feedback

CogSketch Goal 2: Platform for Sketch-based Intelligent Educational Software

- Focus on helping students learn STEM concepts
- Explore two models of intelligent educational sketching software
  - Sketch Worksheets, Design Coach
- **Vision: Sketch understanding software to help students learn could be widely available**

Sketch Recognition Systems

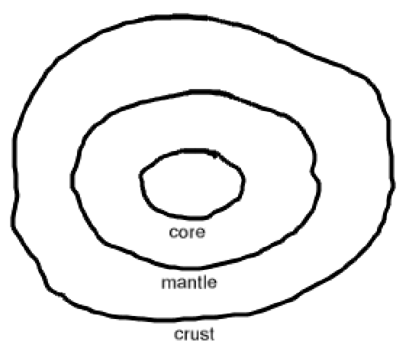
- Goal: Provide natural, fluent interaction
- Assumes small set of visual symbols/shapes suffice to express everything



System	Problem
Newton's Pen	Draw free-body diagrams
Kirchoff's Pen	Draw resistor networks
OrganicPad, ChemPad	Draw 2D molecules, converts to 3D
Mechanix	Draw trusses, get feedback
PhysicsBook	Draw simple mechanics problems
LogiSketch	Draw logic circuits, do simulation
MathPad2	Draw equations, do animations

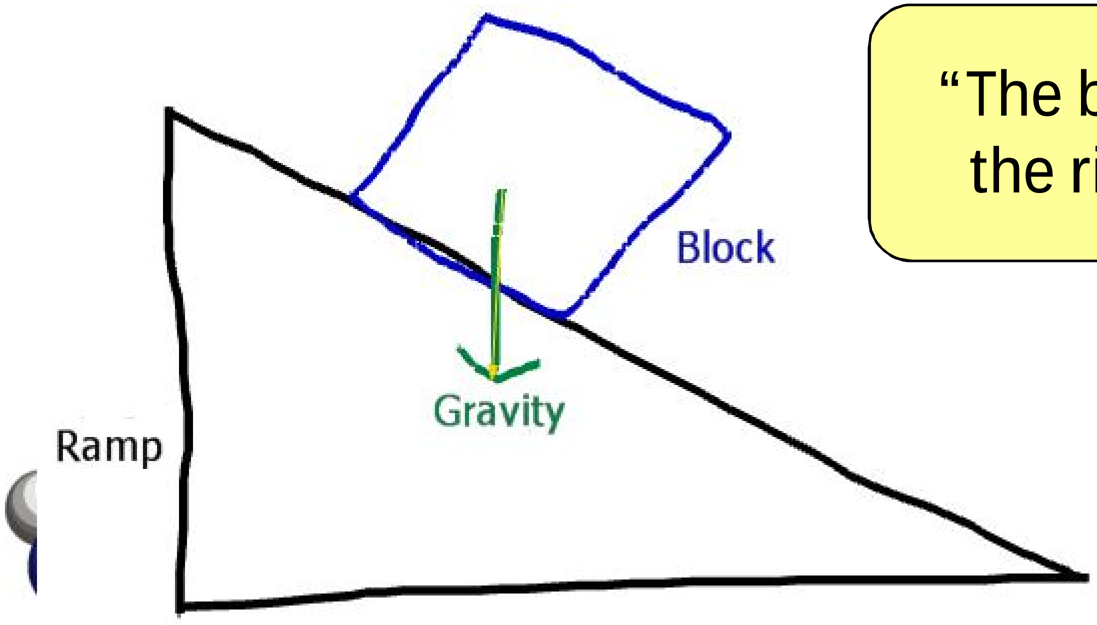
Our approach: Open-domain sketch understanding

- Object recognition is not necessary
  - People talk when they sketch – they label objects
  - CogSketch enables people to label as they draw, avoiding the recognition bottleneck
- CogSketch models aspects of human visual and spatial representations and reasoning
  - Derives rich relational representations
  - Same software operates across many domains



Sketching: A Long-Term Vision

- Software that understands sketches as people do
  - Fluent, natural interaction
  - Human-like visual and spatial reasoning
  - Conceptual reasoning about the sketch
  - Domain-general

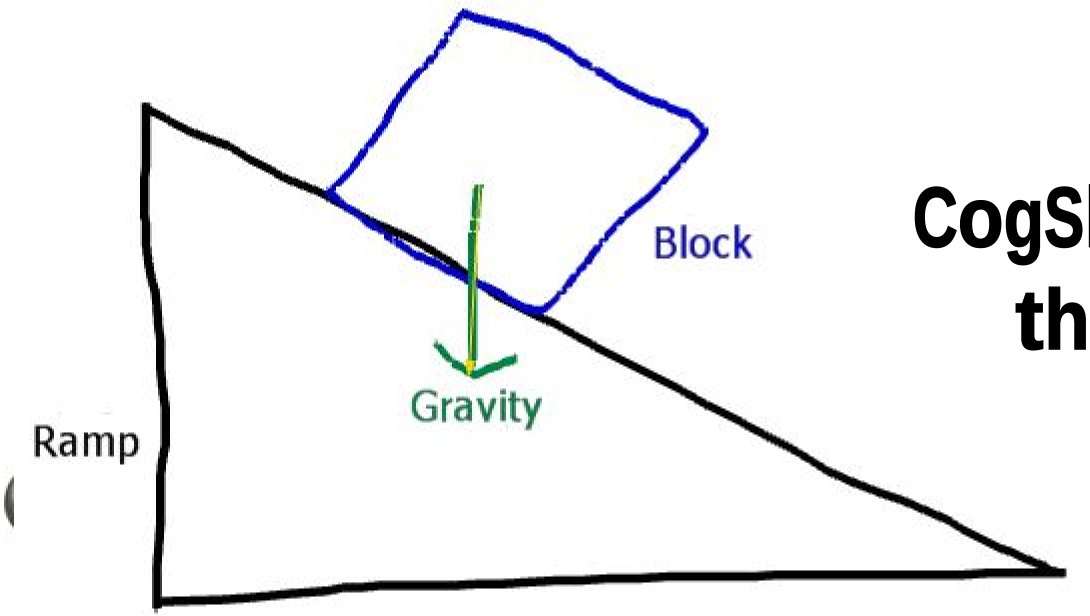


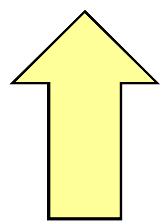
"The block will slide to the right and down"

Sketching: A Long-Term Vision

- Software than understands sketches as people do
  - Fluent, natural interaction
  - Human-like visual and spatial reasoning
  - Conceptual reasoning about the sketch
  - Domain-general

Sketch Recognition Research



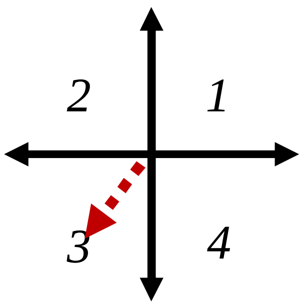


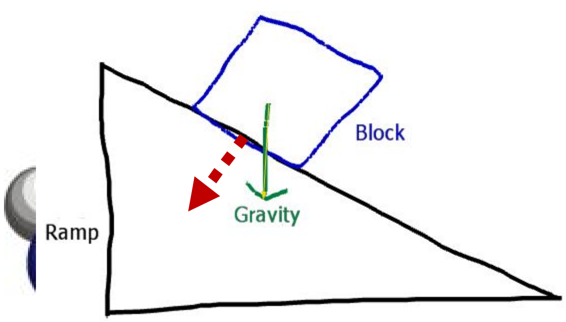
CogSketch explores these aspects

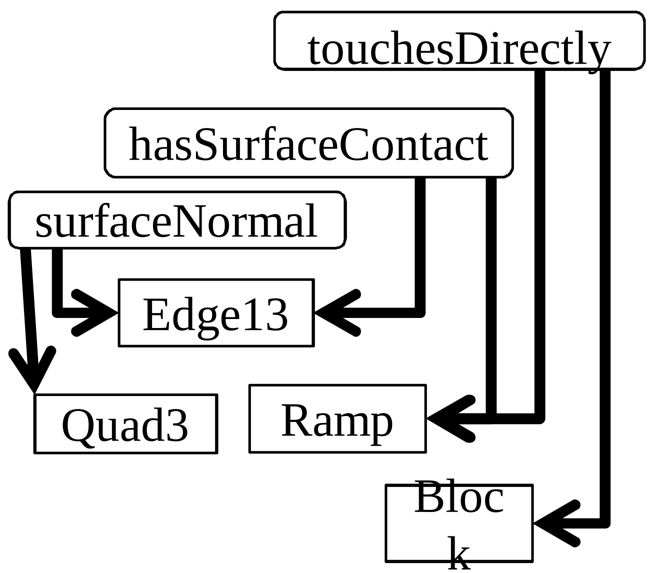
Ideas Underlying CogSketch

- Perceptual processing produces qualitative spatial representations
  - Forbus (1980); Huttenlocher, Hedges, & Duncan (1991)

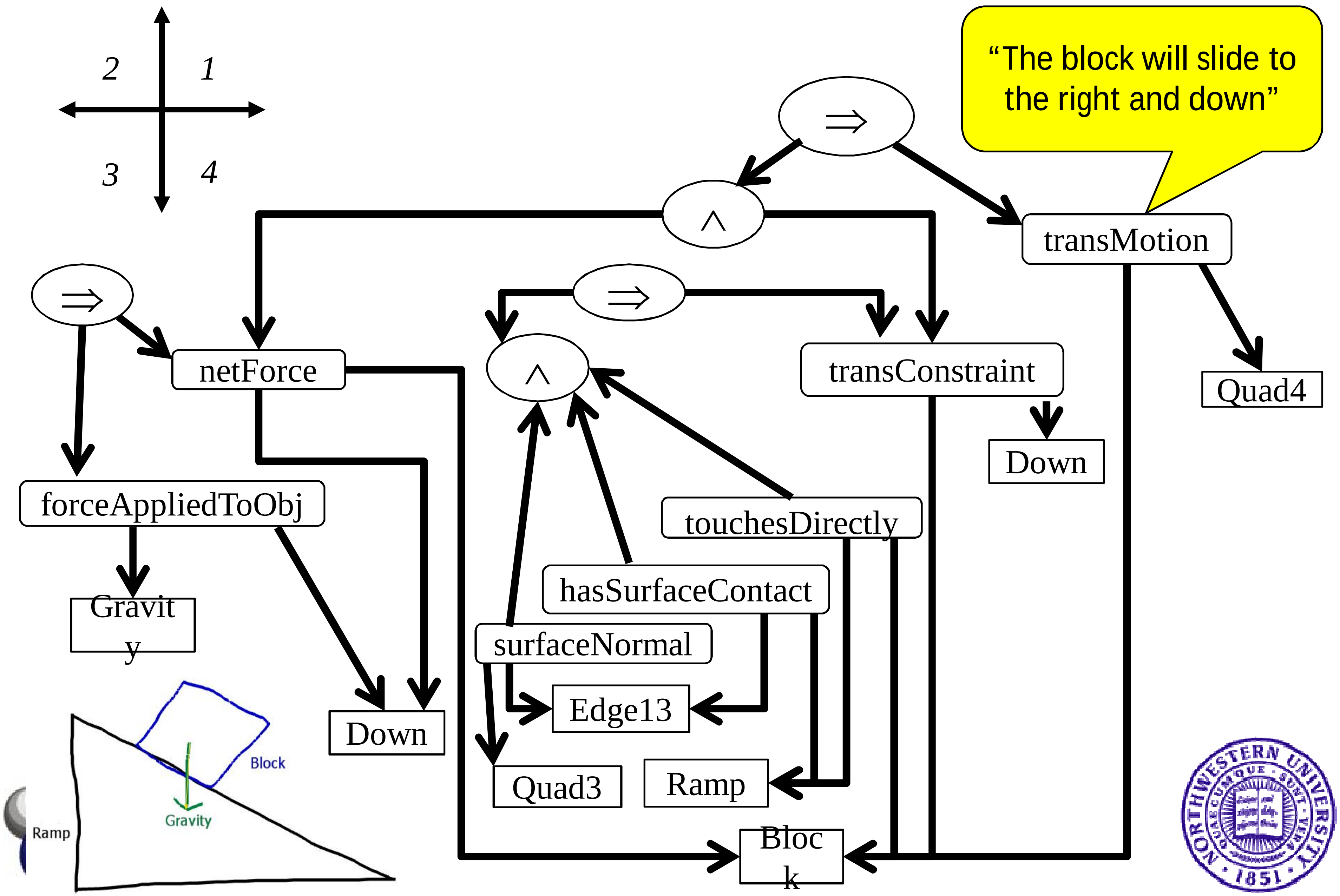
CogSketch Uses Visual Reasoning







CogSketch Uses Qualitative Reasoning



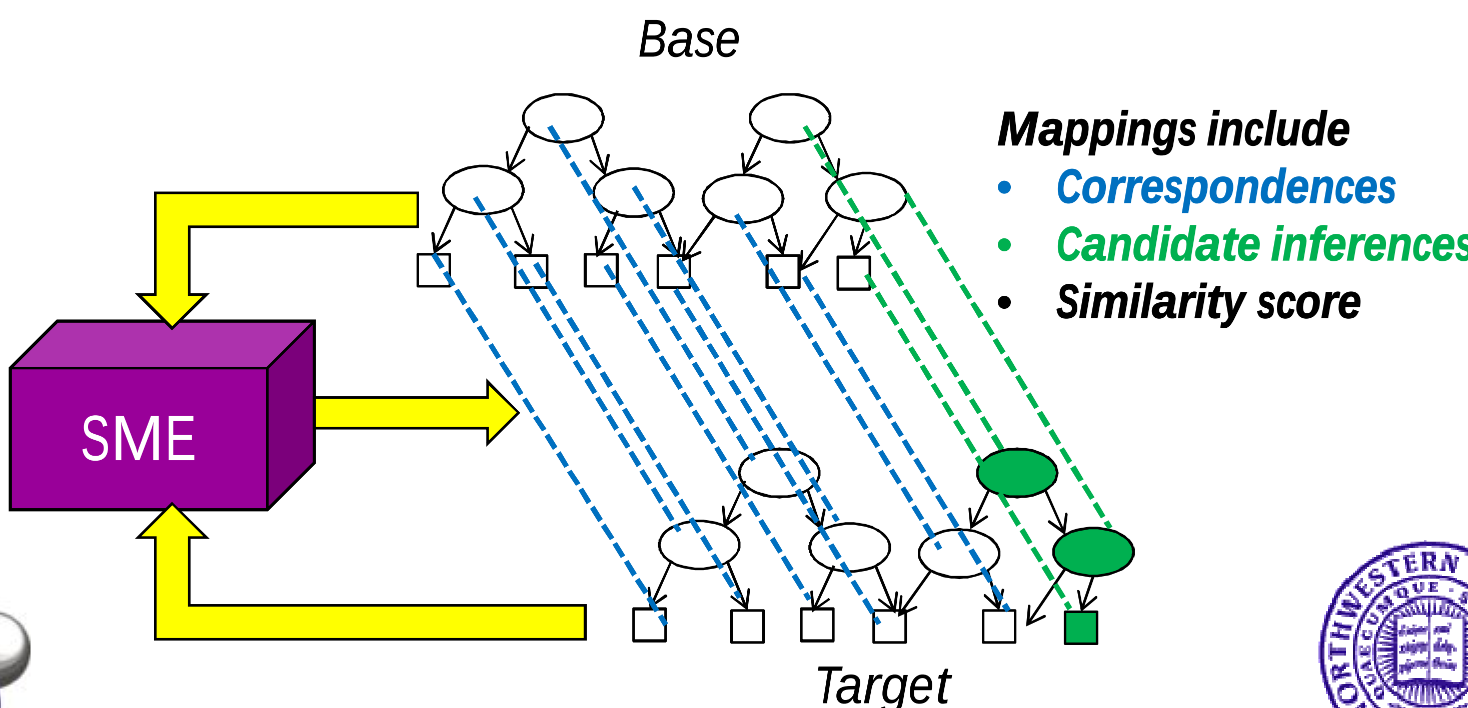
Ideas Underlying CogSketch

- Perceptual processing produces qualitative spatial representations
  - Forbus (1980); Huttenlocher, Hedges, & Duncan (1991)
- Structure-mapping processes are used in visual reasoning
  - Lovett, Gentner, Forbus, & Sagi, 2009; Markman & Gentner (1996)

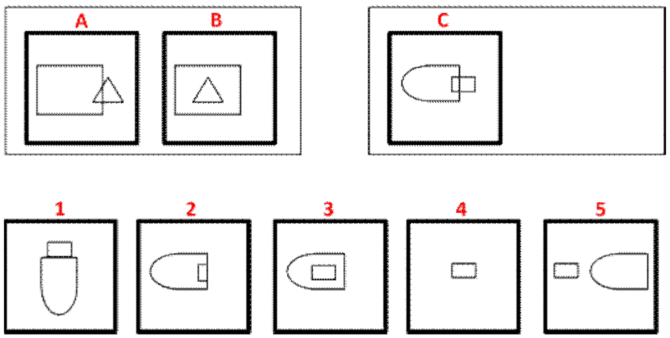
Structure-Mapping Engine (SME)

(Falkenhainer, Forbus, & Gentner, 1986; Forbus, Ferguson, & Gentner, 1994)

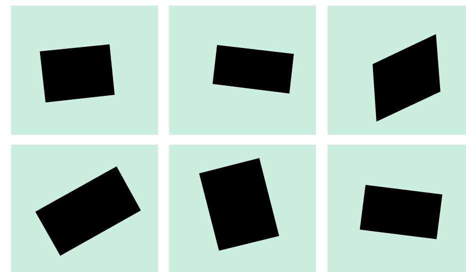
- Model of analogical comparison
  - Based on Gentner's (1983) Structure-Mapping Theory
- Compares cases by aligning their common structure



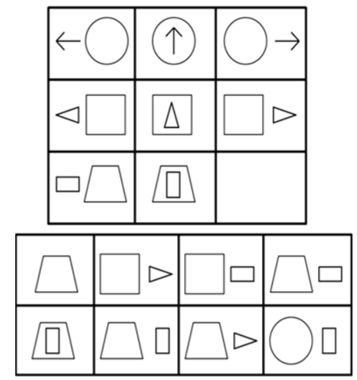
CogSketch Visual Modeling



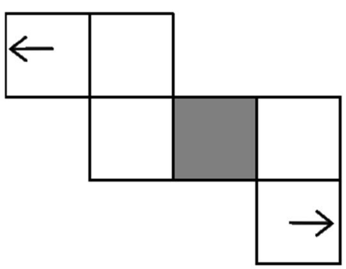
Predicts human reaction time differences in geometric analogies



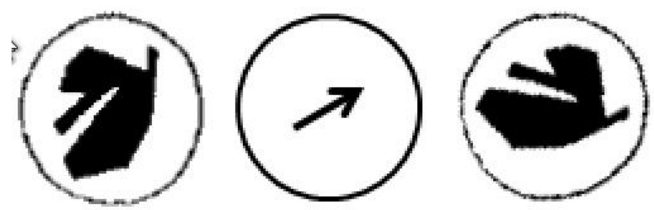
Captures cross-cultural effects in visual oddity task



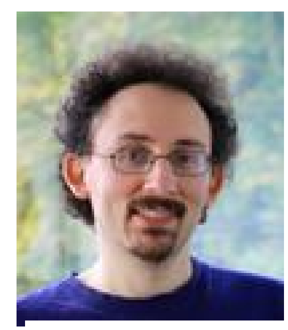
76th percentile, better than most adult Americans, at Raven's Progressive Matrices



Handles all 10 classes of paper-folding tasks

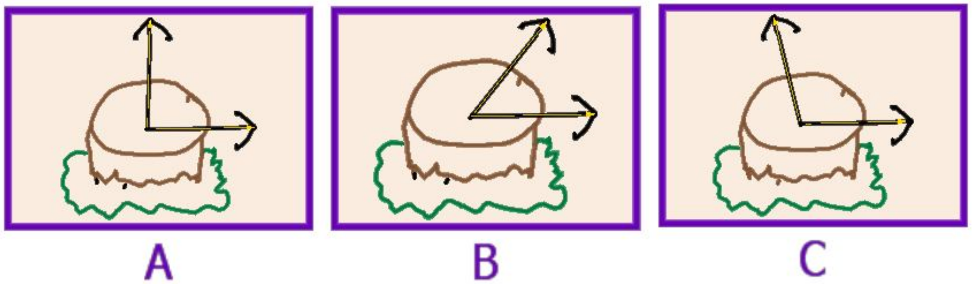


Suggests spatial abstraction strategies as explanation for variations in human performance

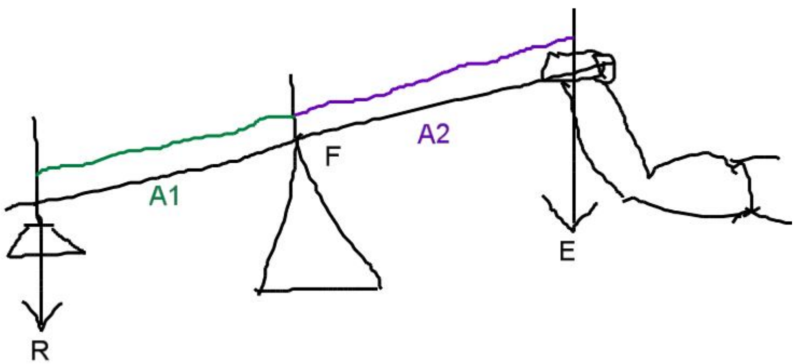


Andrew Lovett

Modeling STEM Reasoning & Learning



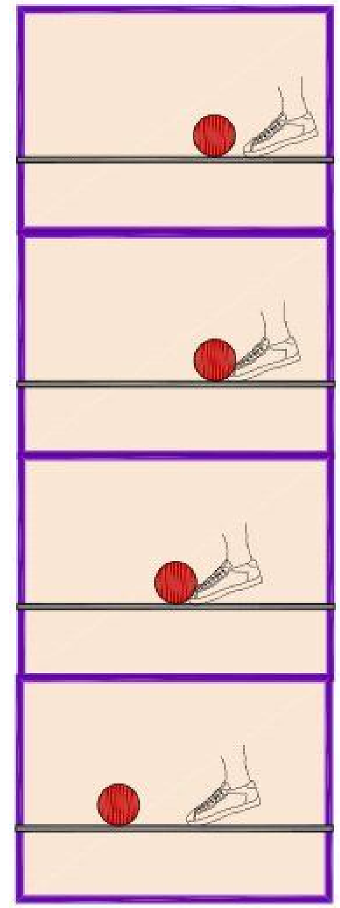
Solving ranking problems from conceptual physics textbook



A lever has three basic parts. A fulcrum is a basic part of a lever.
A force is a basic part of a lever. A weight is a basic part of a lever.
(sketchForDiscourse "kb-resource://Figure1-1.sk" (DrsCaseFn DRS-3446218074-8197))
F is the Fulcrum. E is the force. A2 is the distance between the weight and the fulcrum. A1 is the distance between the force and the fulcrum. A1 is an arm of the lever. A2 is an arm of the lever.

Learning models of force: Trajectory of models similar to human students

Scott Friedman's Ph.D.



Kate Lockwood's Ph.D.: After reading simplified NL version of chapter, correctly answered 12/15 homework questions

Overview

- Introduction to CogSketch ✓
- CogSketch Basics
- Visual processing in CogSketch
- CogSketch in Education
- Advanced features
  - Extending the KB, exporting knowledge…
- Wrap-up

Your feedback will help us improve CogSketch

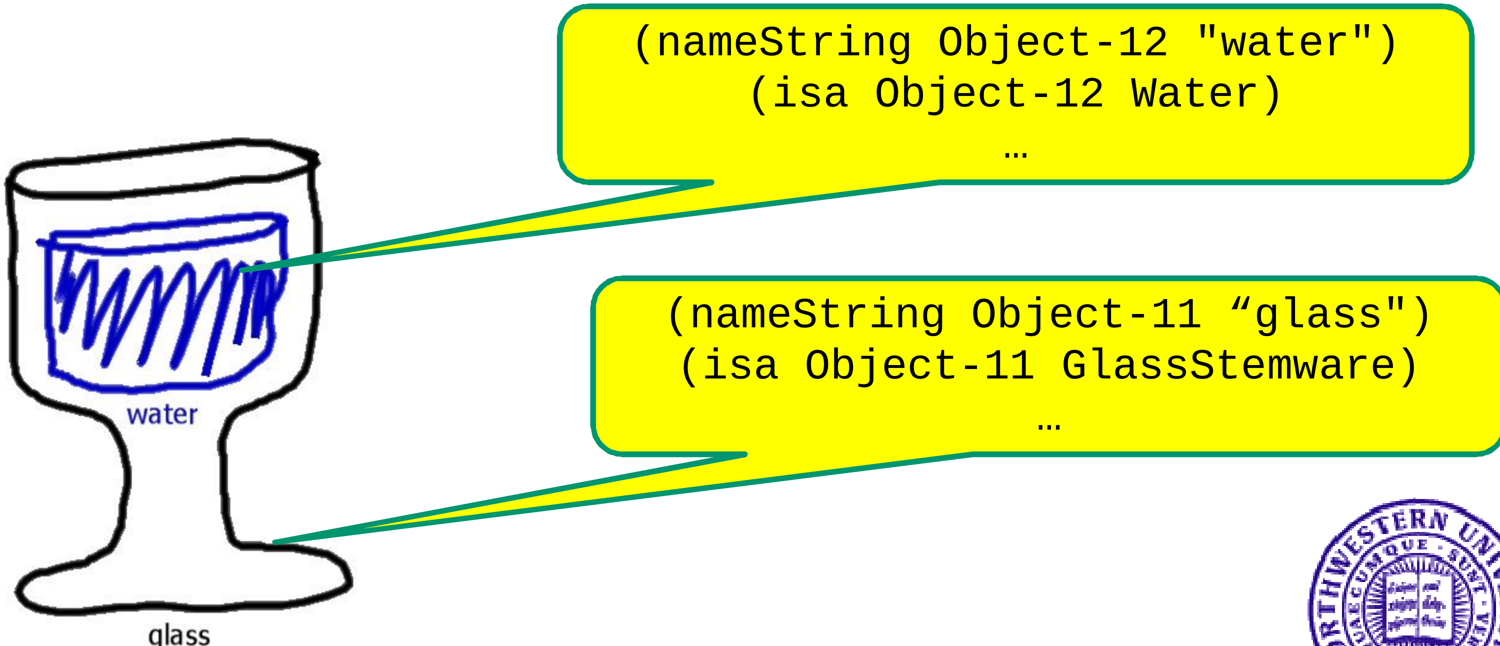
CogSketch Basics

This Section

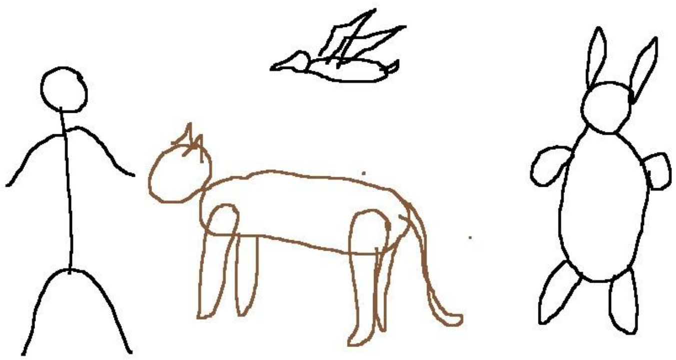
- What's in a sketch?
- Starting a sketch
- Drawing glyphs
  - Inking
  - Conceptual labeling
- Layers
- Subsketches & the metalayer

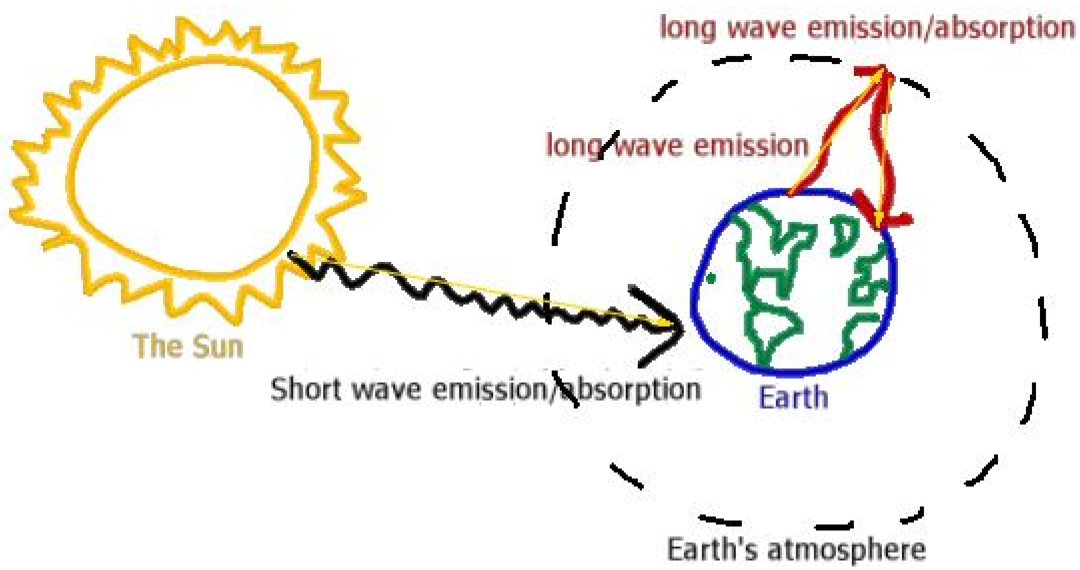
Sketches are made of Glyphs

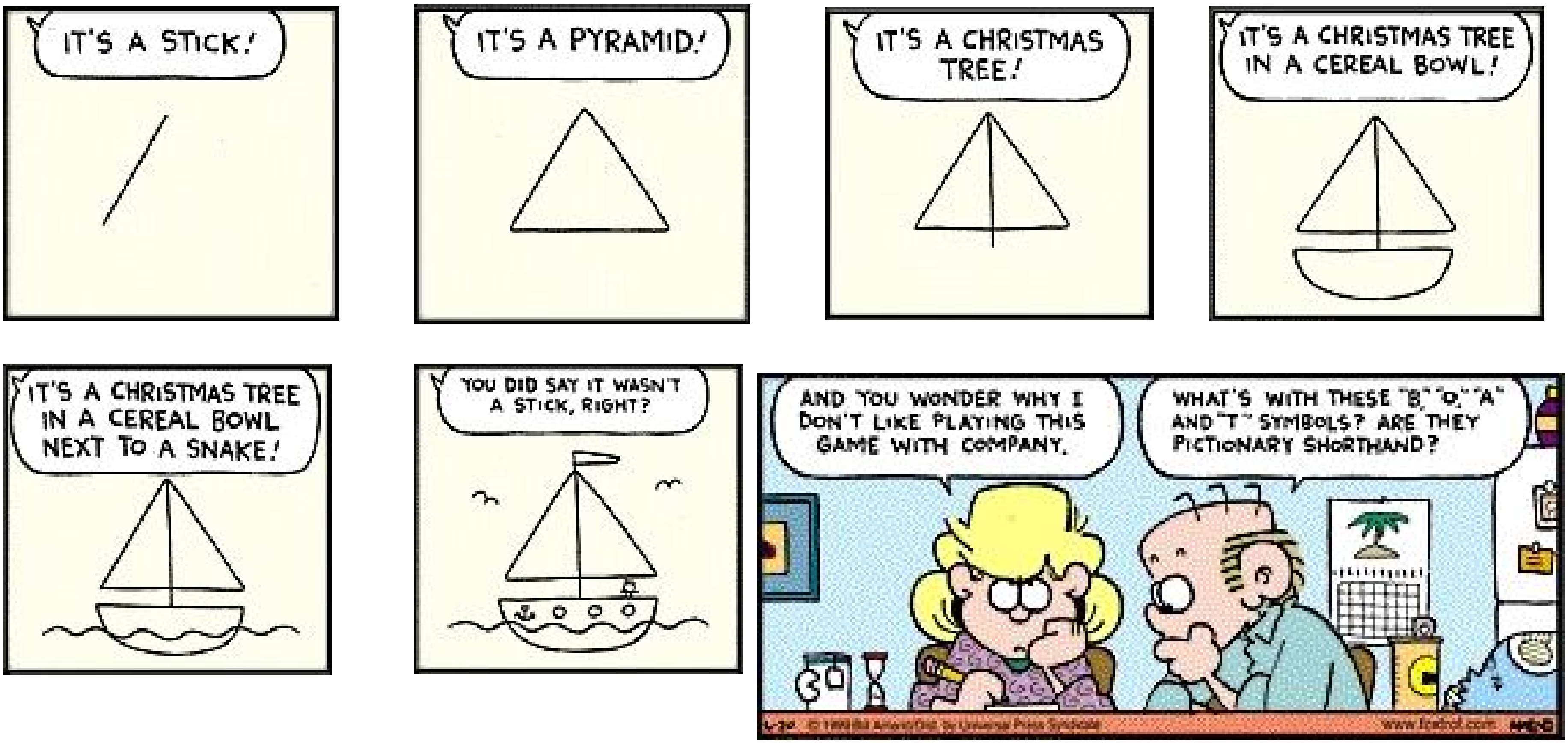
- A glyph has
  - Ink: Colored polylines
  - Content: A token representing what is depicted by the ink



Examples of Glyphs

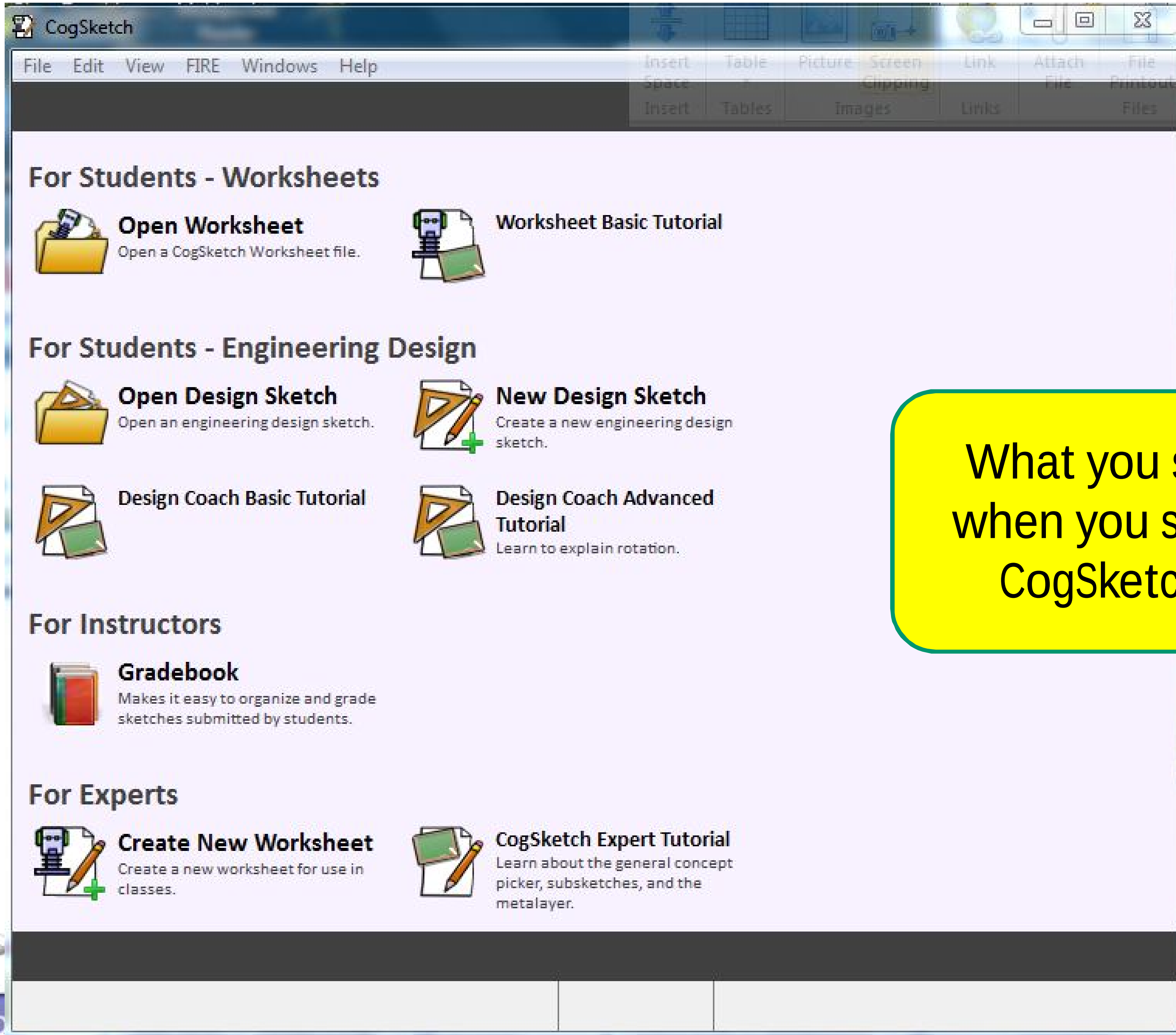





IT'S A STICK!
IT'S A PYRAMID!
IT'S A CHRISTMAS TREE!
IT'S A CHRISTMAS TREE IN A CEREAL BOWL!
IT'S A CHRISTMAS TREE IN A CEREAL BOWL NEXT TO A SNAKE!
YOU DID SAY IT WASN'T A STICK, RIGHT?
AND YOU WONDER WHY I DON'T LIKE PLAYING THIS GAME WITH COMPANY.
WHAT'S WITH THESE "B," "O," "A" AND "T" SYMBOLS? ARE THEY PICTIONARY SHORTHAND?
www.foxtrot.com

Sketches have Structure

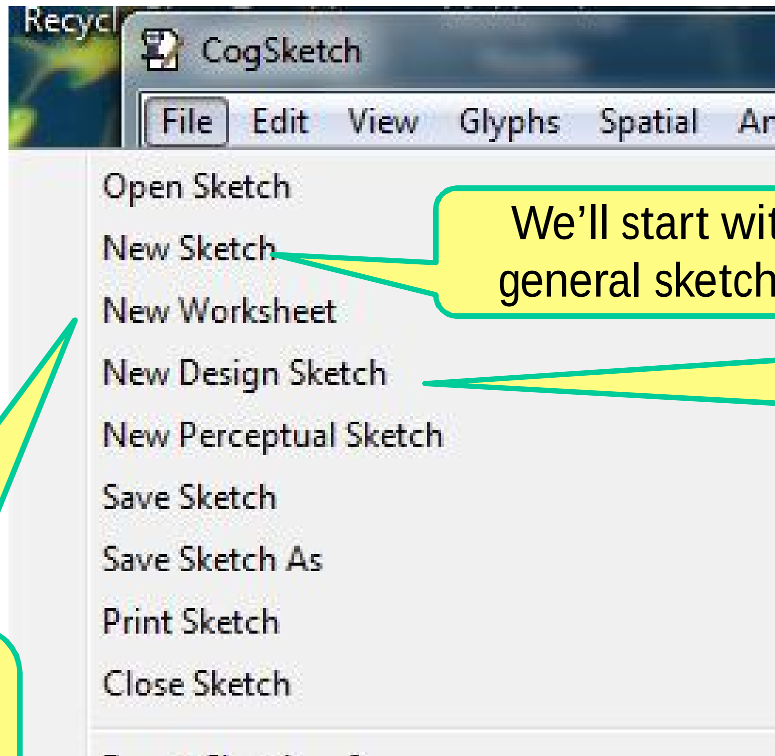
- People often draw several closely related sketches
  - Different perspectives on the same situation
  - A sequence of behaviors
  - Alternative solutions to be compared
- CogSketch captures this via *subsketches*
  - A sketch consists of one or more subsketches
  - A visual language is provided for relating them



What you see when you start CogSketch

Creating a New Sketch

- There are four types of sketches

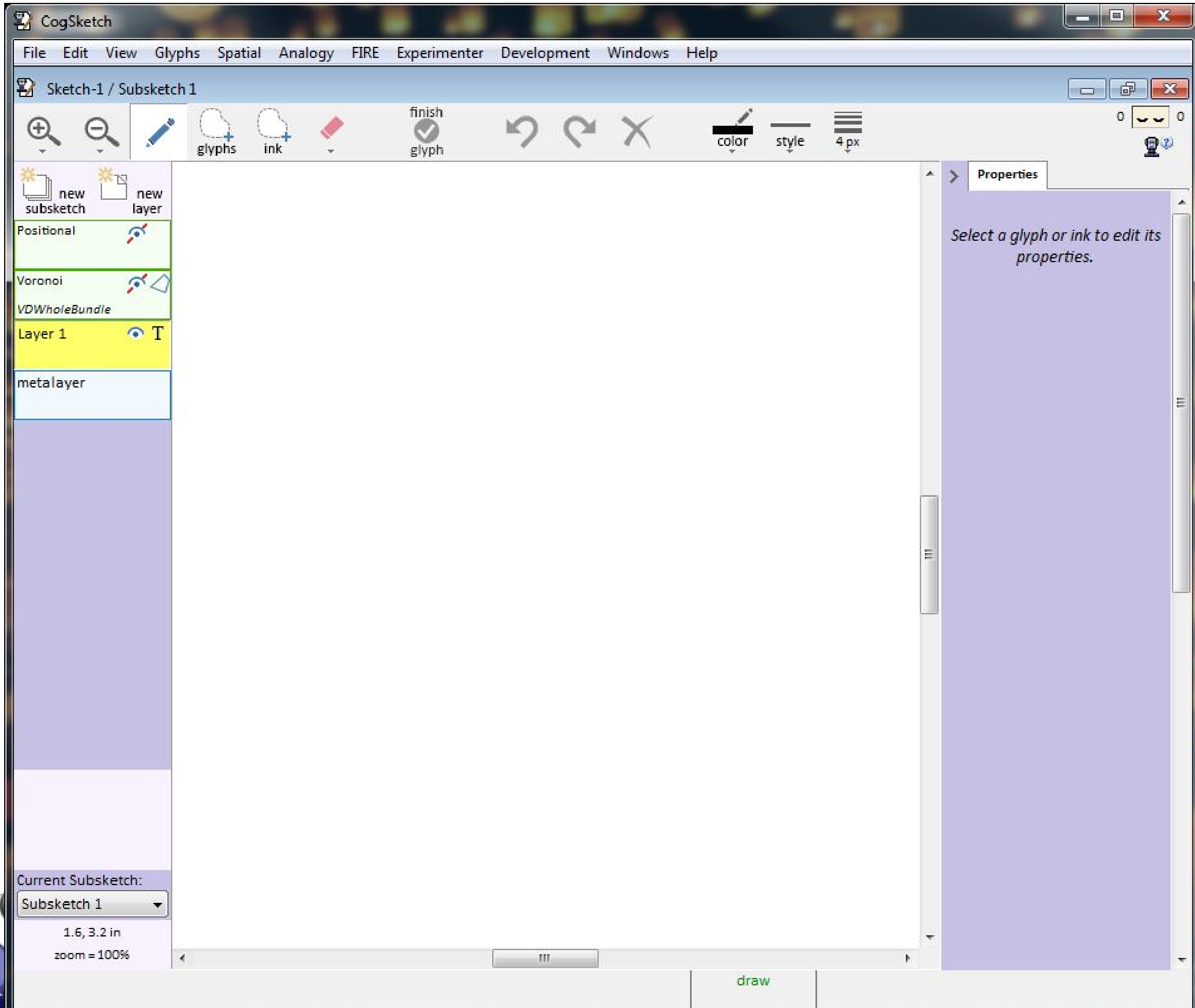


We'll start with general sketches

Perceptual Sketchpad and Design Coach will be discussed later

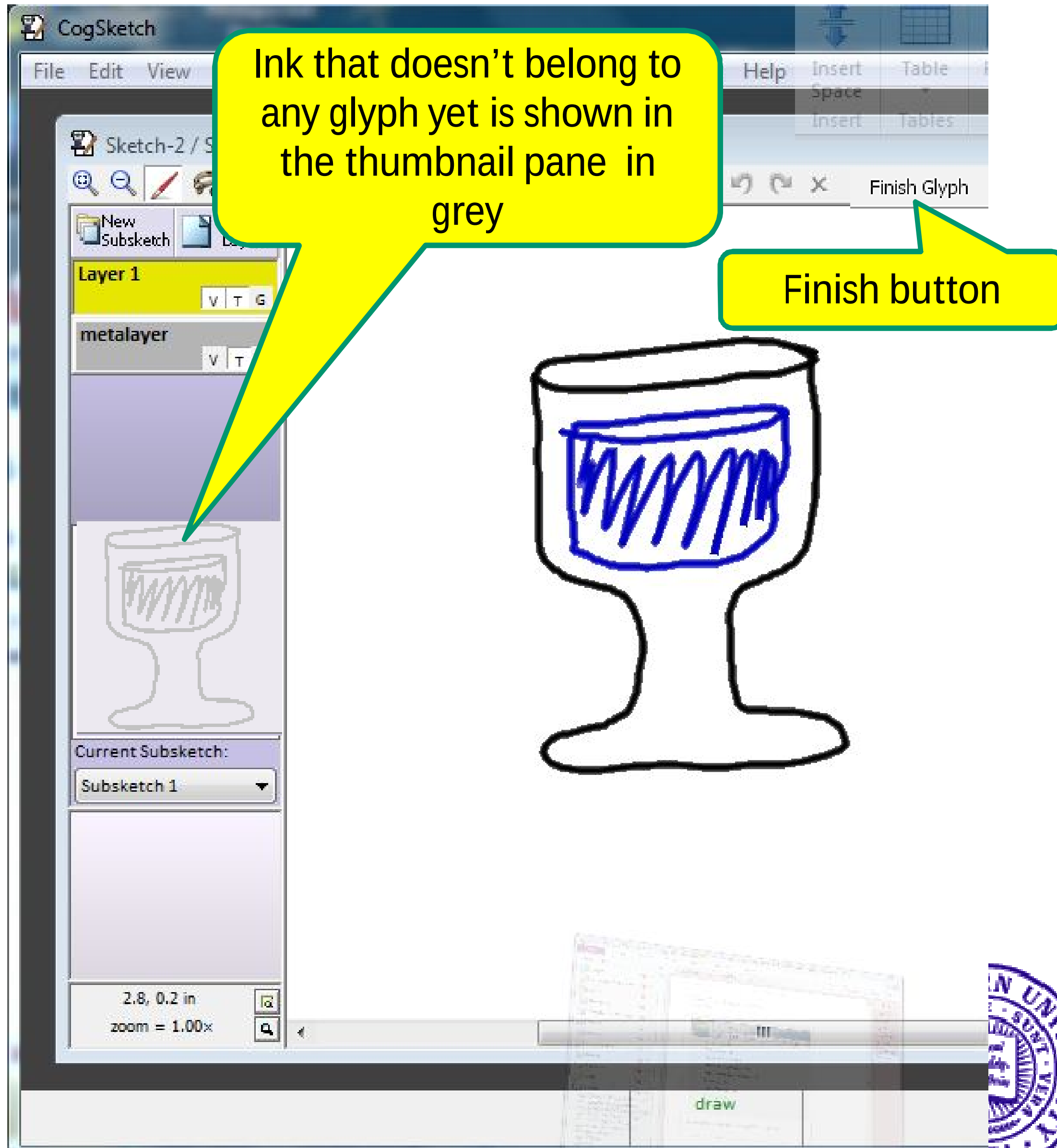
Worksheet authoring will be discussed later

What You Should See



Drawing a Glyph

- Just start drawing
- When you're done, click the finish button
- Thumbnail pane shows how ink is decomposed into glyphs via false colors



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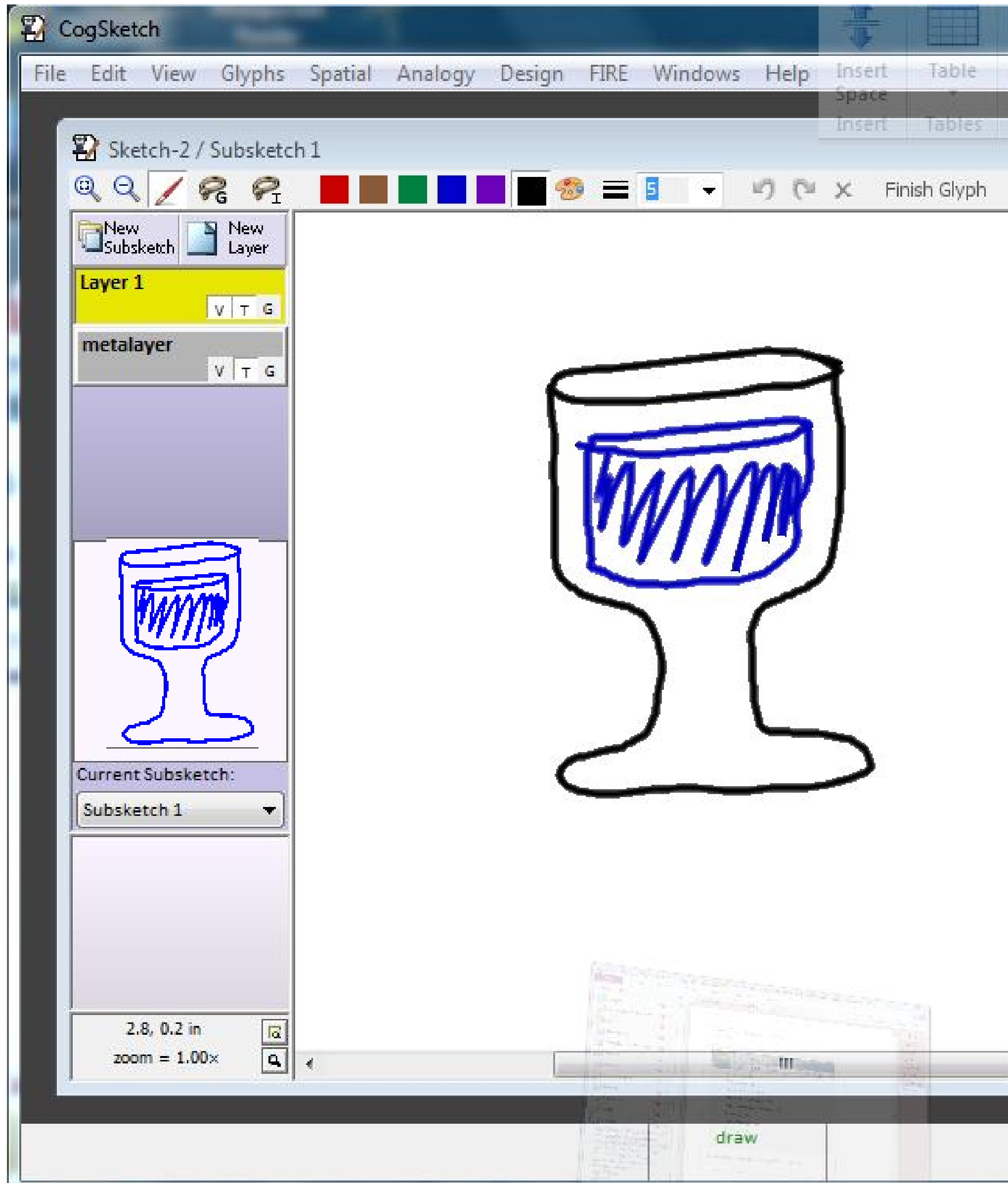
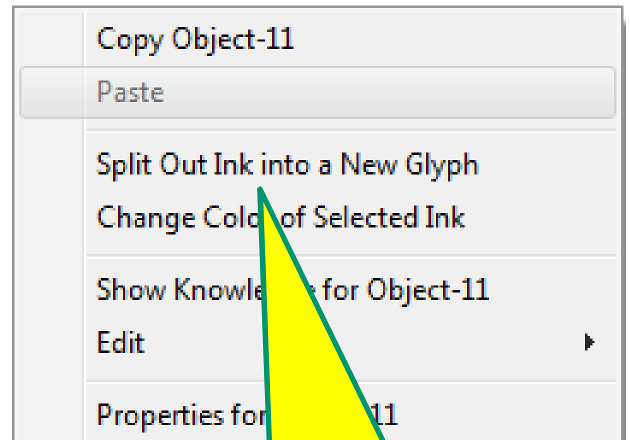
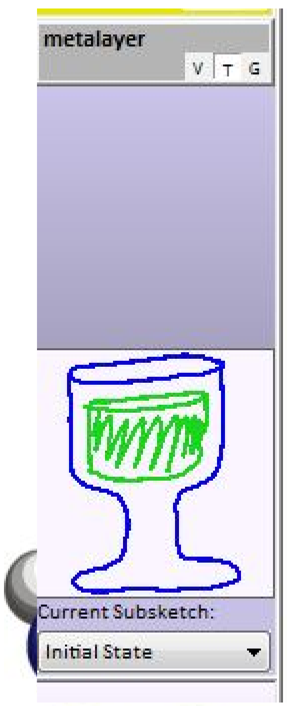


Splitting ink into multiple glyphs

Choose the ink you want to make into a new glyph via the ink lasso





Right-click and choose split

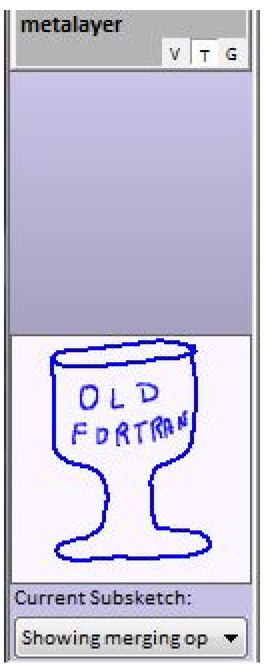
Merging Ink into Glyphs

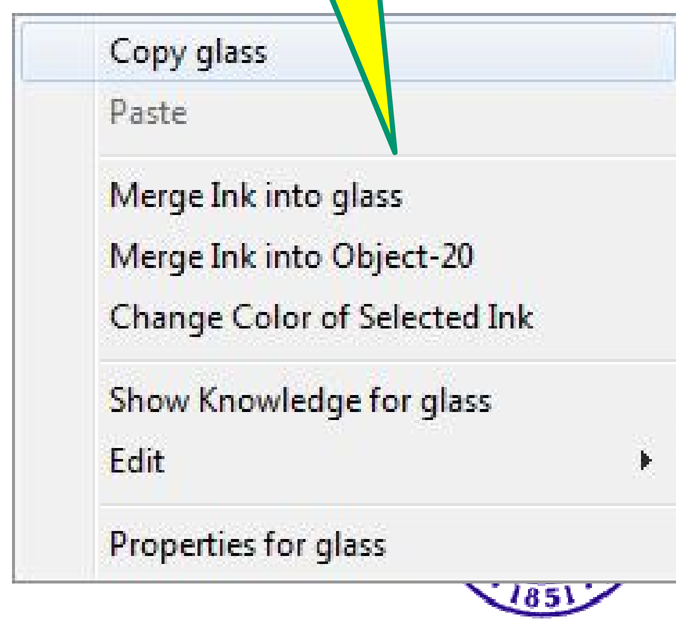
Logo isn't part of the glass

Merging Ink into Glyphs

1. Select ink to be merged via the ink lasso

2. Select which is merged into the other





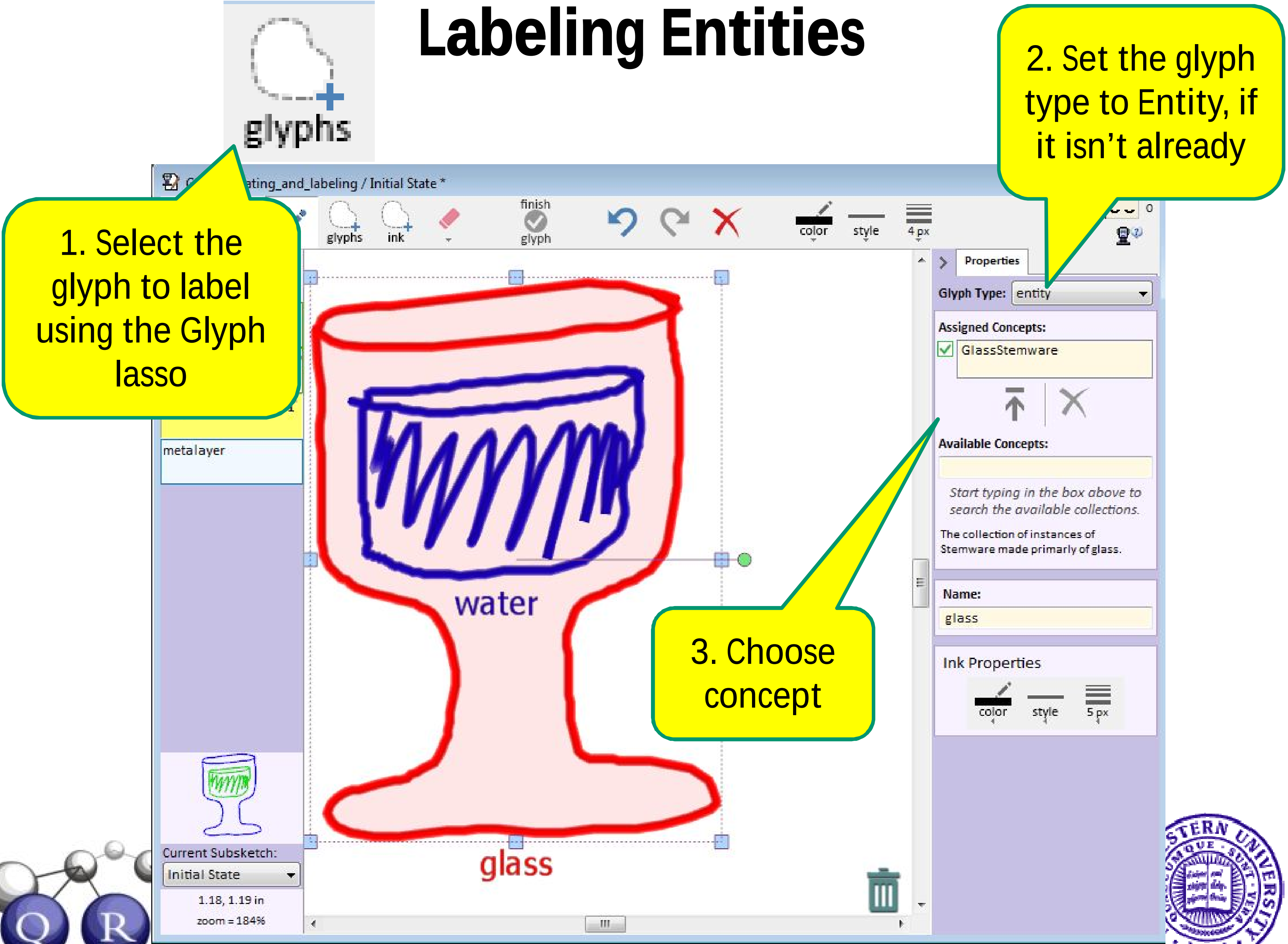
Conceptual Labeling

- When people sketch, they talk
  - They say what objects are
  - They provide information that isn't easily sketched
- CogSketch provides interfaces for you to tell it what your glyphs mean
  - The most general interface is described here
  - Often simpler, customized versions are used
- The vocabulary is drawn from the OpenCyc KB contents, plus extensions
  - Concepts are defined as *collections*
  - Relationships are defined via *relations*

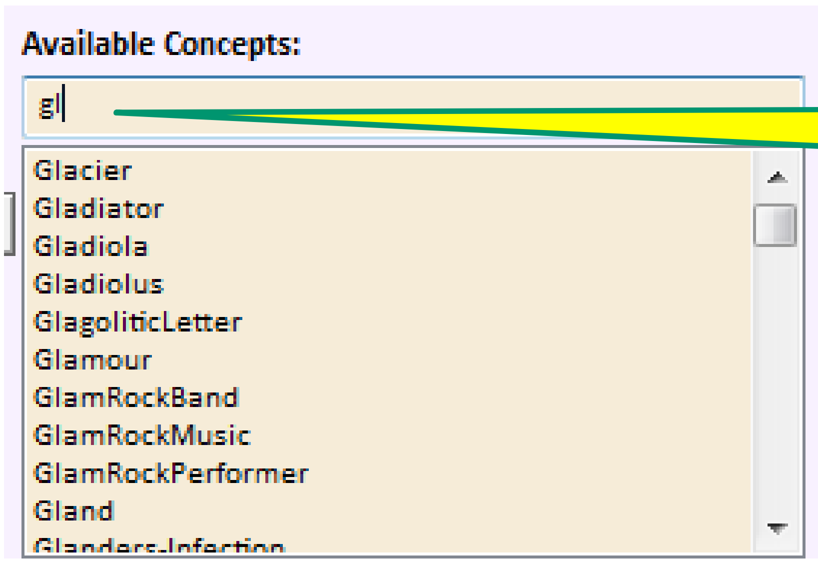
Types of Glyphs

- There are three types of glyphs that you can use in CogSketch
  - **Entities**: Represent objects in a sketch. They can be concrete or abstract
  - **Relations**: Represent binary relationships between other entities in the sketch
  - **Annotations**: Represents a property of another glyph that would be difficult to indicate in a purely visual manner

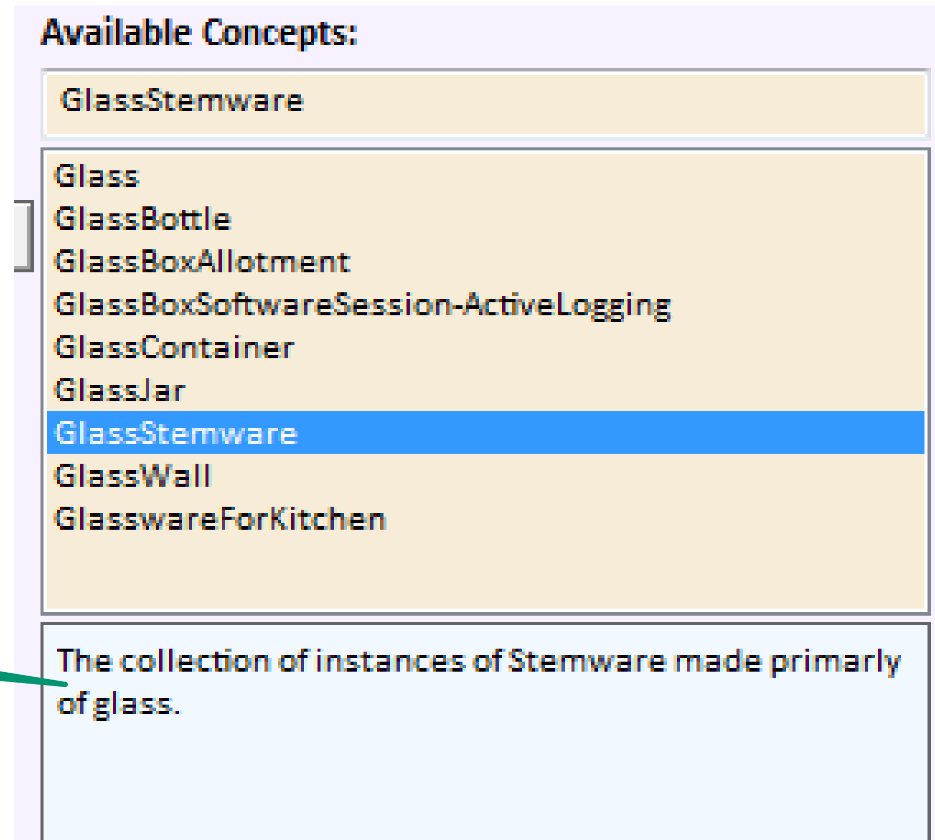
Labeling Entities



Choosing a Concept

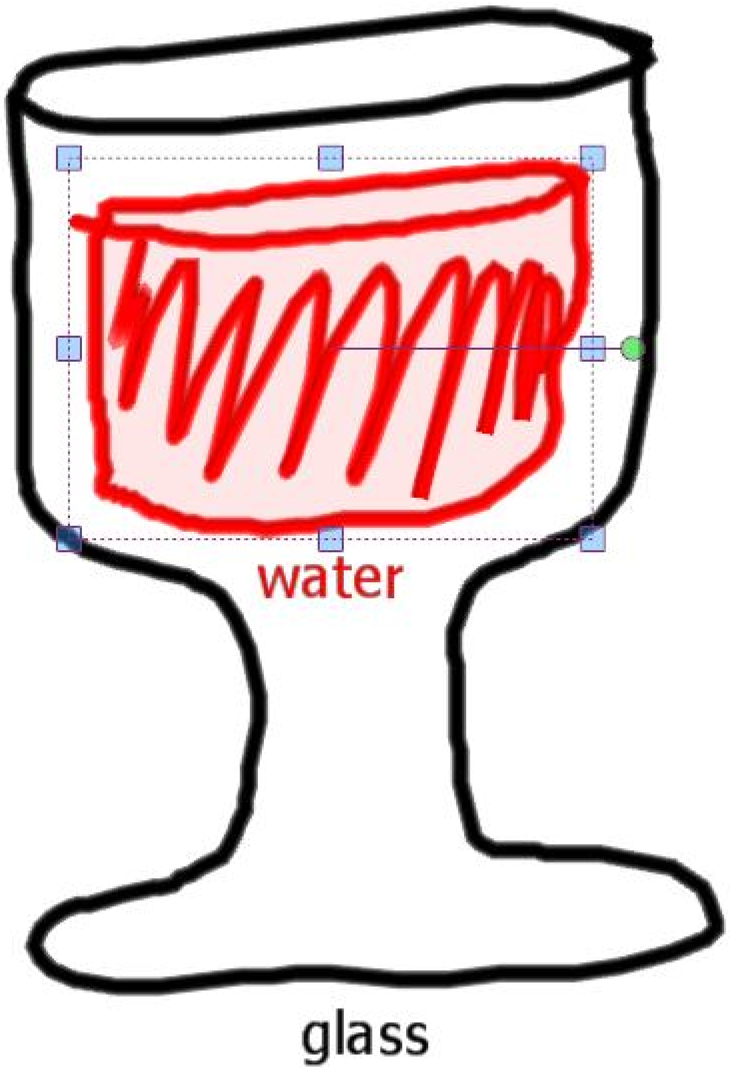


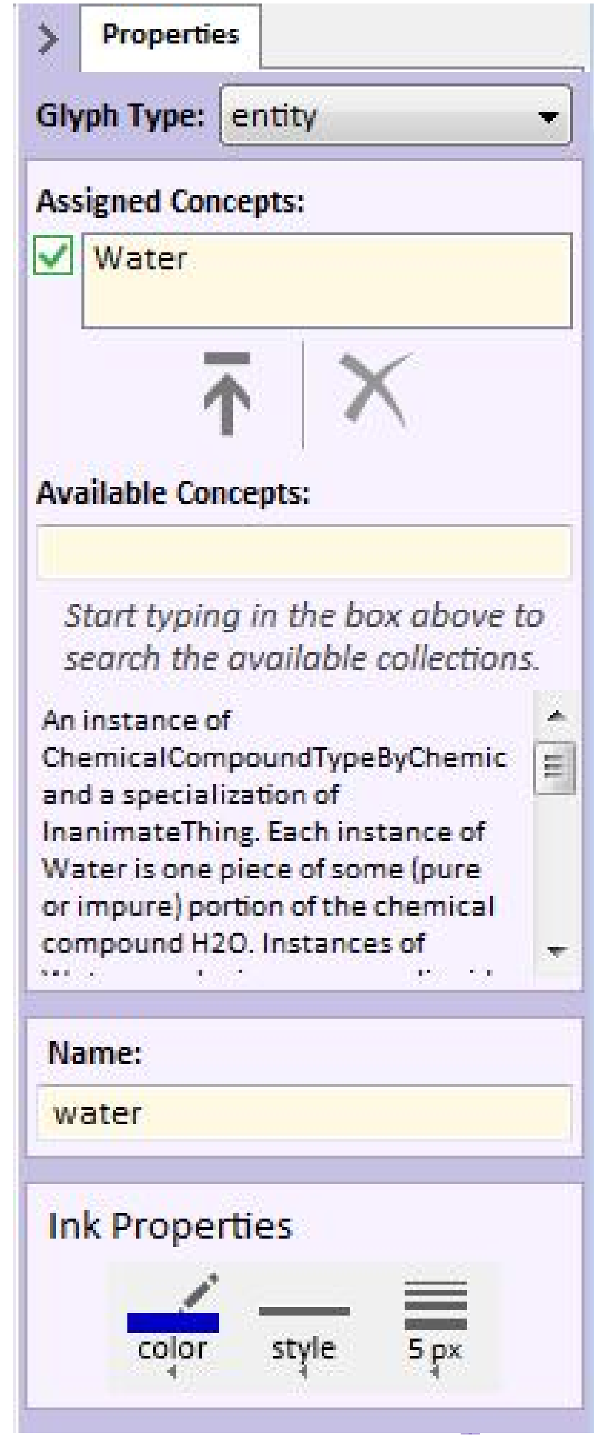
1. Start typing to see candidates



2. Comments help indicate which choice might be best

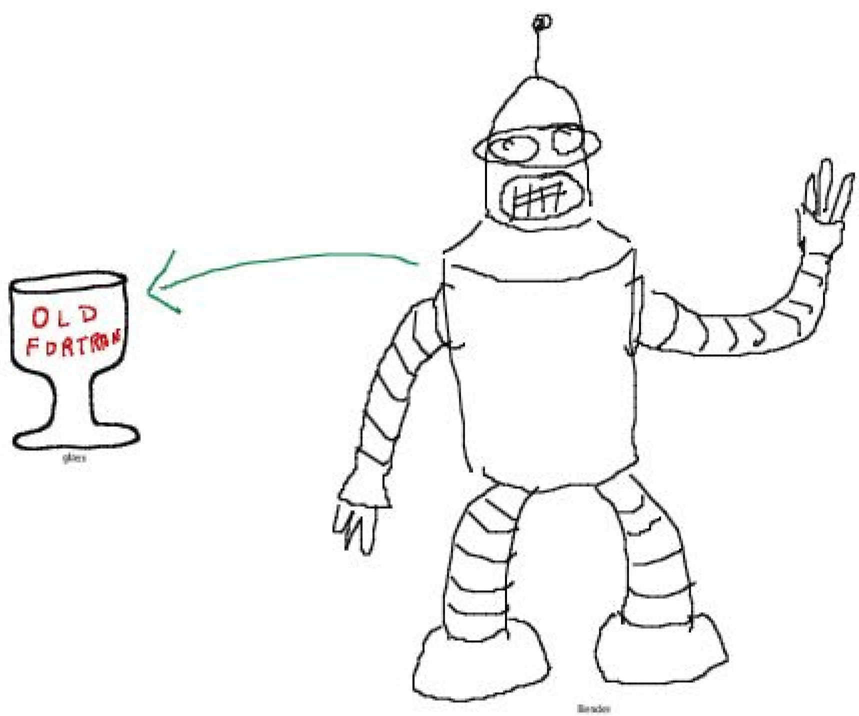
Choosing a Concept, continued



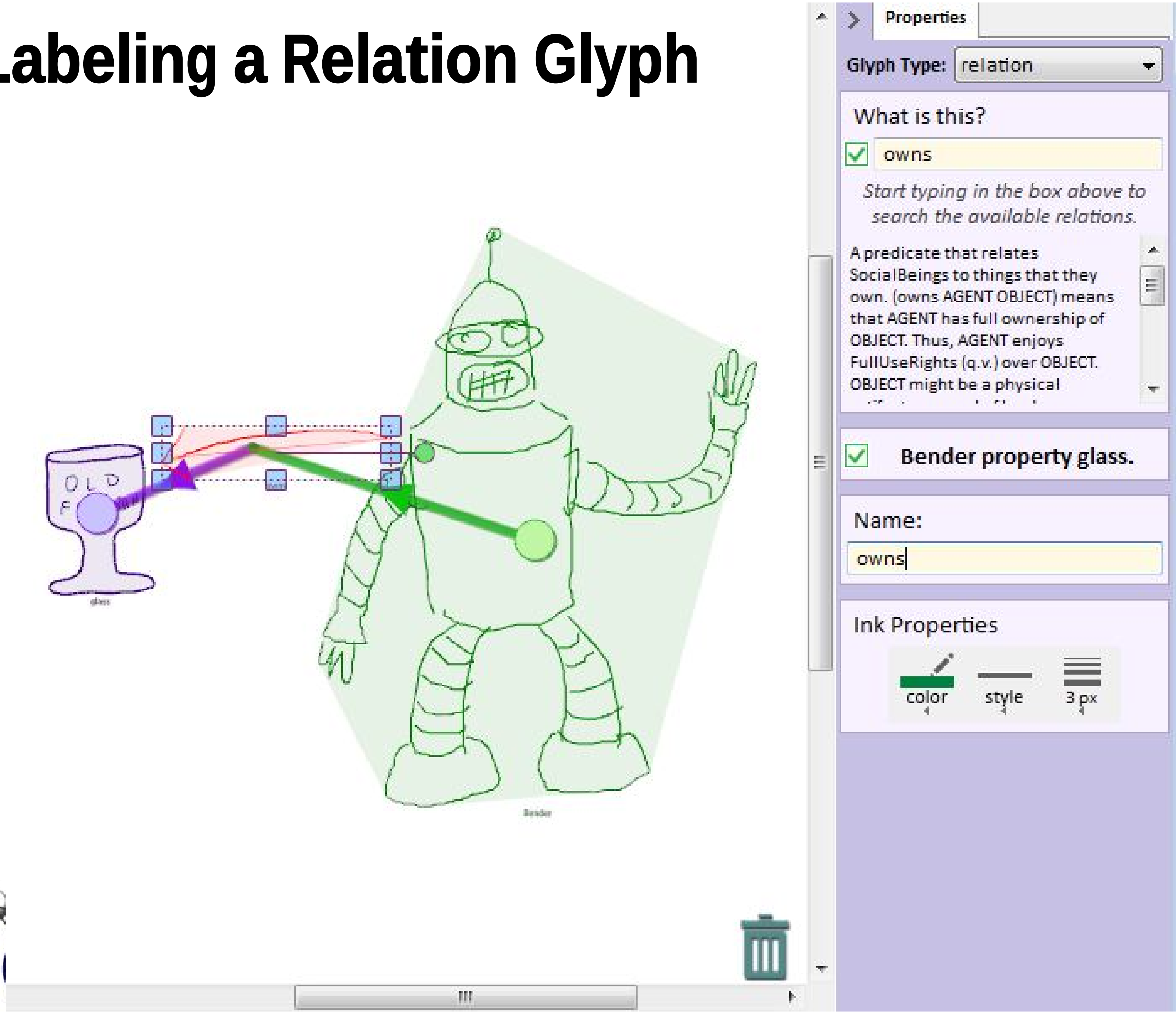


Relation Glyphs

- Indicate relationships between two things in the sketch
- Always drawn as arrows, as per concept maps

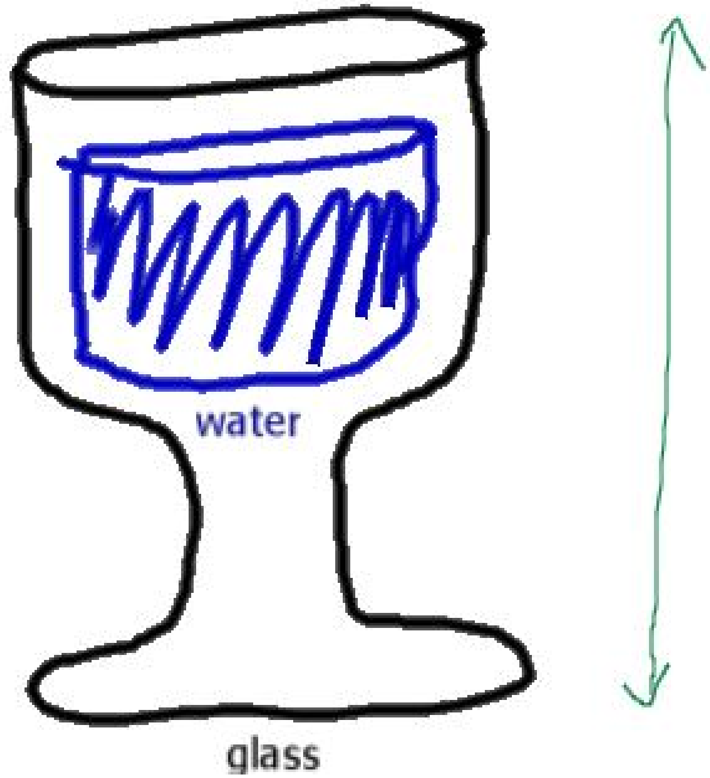


Labeling a Relation Glyph

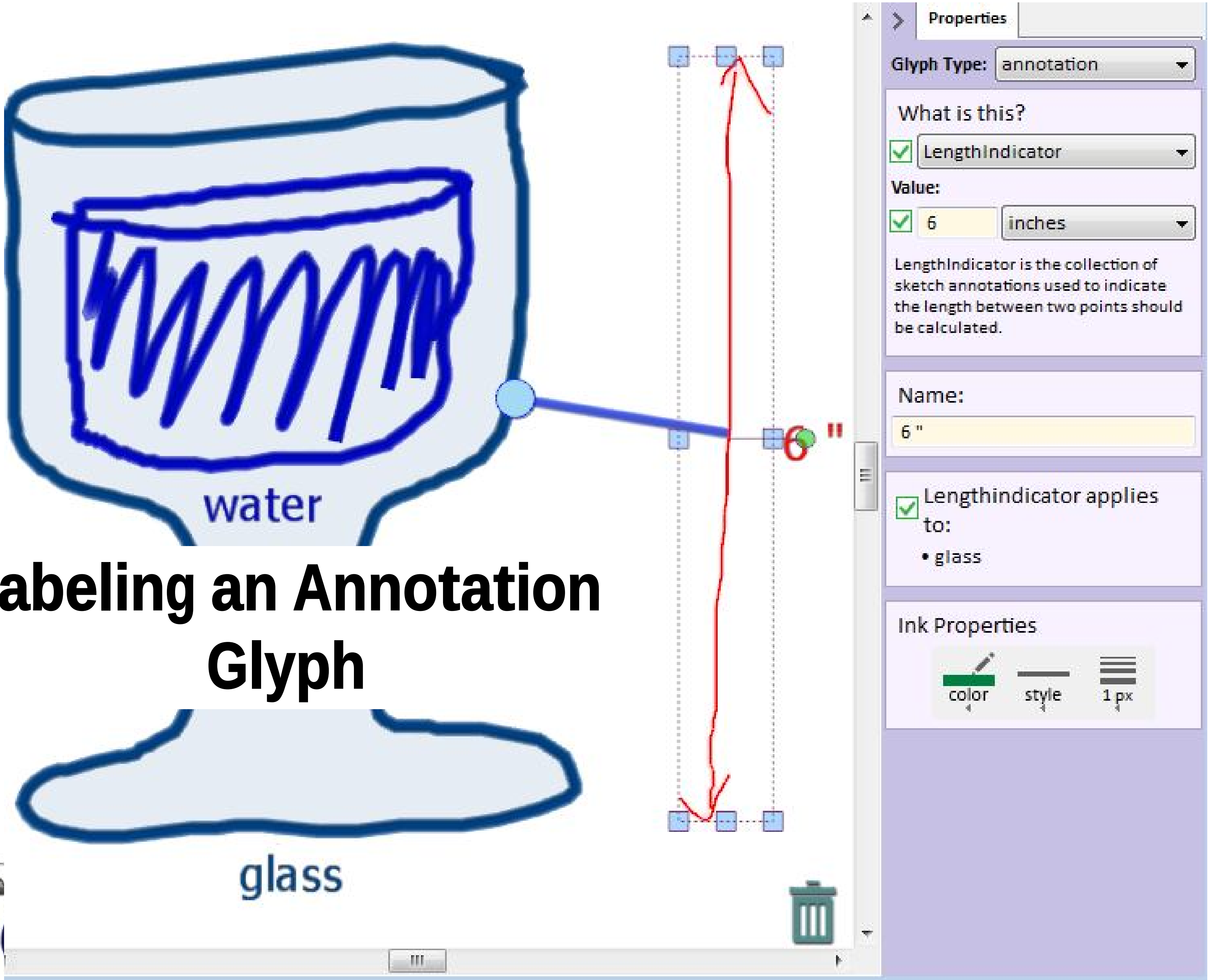


Annotation Glyphs

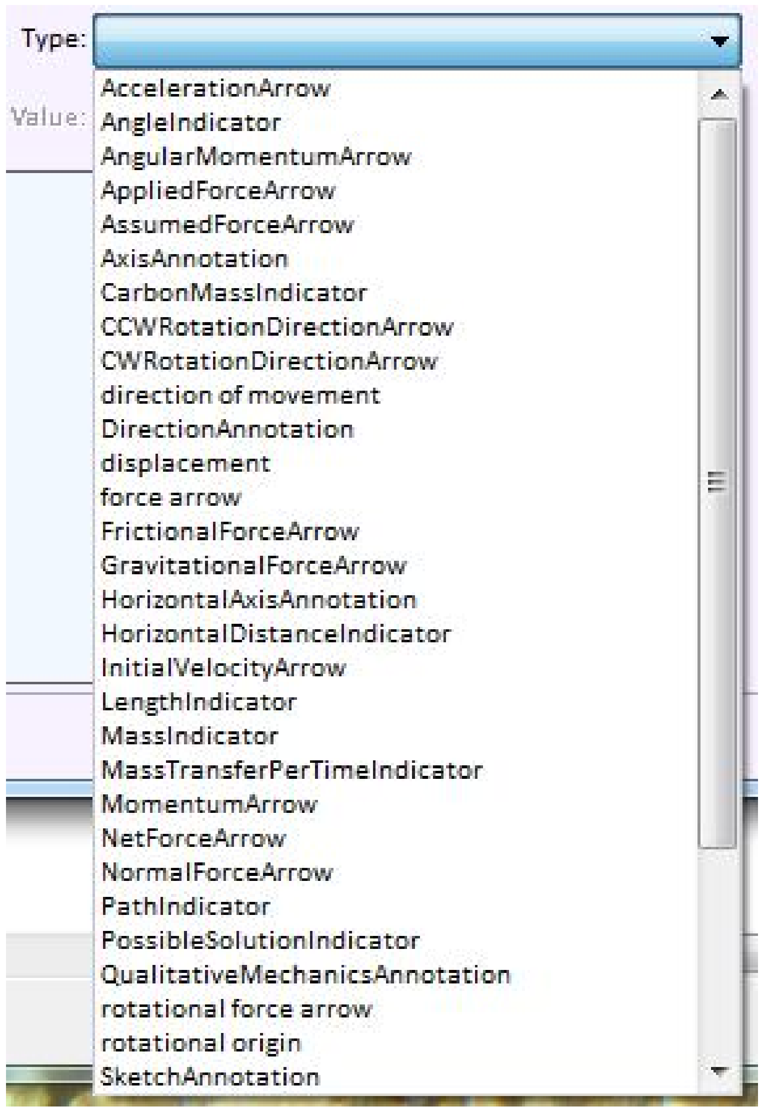
- Represent information about a glyph that would be hard to express visually
- Annotation glyph provides
  - Visual indicator in the sketch
  - Non-visual information



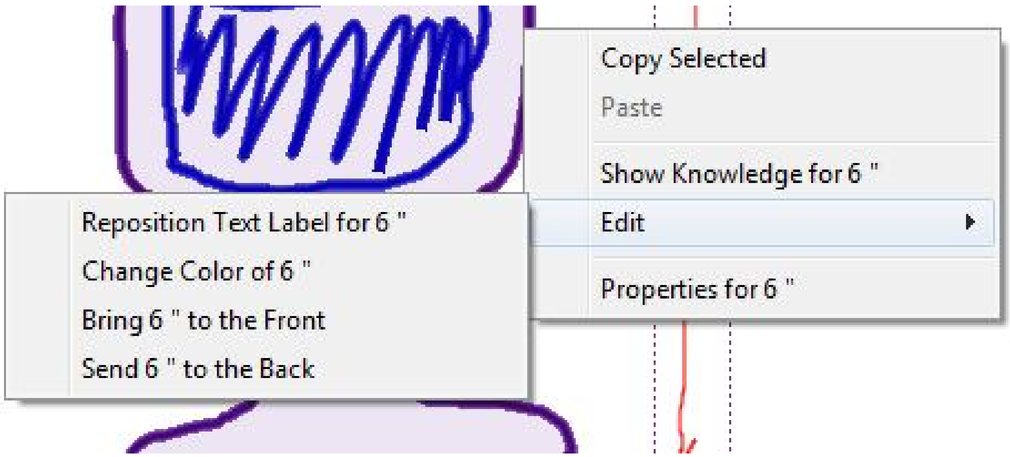
Labeling an Annotation Glyph

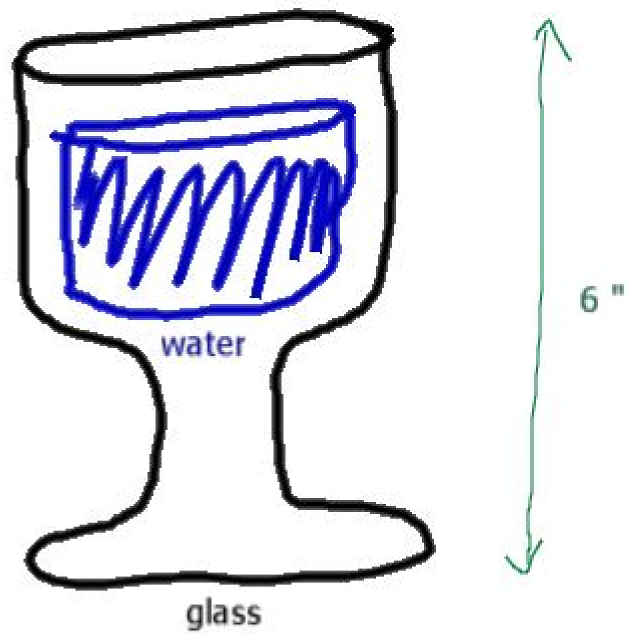


Types of Annotations



Neatening your Sketch

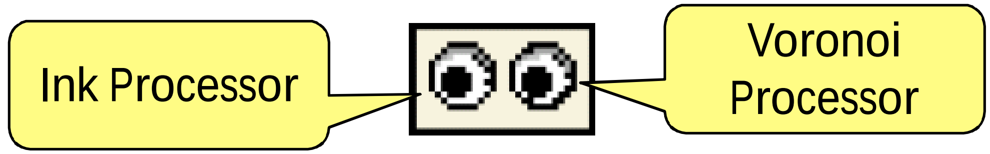


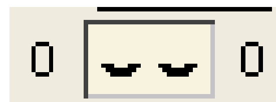


What CogSketch Does with This Information

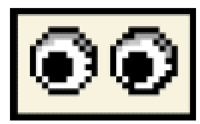
- It enables CogSketch to reason about the objects you sketched
  - e.g. simple qualitative mechanics is built-in
  - Used in Design Coach, mentioned later
  - You can hook up your own reasoners to it
- It enables CogSketch to match sketches
  - e.g., sketch worksheets for education compare a student's sketch with a teacher's sketch
  - Understanding intended meaning of glyph via labeling is vital because students are often incorrect

Status Indicators



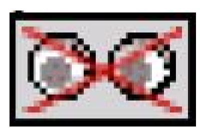


Idle. Digits indicate the number of tasks queued



Both processors running

Waiting. Happens while you are drawing/moving something, postponing visual processing until you are finished, for responsiveness.

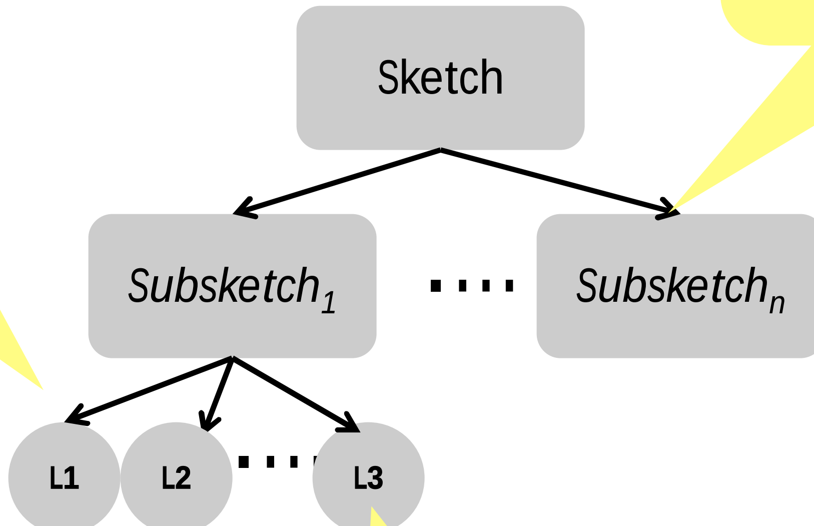


Crashed. (Very rare) Touch to restart

The Structure of Sketches

Multiple layers in the same subsketch may be visible at the same time, like in drawing programs or acetate sheets over paper.

Each sketch must have at least one subsketch, and each subsketch must have at least one layer

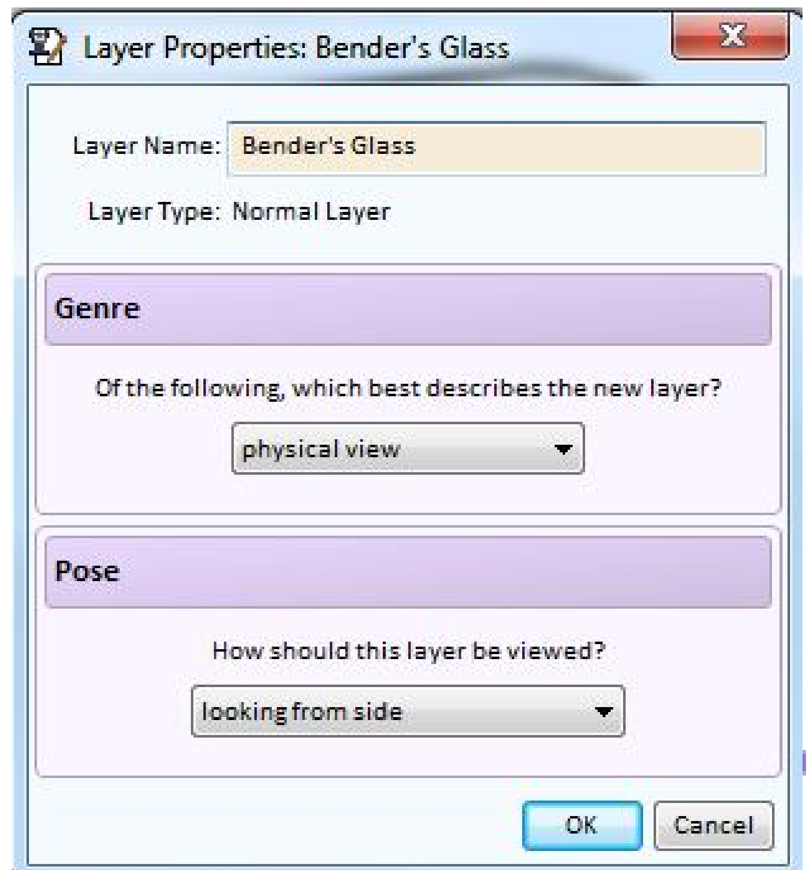


Only one subsketch is active at one time

By default, spatial relations are only computed between glyphs on the same layer

How Layers are Interpreted

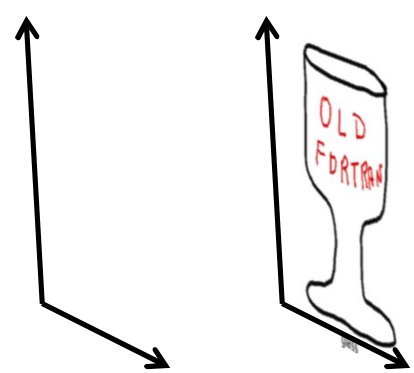
- Every layer has a *genre* and *pose*
- *Genre* indicates the kind of sketch it is
- *Pose* concerns frame of reference, defining how visual properties map to spatial properties



Genres

- *Abstract*: Visual relationships between glyphs provide no information about spatial relationships between them
- *Discrete graph*: Visual contact relationships important, but other visual properties (e.g. distances and locations) are not
  - Example: Concept maps
- *Geospatial*: Visual coordinates map onto geospatial coordinates, direction into N/S/E/W
- *Physical*: Visual coordinates map onto spatial coordinates, spatial relations are up/down/left/right

Spatial coordinates (unless genre is abstract or discrete graph)

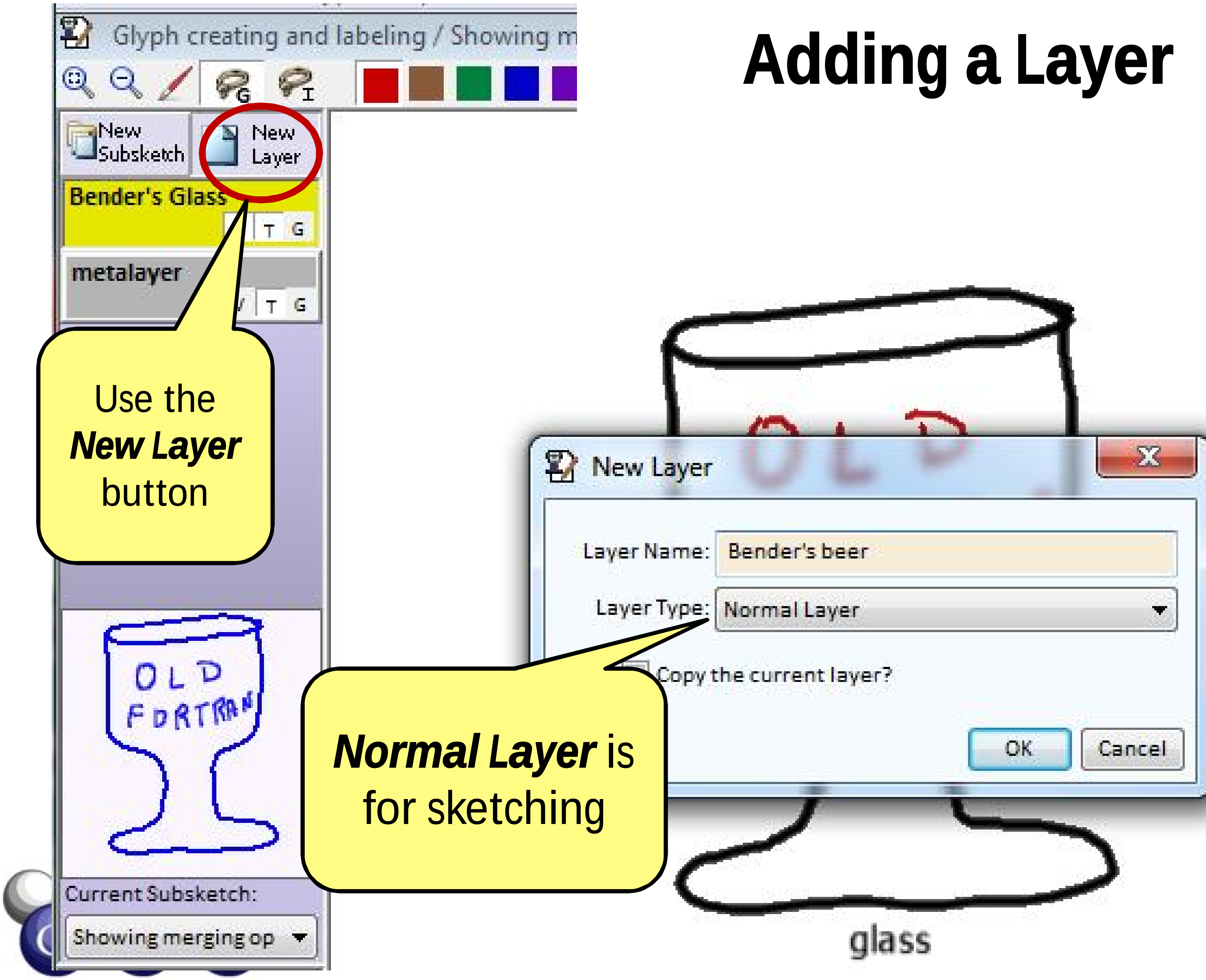


Visual coordinates

Pose

- *Unspecified*: Holds for abstract and discrete graph genres only.
- *Looking from bottom*: Up vertical = from user into the sketch.
- *Looking from top*: Up vertical = from the sketch to the user.
- *Looking from side*: Up vertical = up in glyph space

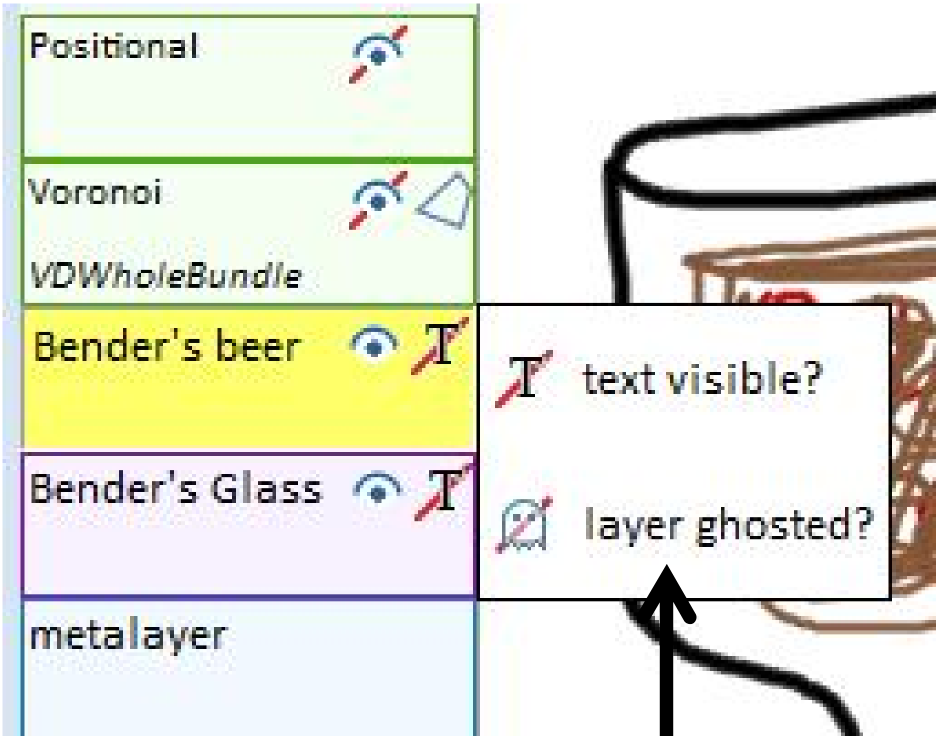
Adding a Layer

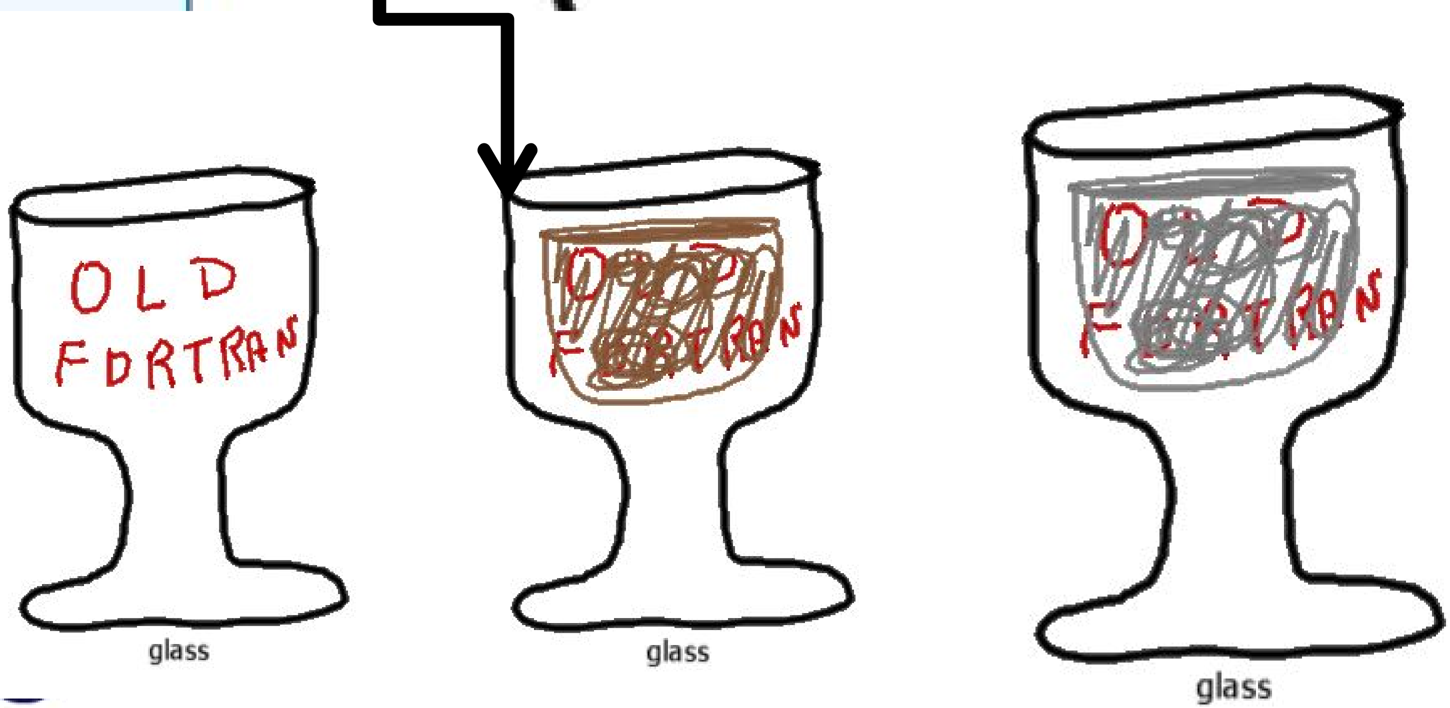


Use the ***New Layer*** button

Normal Layer is for sketching

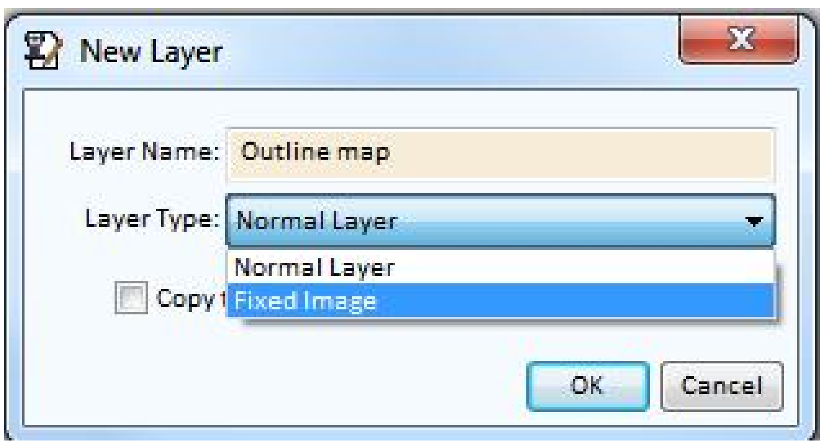
Controlling Visibility

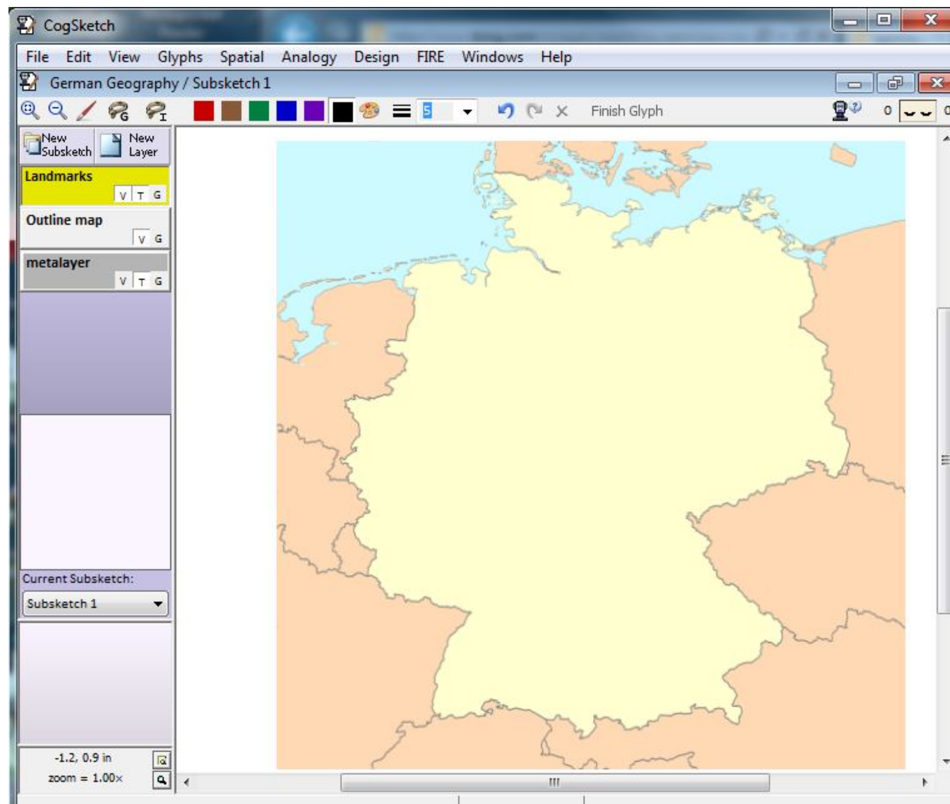




Adding a Bitmap Layer

- Useful for providing something to draw on top of
  - Annotating photographs or diagrams is a common task for sketch worksheets

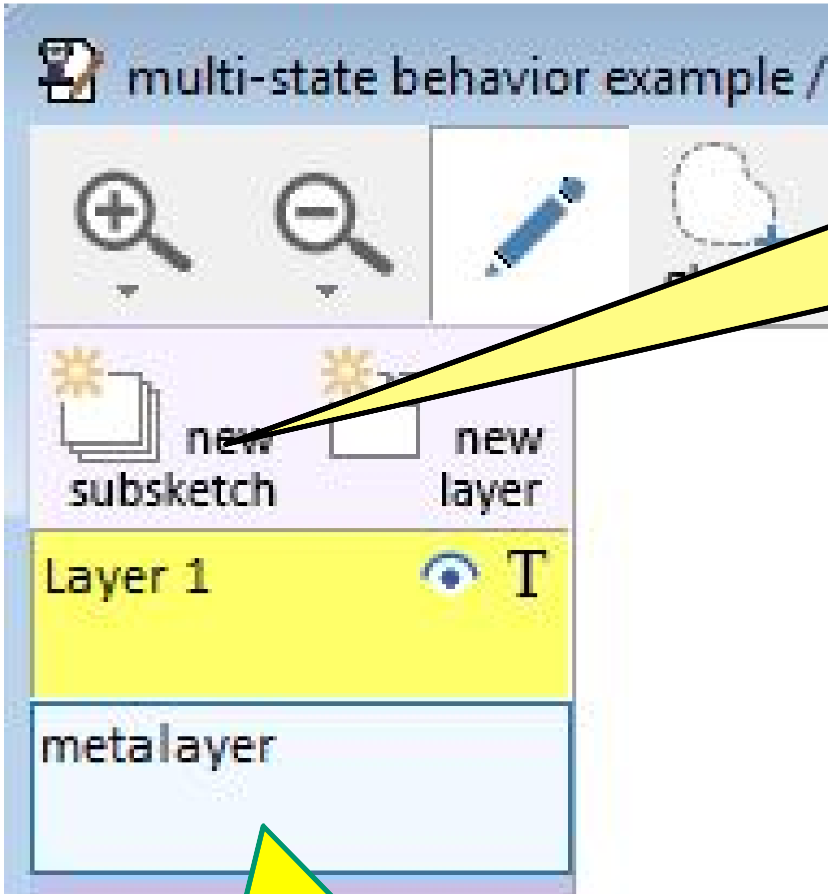




Uses for Multiple Subsketches

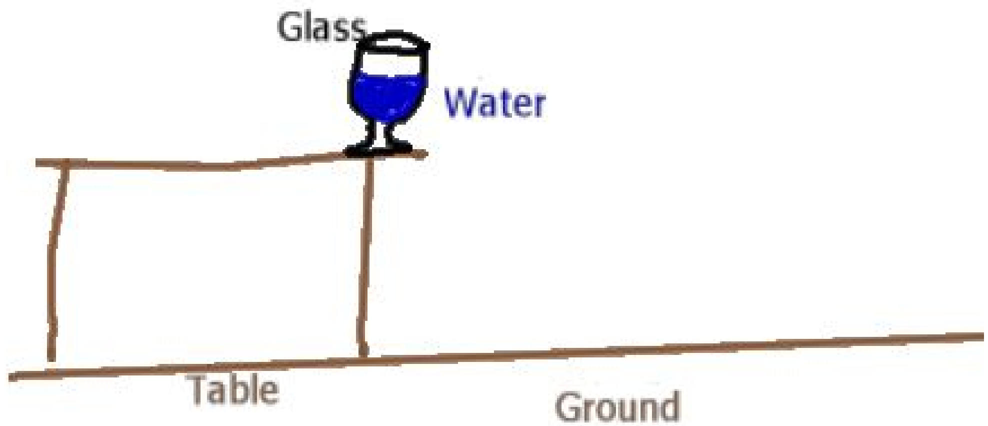
- Describing a complex behavior
  - Each subsketch might represent a distinct qualitative state
  - Can create *comic graphs*, a generalization of comic strips, that allow branches and joins in addition to sequentiality
- Describing alternatives
- Describing something from multiple perspectives

Adding a Subsketch



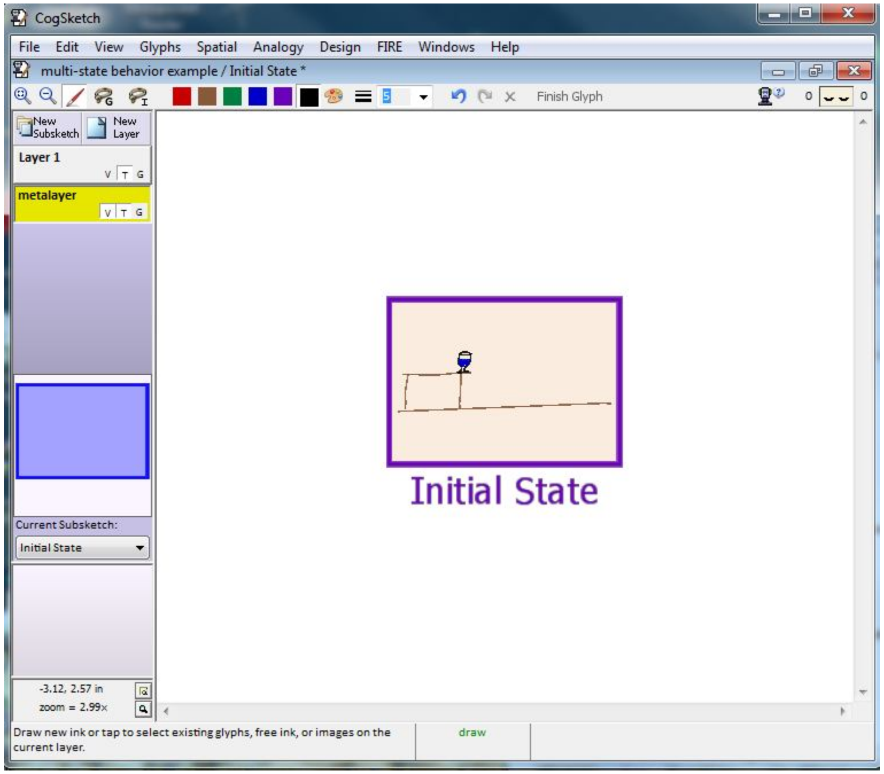
You can add a subsketch using the ***New Subsketch*** button

The *metalayer* lets you manipulate subsketches

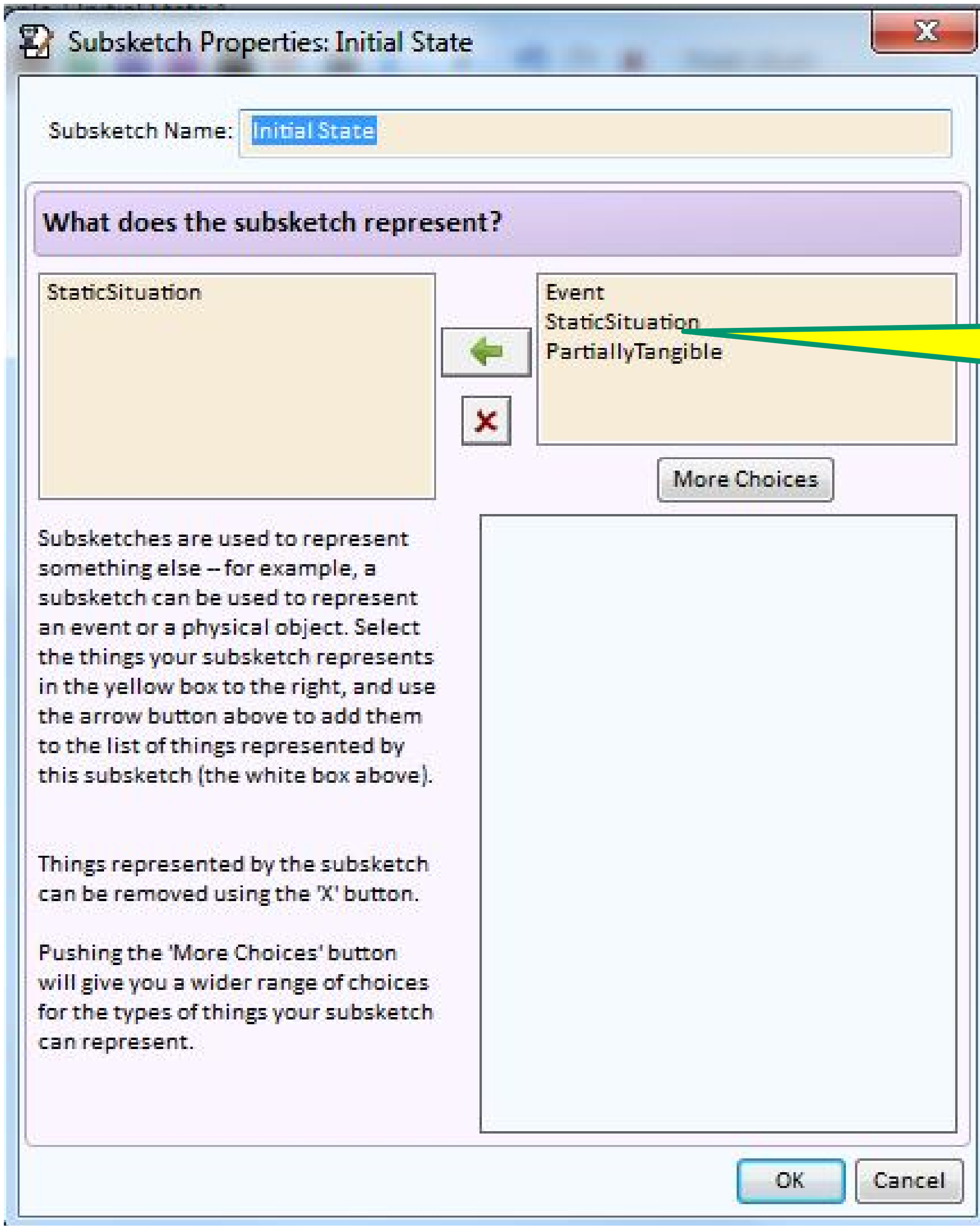


The Metalayer

- Every subsketch is a glyph on the metalayer
- Subsketch glyphs can be connected via relation glyphs, and annotated

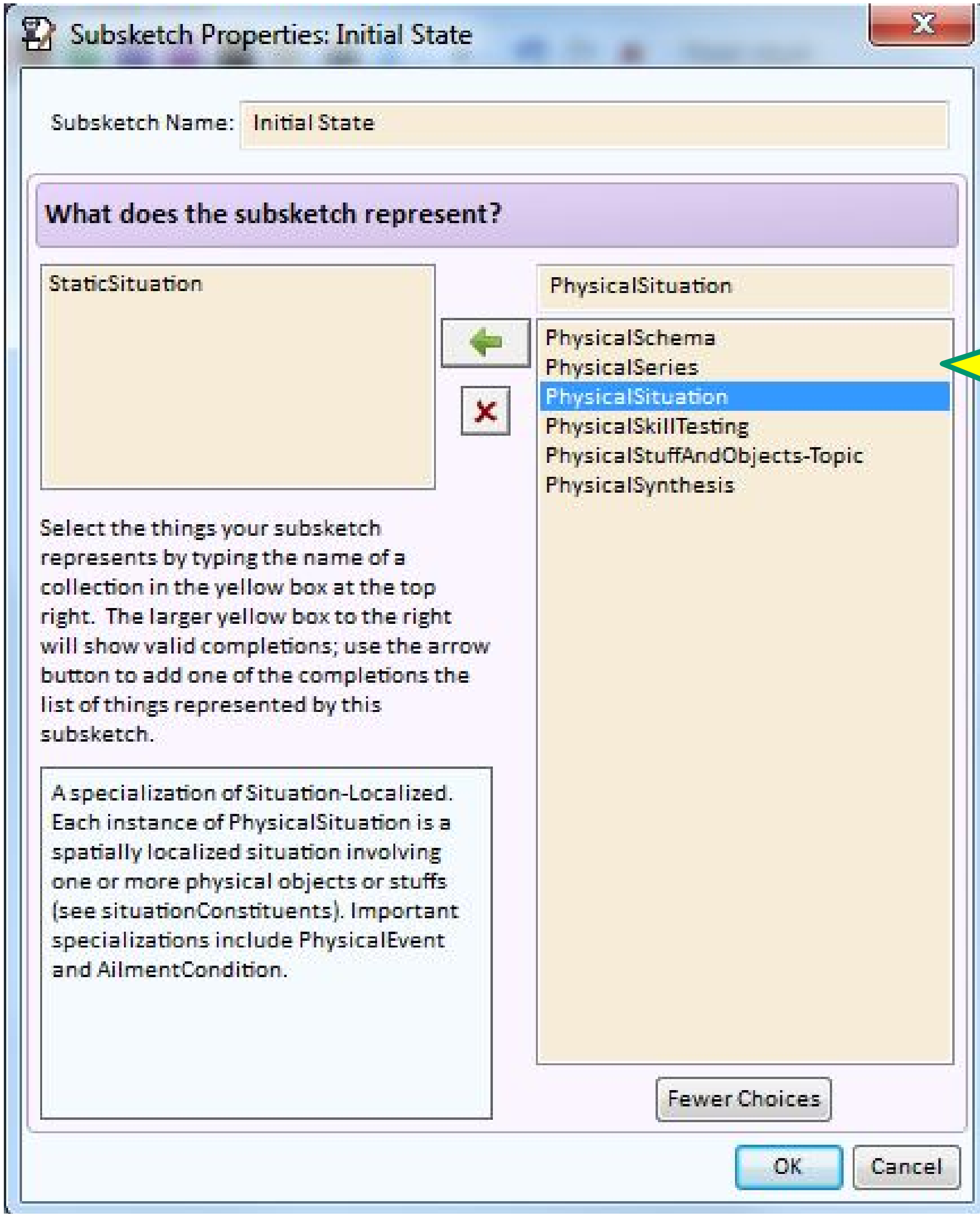


Conceptually Labeling a Subsketch



Default = a static configuration

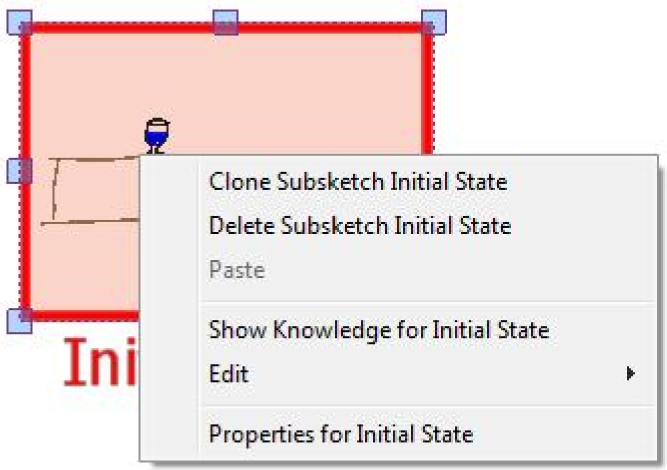
Conceptually Labeling a Subsketch

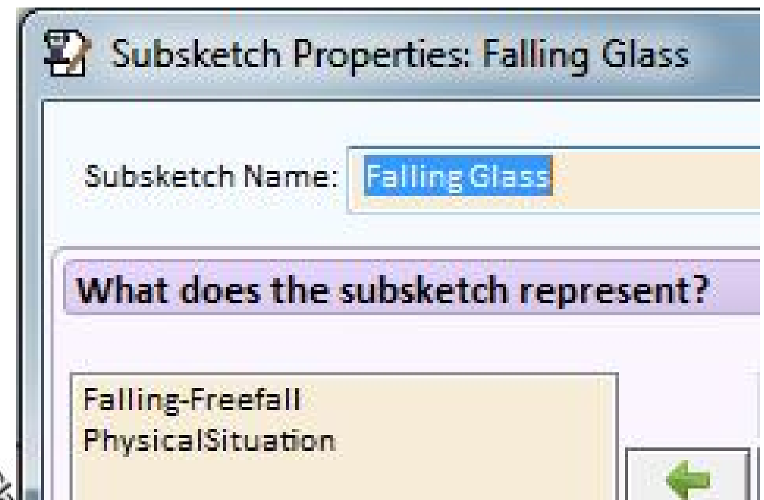


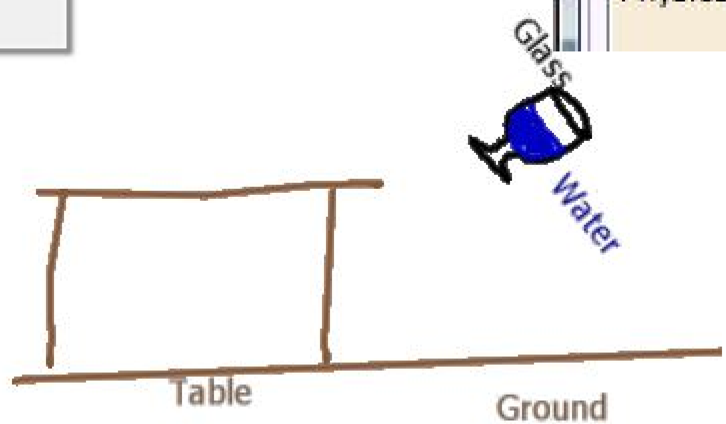
You can indicate that the subsketch is an instance of something else via selecting a different concept

Cloning

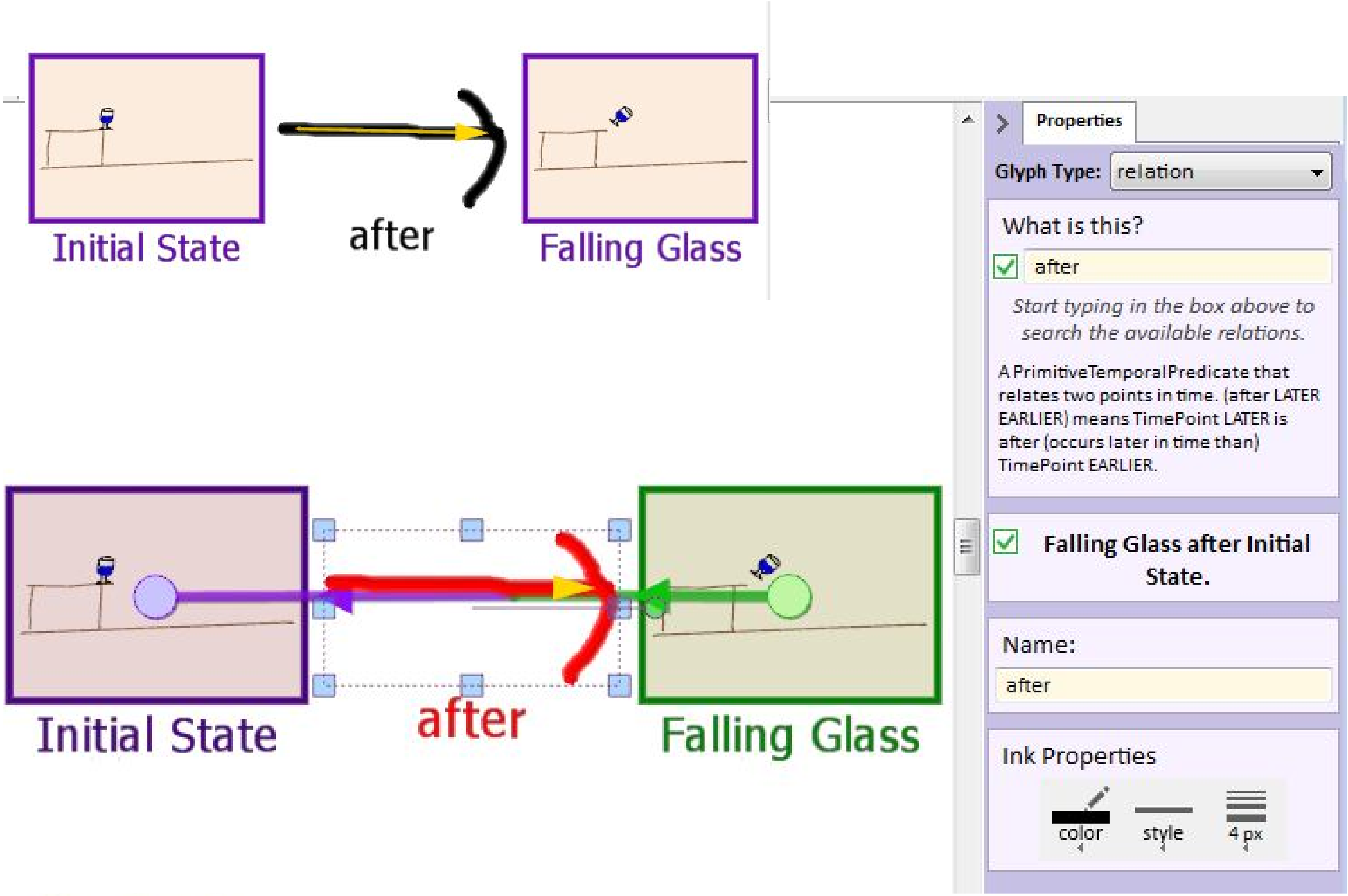
- Easiest way to rapidly describe complex behaviors
  - Clone subsketch, then modify the clone appropriately
  - Add arrows to indicate how they are related



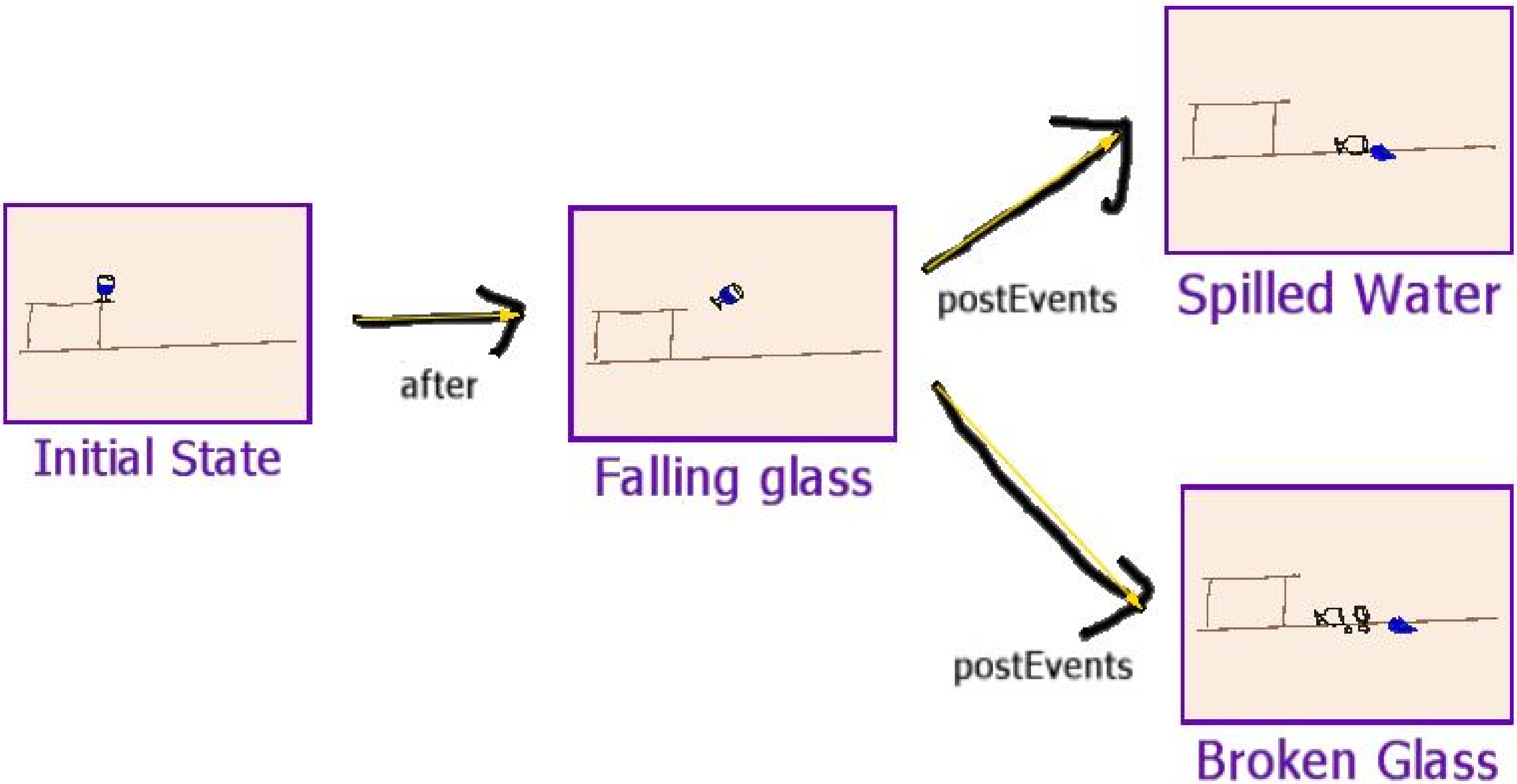




Linking the Behaviors



A Comic Graph



What You Have Seen

- Sketches are made of glyphs
  - How to draw glyphs
  - Types of glyphs: Entities, relations, annotations
- Structure of sketches
  - Layers, subsketches, and the metalayer

Visual Processing in CogSketch

Some Preliminaries

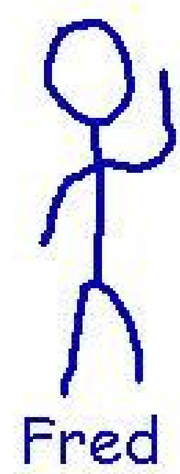
Visual versus Spatial relationships:

- Visual relationships: Computed over glyphs
- Spatial relationships: Hold between what is denoted by the glyphs
- Visual relationships + genre + pose → Spatial relationships

Our visual computations are inspired by psychological evidence when available

- Best guesses otherwise
- We expect it to continue to evolve

Glyphs



Glyphs have two parts: *Ink* and *Content*

- Content = the entity represented by the glyph
  - Instance of some collection in the KB
- Ink = visual representation of the content
  - Consists of all of the ink drawn between button presses

Visual properties are computed on the ink

- Only coarse visual properties computed automatically
  - Bounding box
  - Closed contour (ink needn't be connected)
  - Major/minor axes
- Small set of visual relationships between glyphs
- Decompositions, other visual relationships computed on demand
  - See CogSketch_Spatial_Reasoning.pdf for API

Qualitative Spatial Reasoning

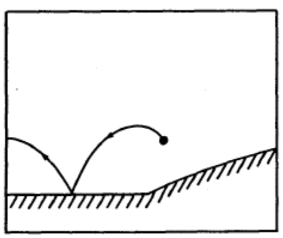
Claim: Symbolic vocabularies of shape and space are central to human visual thinking (cf. Forbus 1980; Forbus, Ferguson & Usher 2001; Kosslyn et al., 1989)

- They are computed by our visual system
- Their organization reflects task-specific conceptual distinctions and conventional symbol systems as well as visual distinctions
- They provide the bridge between conceptual and visual representations

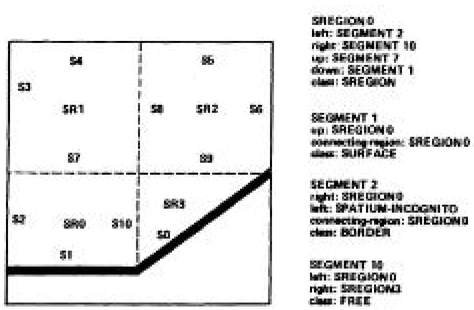
Metric Diagram/Place Vocabulary model

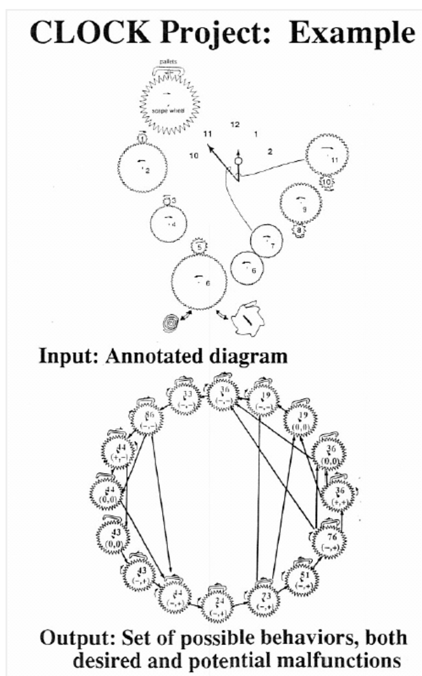
Metric Diagram: Quantitative, visual representations and processing

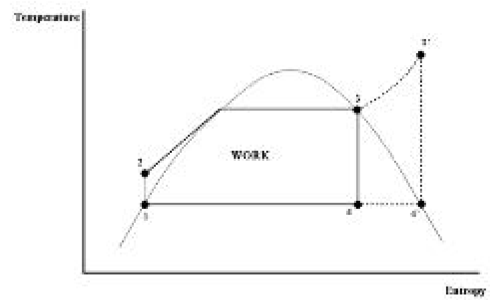
Place Vocabulary: Task-specific qualitative representations of shape and space, grounded in the metric diagram



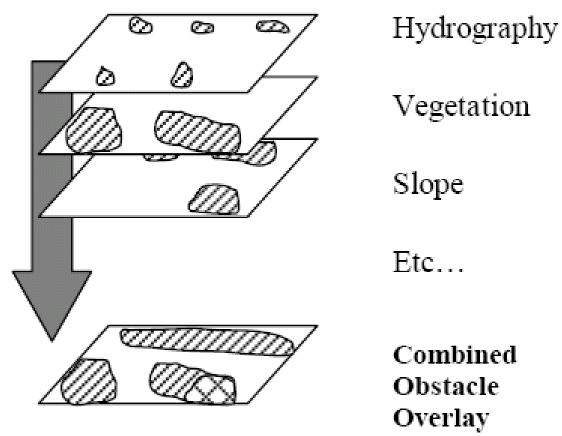
FROB (Forbus, 1980)







SKETCHY
(Pisan, 1994)



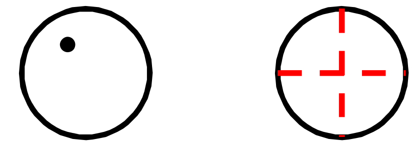
GIS-based Trafficability Reasoner (Donlon & Forbus, 1999)

Qualitative/Quantitative Representations in Psychology

Qualitative vs. Quantitative

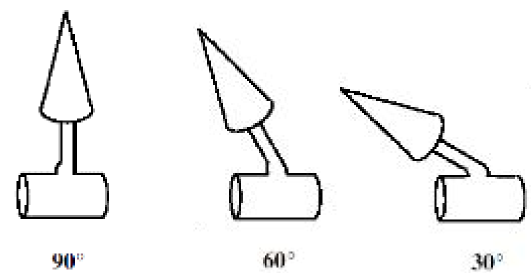
Remembering locations

(Huttenlocher, Hedges, & Duncan, 1991; Holden et al. 2010)



Categorical perception of angle

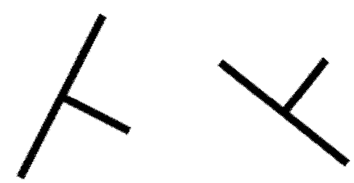
(Rosielle & Cooper, 2001)



Qualitative advantages for complex reasoning

Smaller memory footprint

More robust across transformations



Qualitative Spatial Relations

Topological

- Describes intersections and containment
- Computed automatically

Positional

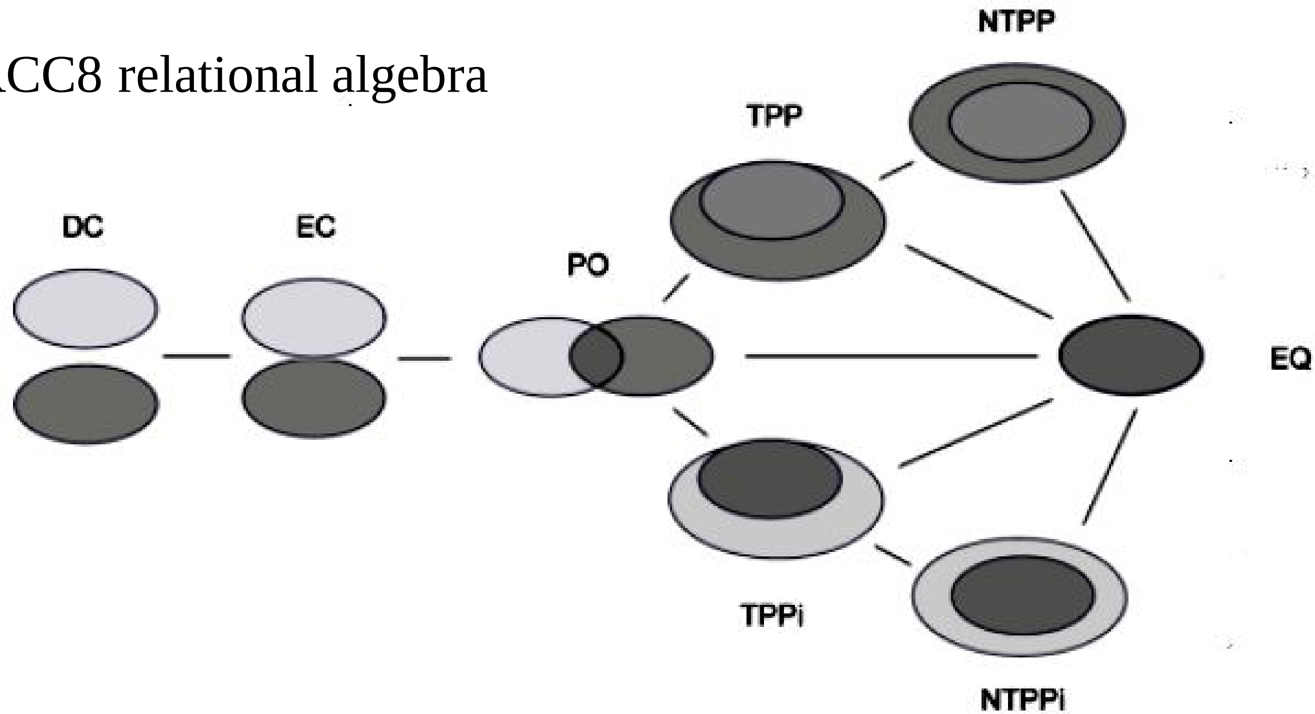
- Describes relative position
- Computed on demand

Decompositional

- Describes cycles and edges within each glyph
- Computed on demand

Topological Relations

Cohn et al's RCC8 relational algebra



Provides natural vocabulary for some visual concepts

- Containment: NTPP, TPP
- Touching: PO, EC

Using RCC8

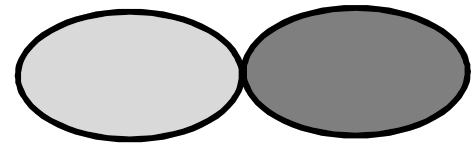
- Compute relationships directly from ink
  - Transitivity algebra unnecessary.
  - Need to be clever about noise.
- Computed between every pair of glyphs on a layer
  - Incrementally updated when a glyph is moved or resized.
  - Only computed across layers on demand.
- Internal uses
  - Controlling computation of other relations.
    - Positional relations aren’t computed when there’s containment.
  - Direct inference of other topological relations.
- Convex hull topologicals can be queried for

```
(hasRCC8Relation (ConvexHullFn Object-1)
                 (ConvexHullFn Object-2)
                 ?rel)
```

Higher-Level Topological Relations

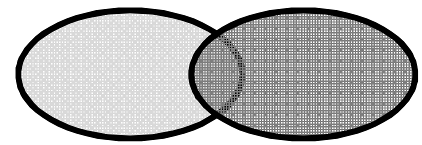
objectsIntersect

The ink of the two glyphs intersects



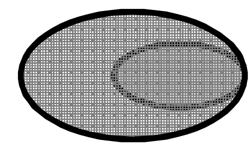
objectsOverlap

The interiors of the two glyphs overlap



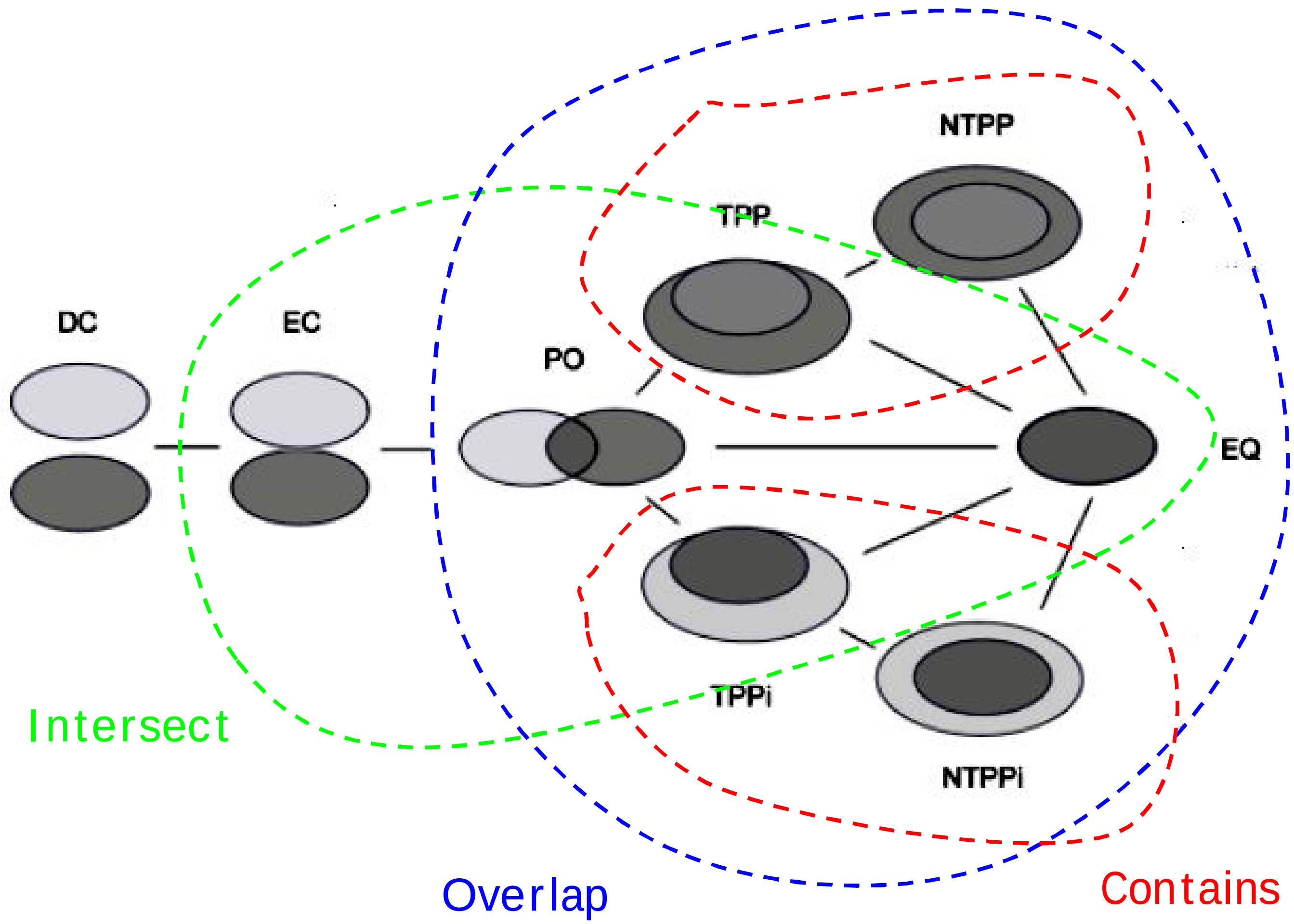
objectContains

One glyph lies within another glyph's area



- Not mutually exclusive
- Used in comparison

RCC8 Conceptual Neighborhood



Contained Glyph Groups

- When more than one glyph is NTTPi, TPPi of some other glyph

```
(ContainedGlyphGroupFn
  (GlyphFn Object-9 User-Drawn-Sketch-Layer-1)
  (TheList (GlyphFn Object-15 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-16 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-19 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-20 User-Drawn-Sketch-Layer-1)))
```

Connected Glyph Groups

- Set of glyphs connected via EC or PO

```
(ConnectedGlyphGroupFn
  (TheList (GlyphFn Object-10 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-11 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-12 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-21 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-22 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-9 User-Drawn-Sketch-Layer-1)))
```

Positional Relations

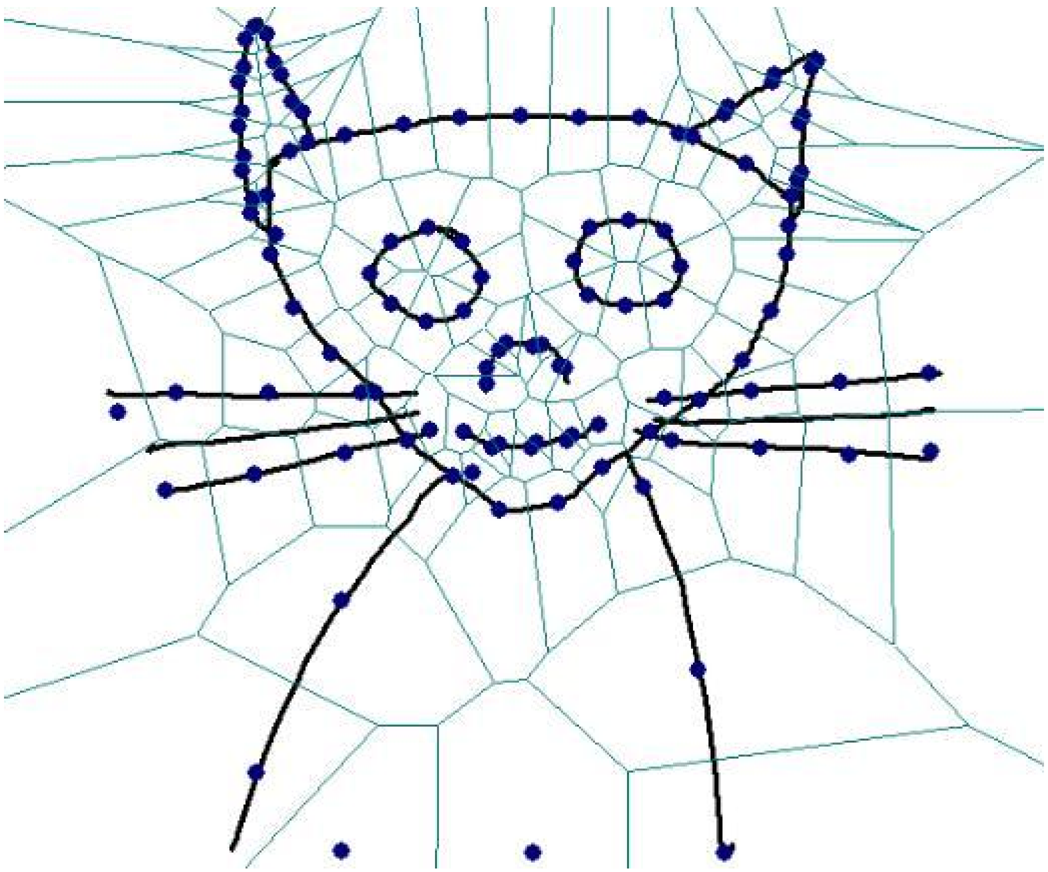
Provide qualitative position, orientation information with respect to global frame of reference

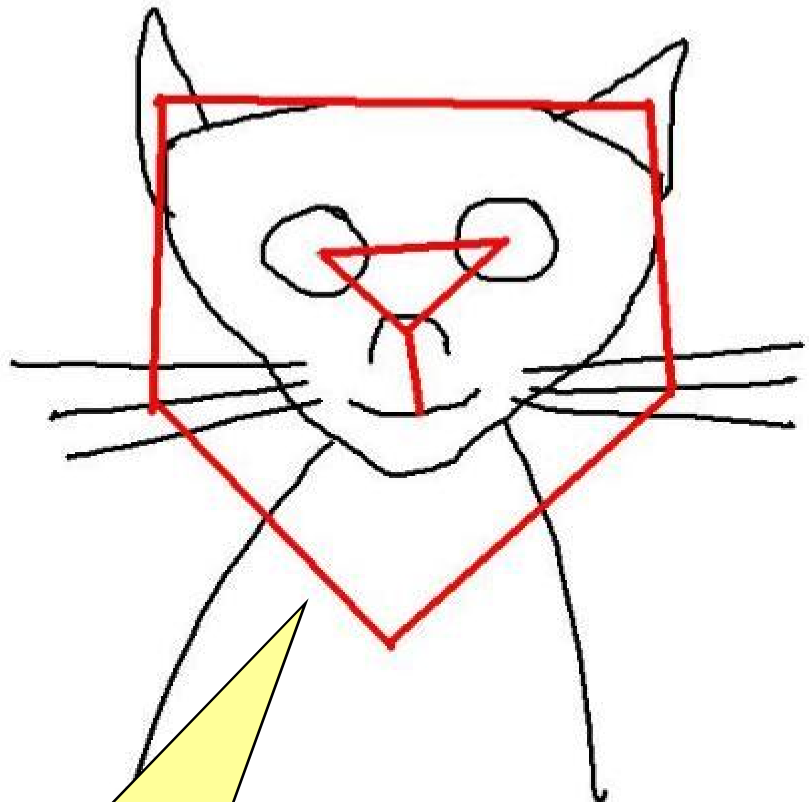
- For glyphs, `rightOf`, `above`, `leftOf`, `below`
- For contents, depends on genre and viewpoint
  - Physical/side: Same as glyphs
  - Geospatial/TopDown: `northOf`, `southOf`, `eastOf`, `westOf`
  - Abstract or Discrete: No implications for contents

Local Relational Neighborhood Hypothesis

- When to compute positional relations? Between every pair of glyphs on a layer, like RCC8?
  - Bad idea! Loses locality
- Idea: Network of positional relations should provide "framing effect" in visual structure.
- Necessary condition: Glyphs must be *adjacent* in the sketch.
- Hypothesis: This local neighborhood structure corresponds to default encoding method in human sketch perception.

Voronoi adjacency guides positional relation finding



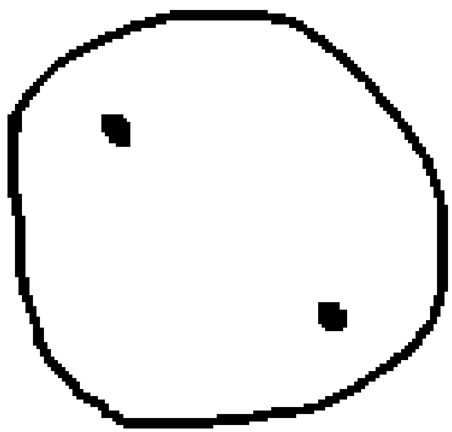


Positional relations only created between site-adjacent glyphs

Frame of Reference (FoR) Relations

Glyphs create a *frame of reference* by which other glyphs' positions can be judged.

`centeredOn`, `onRightHalfOf`, `onBottomHalfOf`, etc.



Decompositions

Hypothesis: *Shape* can be described in the same way as *space.*

Space: Qualitative spatial relations between glyphs

Shape: Qualitative spatial relations between parts of a glyph

Two levels of decomposition:

Edges

Ink segmented based on sharp changes in curvature, junctions where multiple edges meet

Edge Cycles

Adjacent edges grouped to form cycles

Examples from TU Berlin corpus (Eitz et al. 2012; 20,000 sketches spanning 250 concepts)

Decompositions

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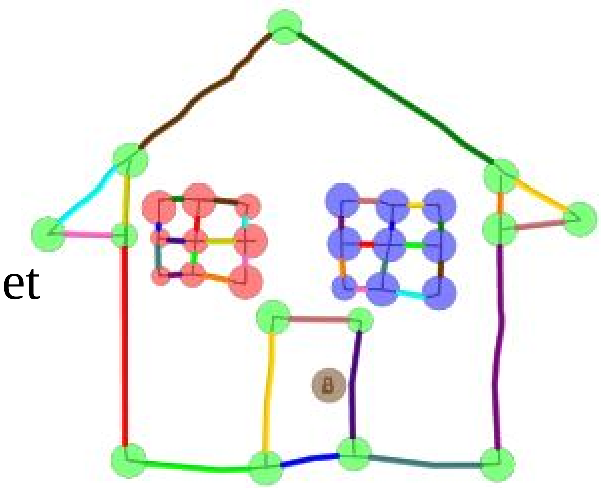

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Hypothesis: *Shape* can be described in the same way as *space.*

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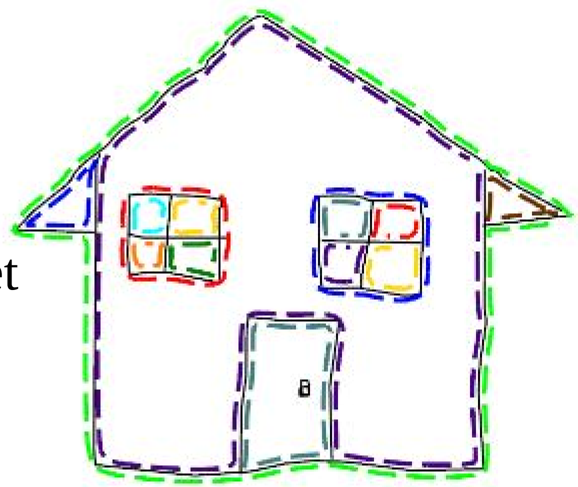
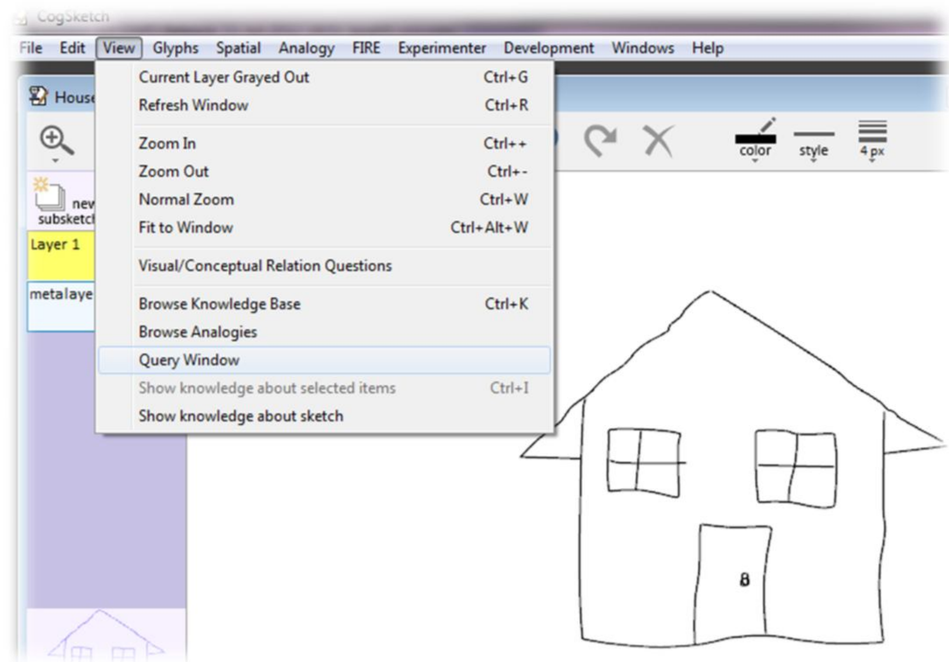


Querying for Representations

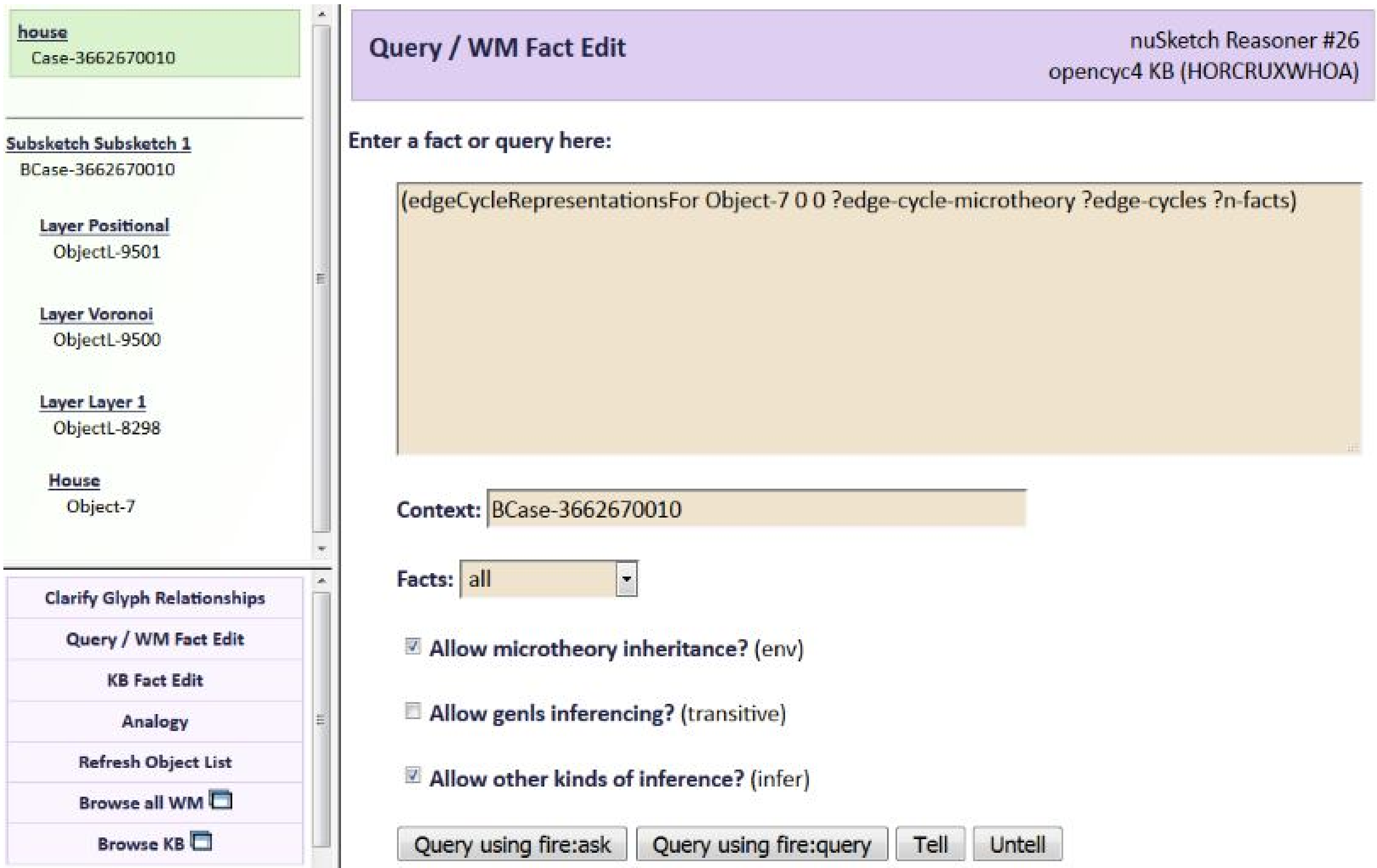
…via Query Window



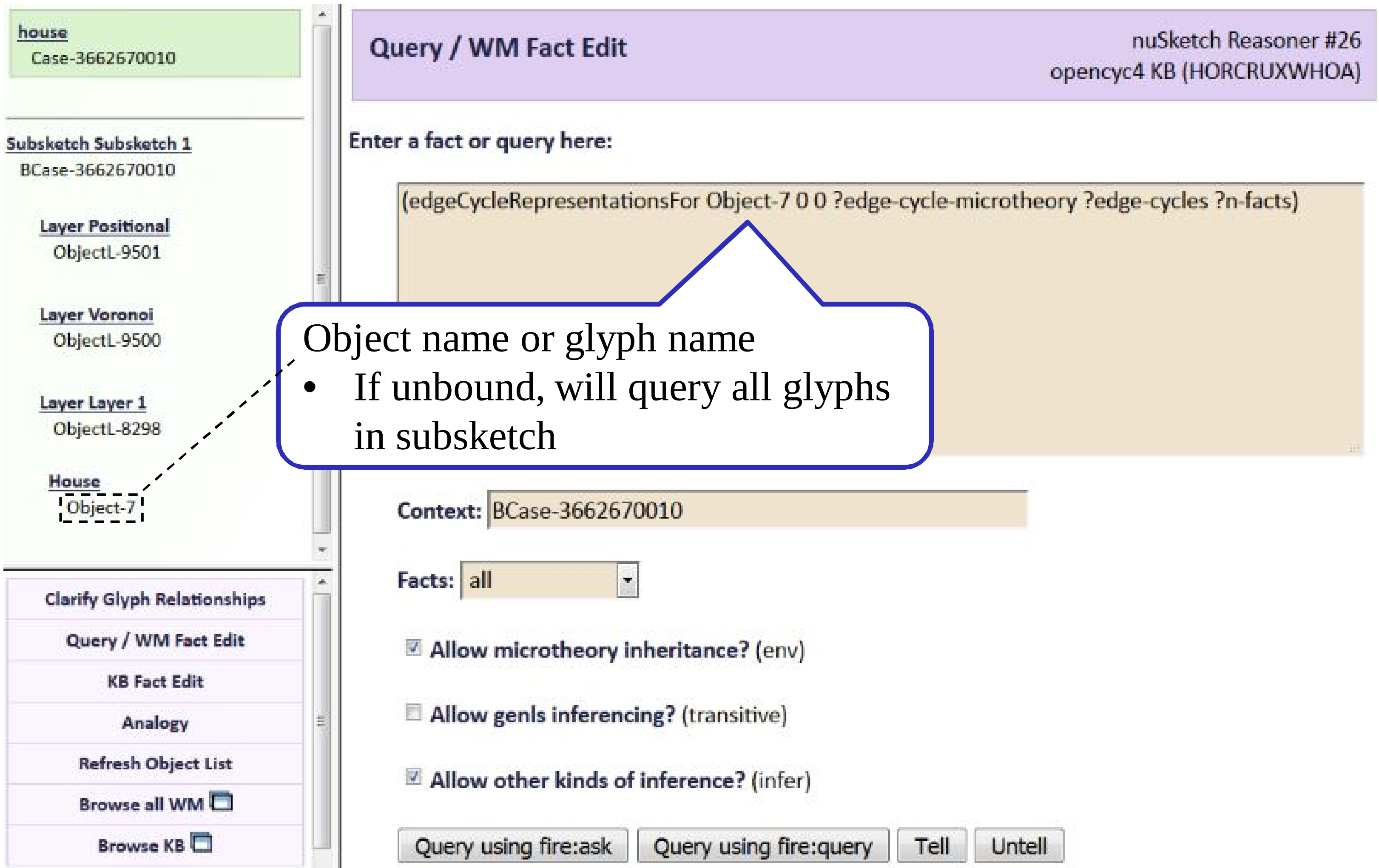
…via KQML interface

```
(query :sketch-id <sketch-id>
       :query <query>
       :num-responses :all)
```

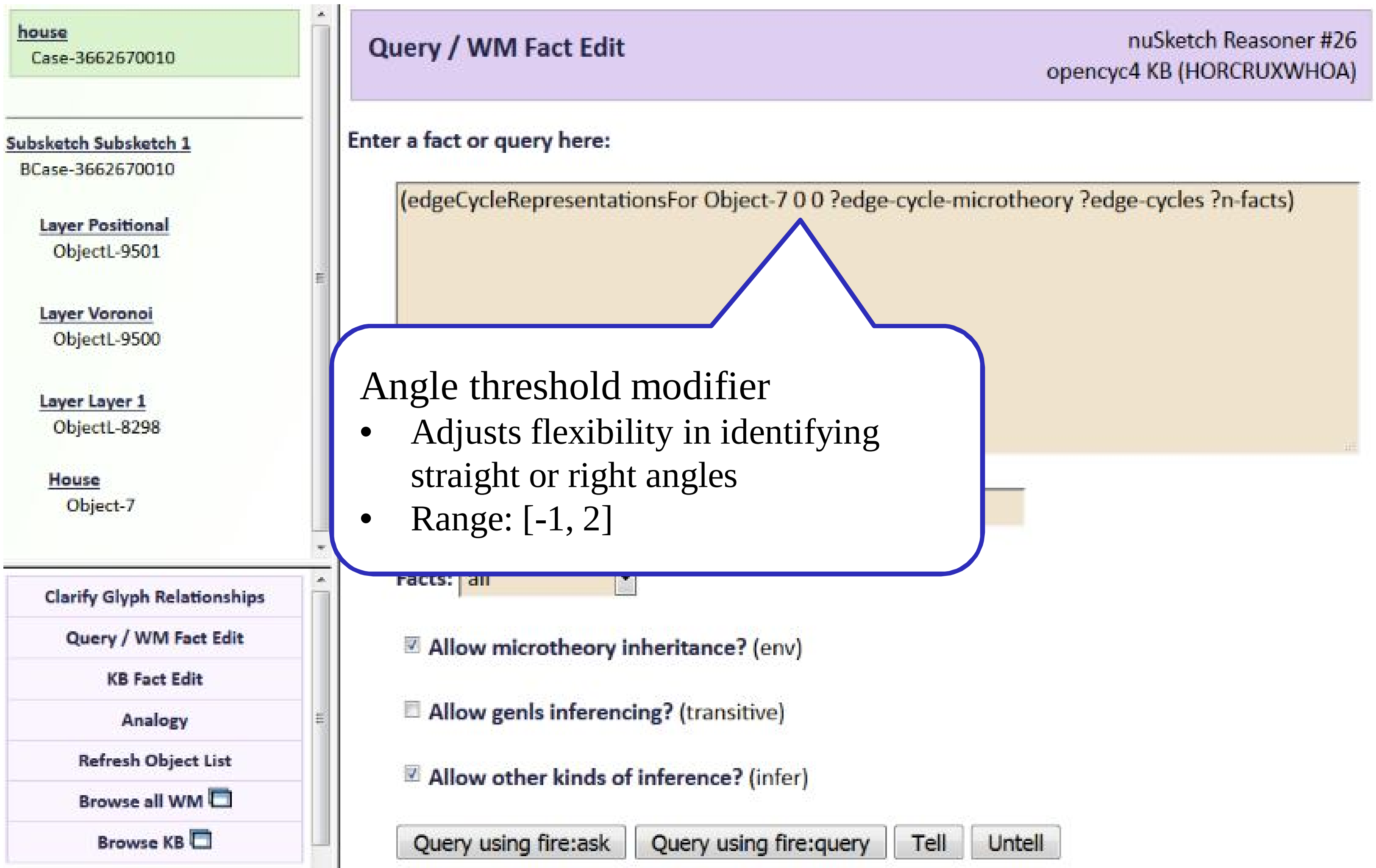
Query Window



Query Window



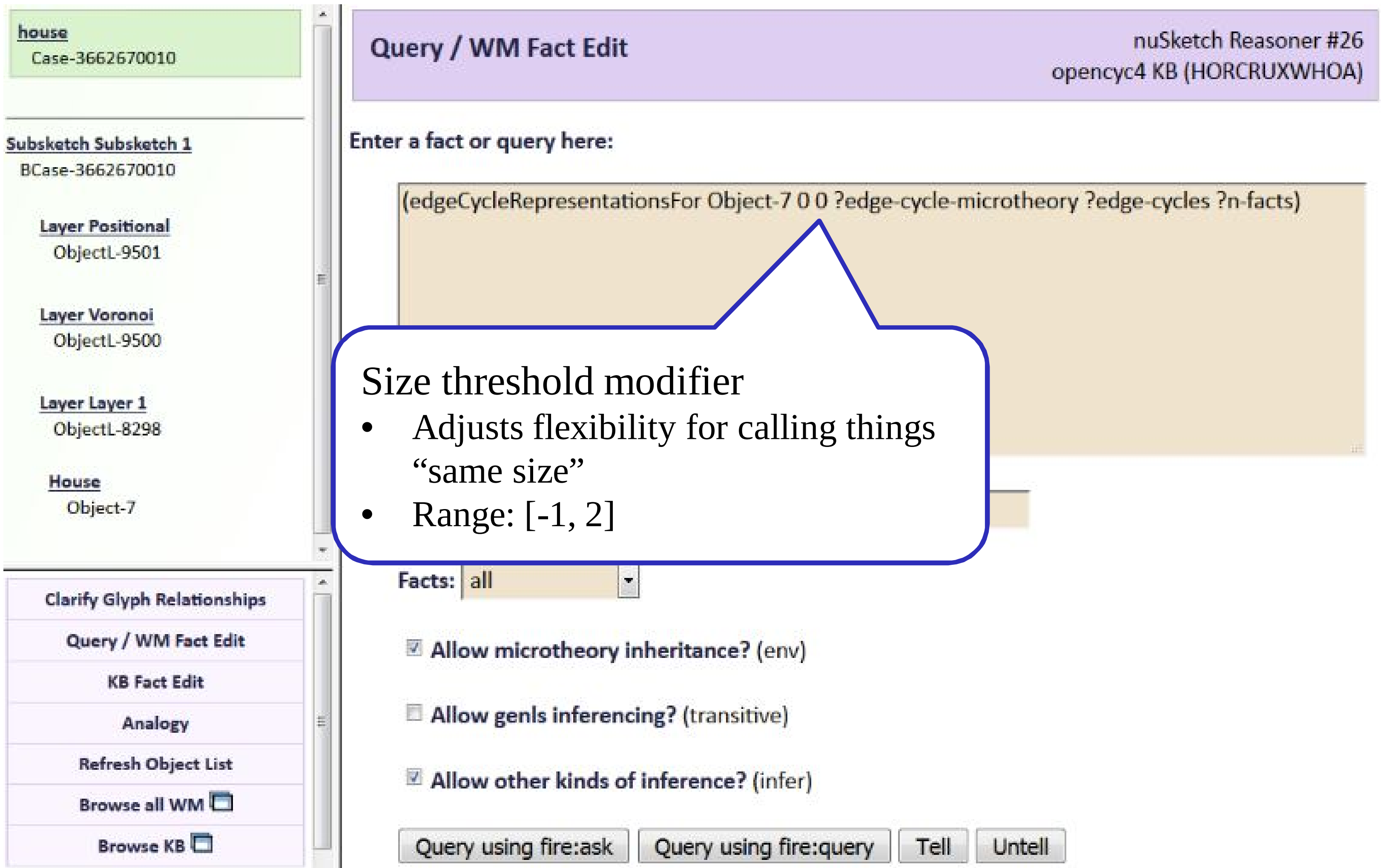
Query Window



Angle threshold modifier

- Adjusts flexibility in identifying straight or right angles
- Range: [-1, 2]

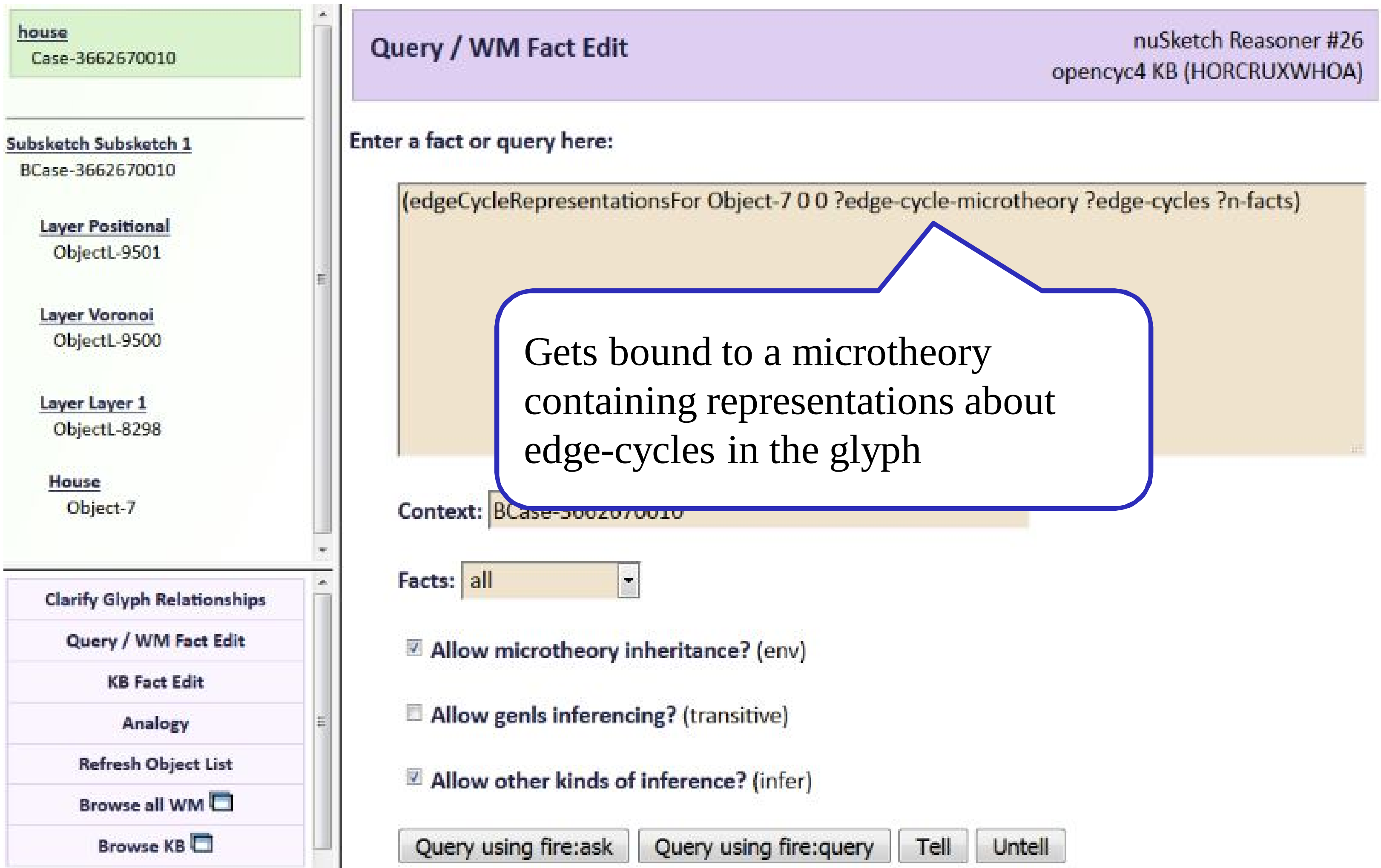
Query Window



Size threshold modifier

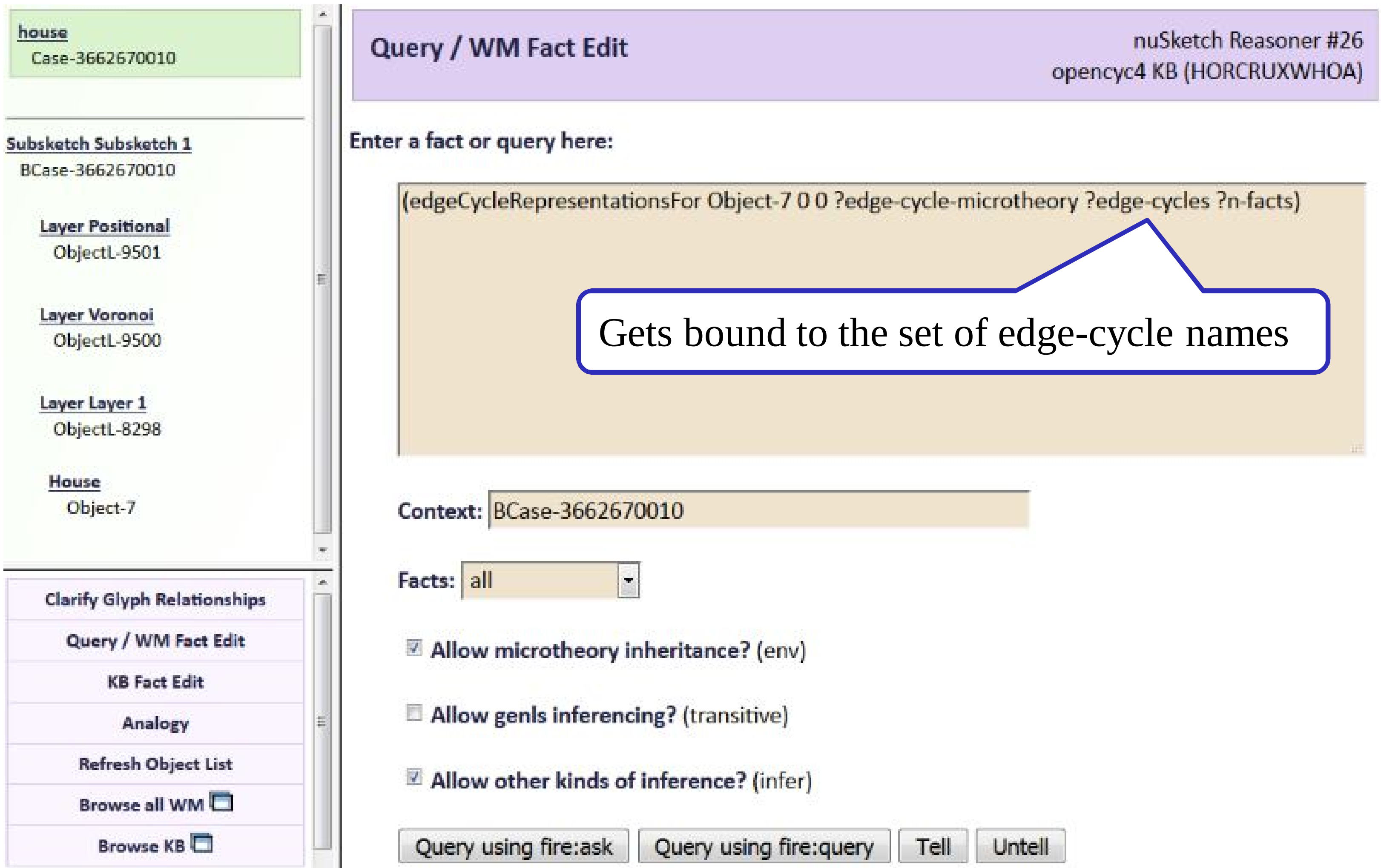
- Adjusts flexibility for calling things "same size"
- Range: [-1, 2]

Query Window

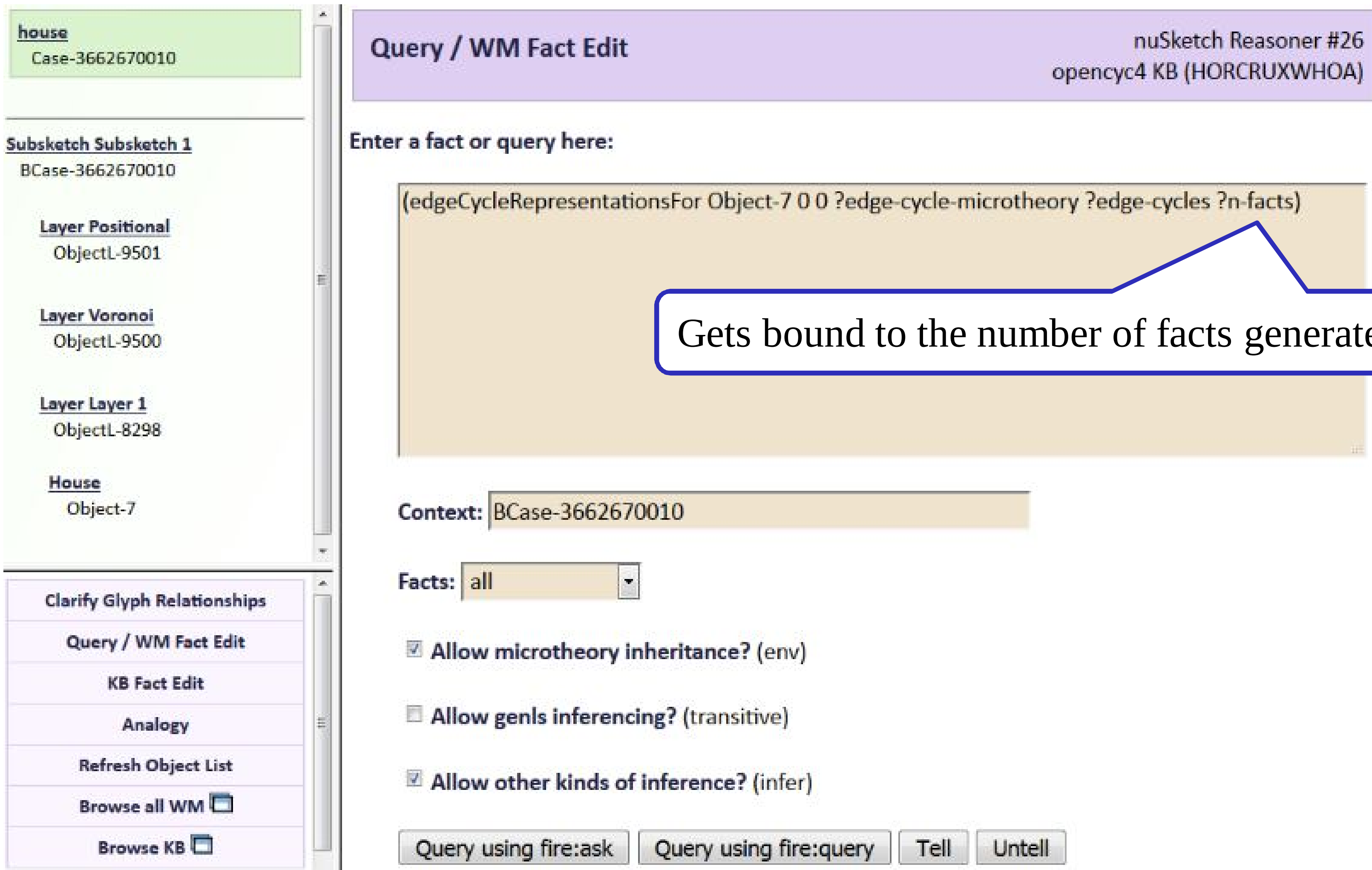


Gets bound to a microtheory containing representations about edge-cycles in the glyph

Query Window

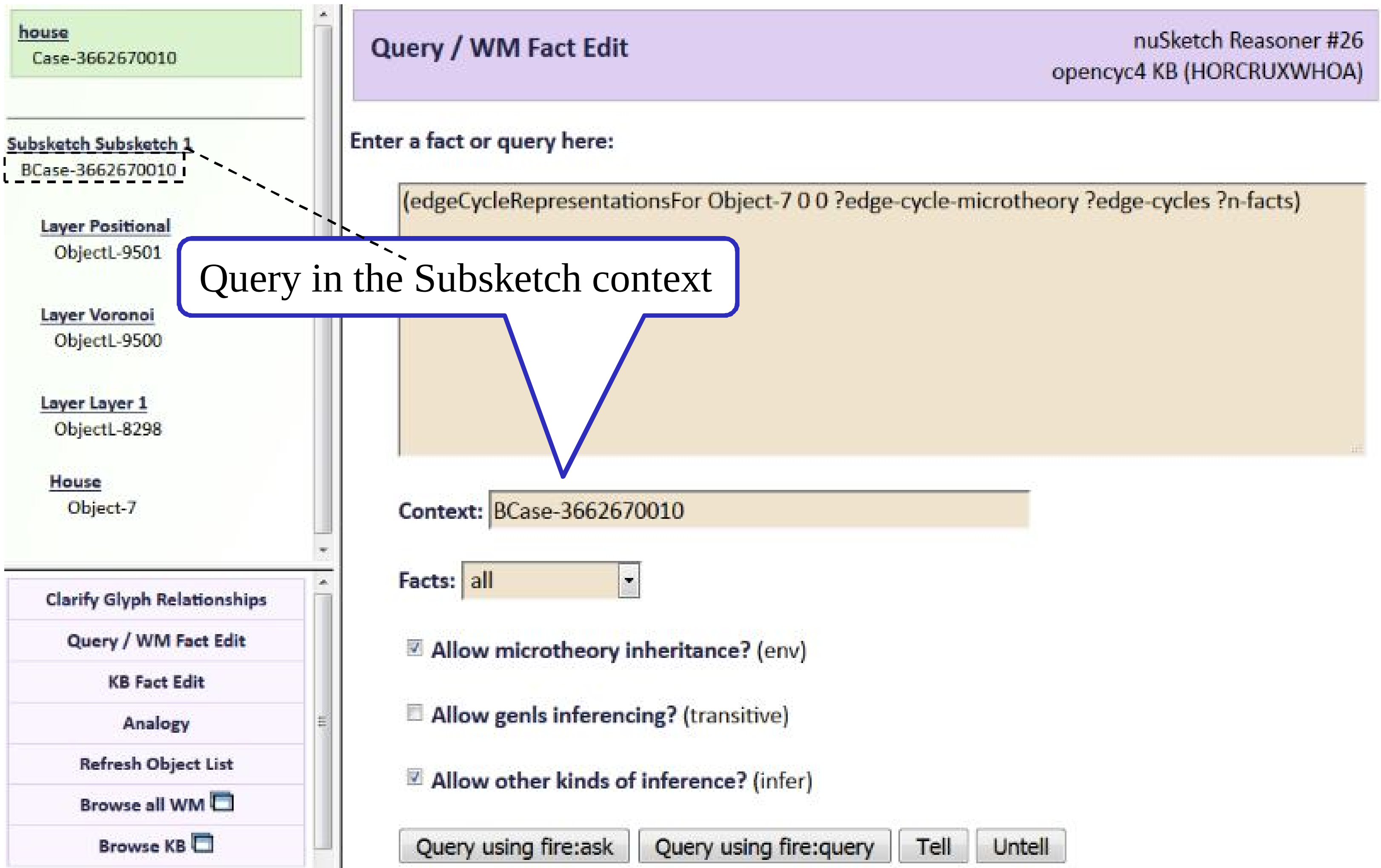


Query Window

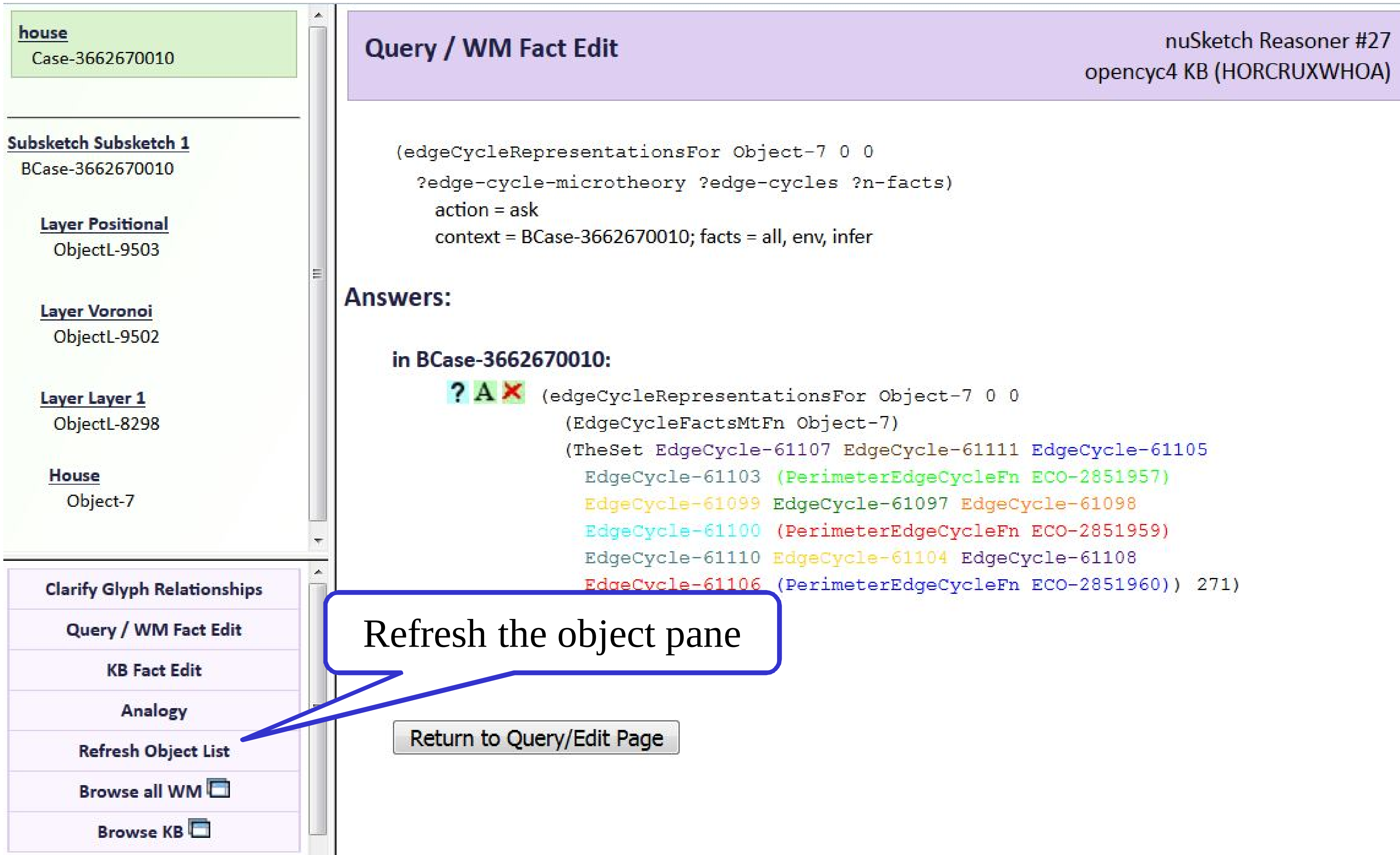


Gets bound to the number of facts generated

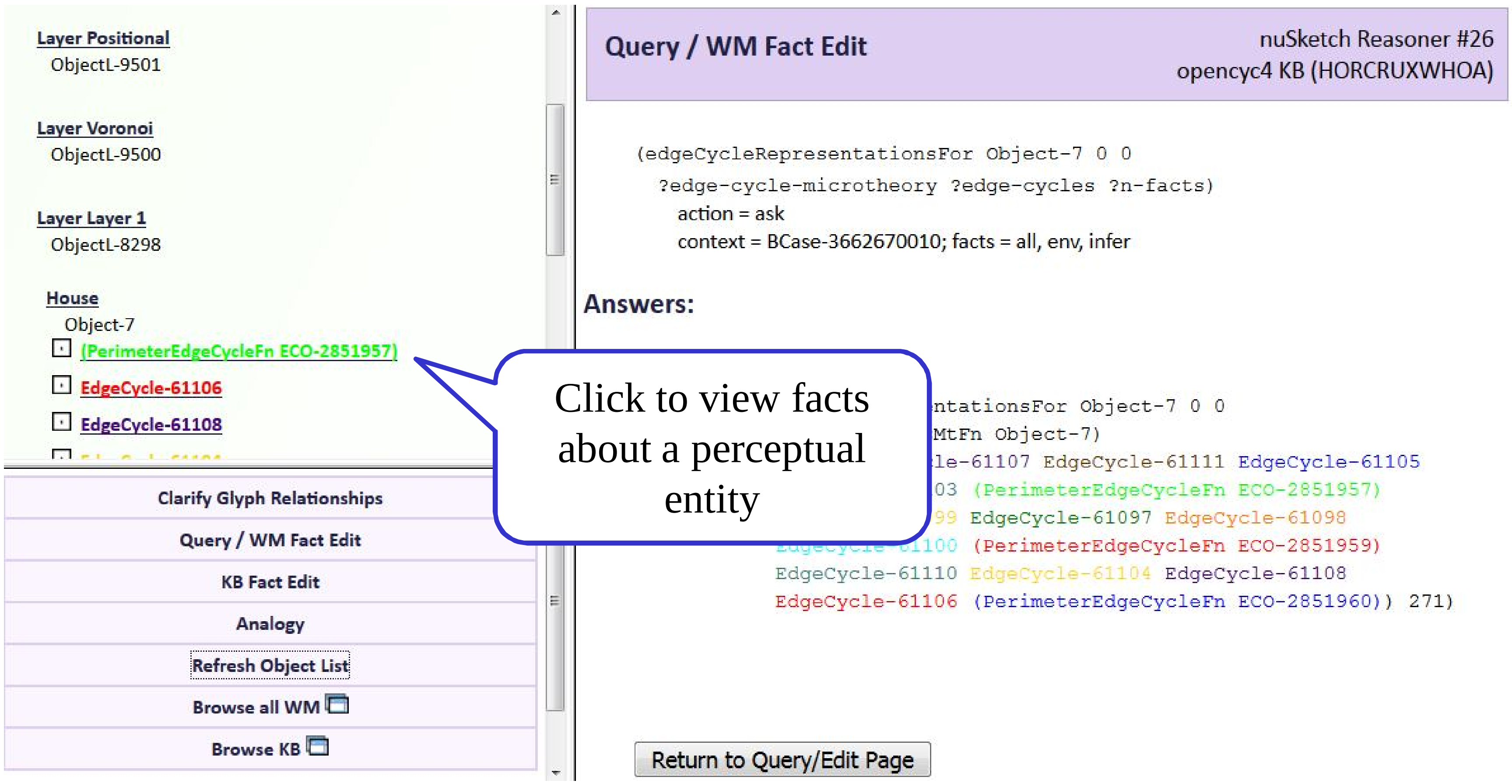
Query Window



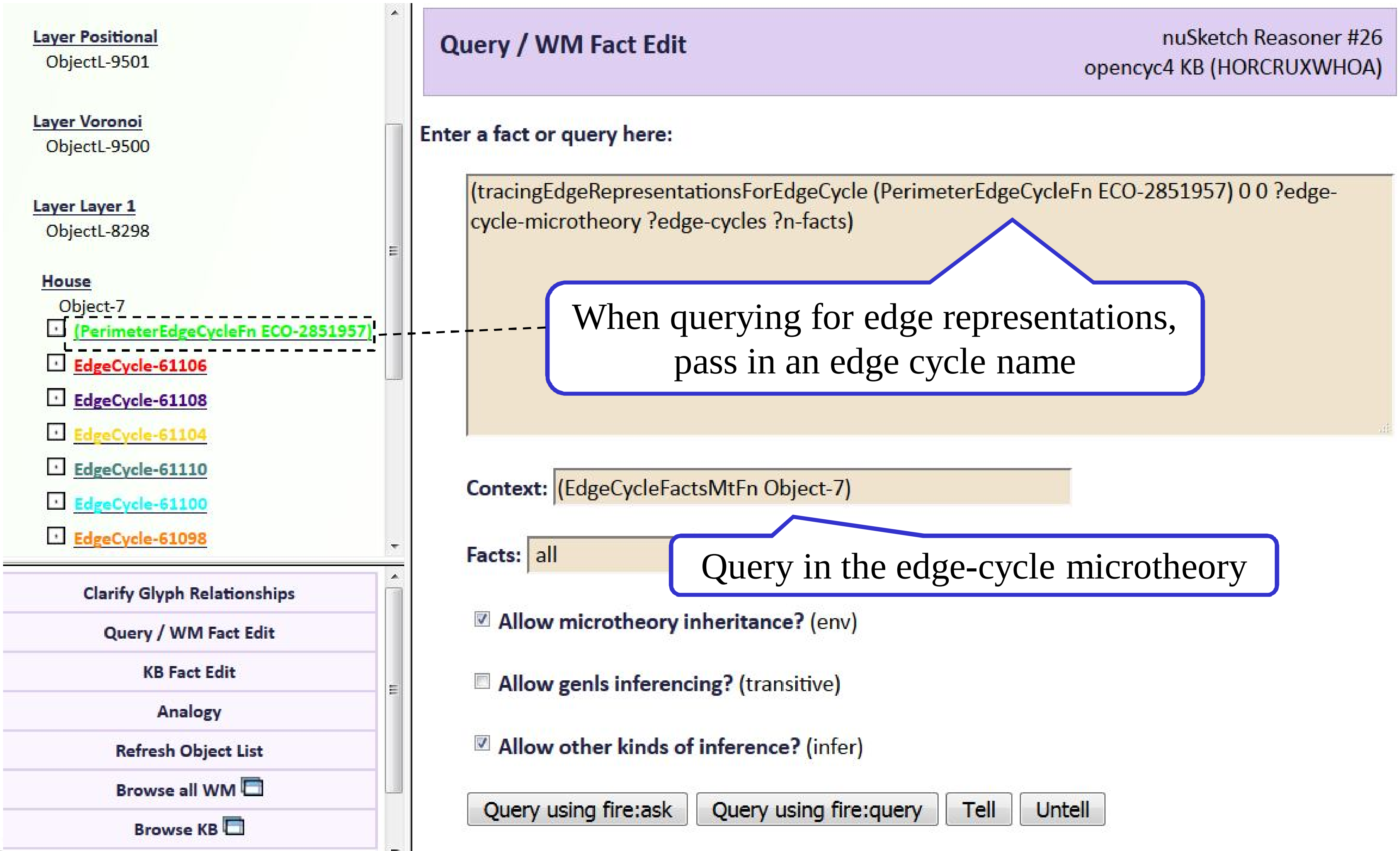
Query Window



Query Window



Query Window



Edge-Level Representations

Edge Attributes

- Straight, Curved, Ellipse
- Curve details: Concave/Convex,
  - Major/Minor/Semicircle arcs
- Orientation
- Relative length

```
(isa Edge-104451 StraightEdge)
(isa Edge-104451 VerticalEdge)
(lengthMedium Edge-104451)
```

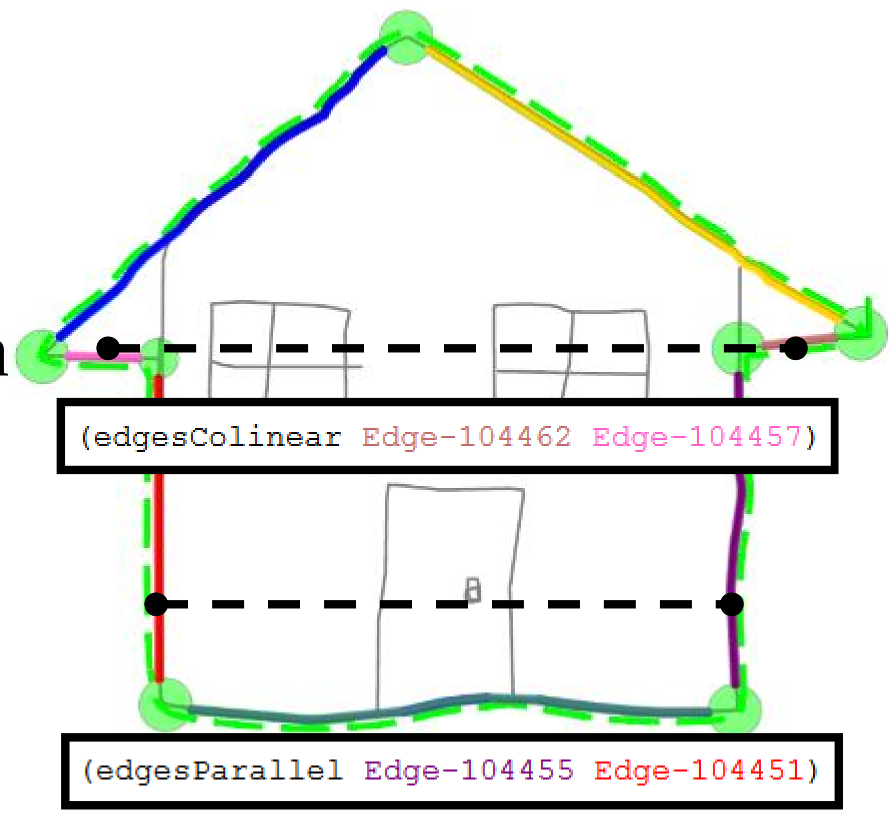
Edge-Level Representations

Edge Attributes

- Straight, Curved, Ellipse
- Curve details: Concave/Convex,
  - Major/Minor/Semicircle arcs
- Orientation
- Relative length

Relative Orientation/Position

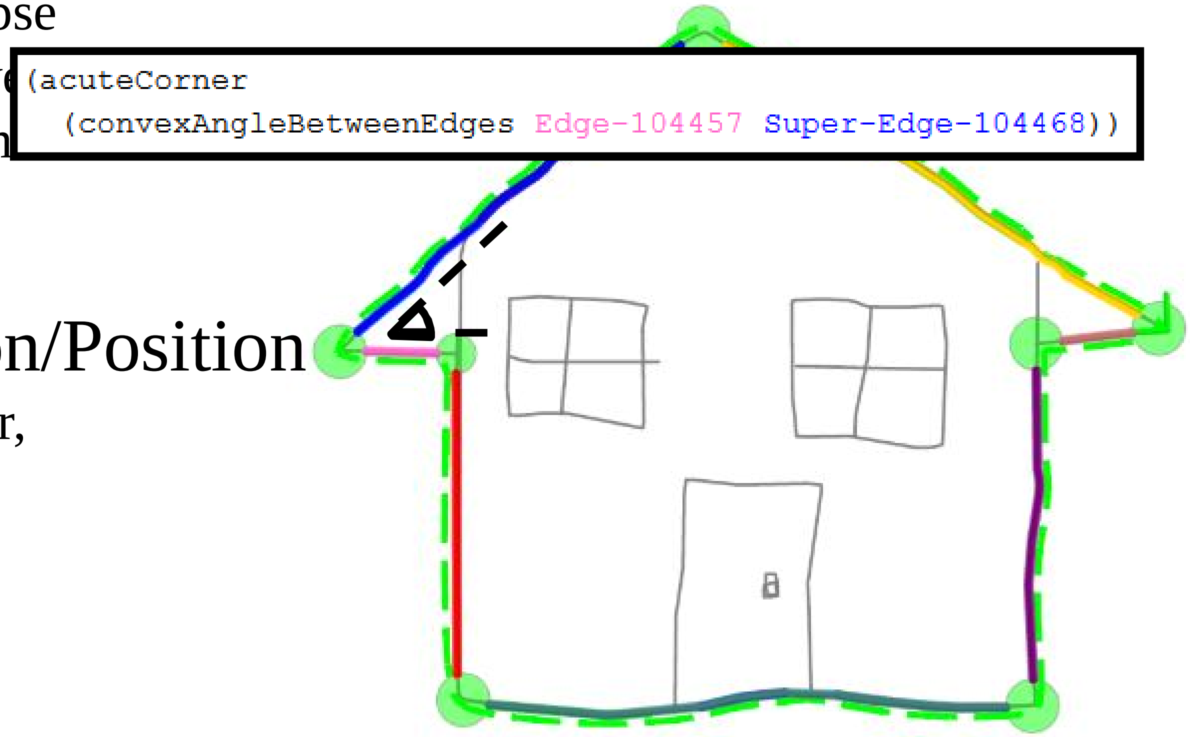
- Parallel, Perpendicular,
- Collinear



Edge-Level Representations

Edge Attributes

- Straight, Curved, Ellipse
- Curve details: Concave
  - Major/Minor/Sem
- Orientation
- Relative length



Relative Orientation/Position

- Parallel, Perpendicular,
- Collinear

Corner Attributes

- Convex, Concave
- Right, Acute, Obtuse

Edge-Level Representations

Edge Attributes

- Straight, Curved,
- Curve details: Co
  - Major/Minor/Semicircle arcs
- Orientation
- Relative length

Relative Orientation/Position

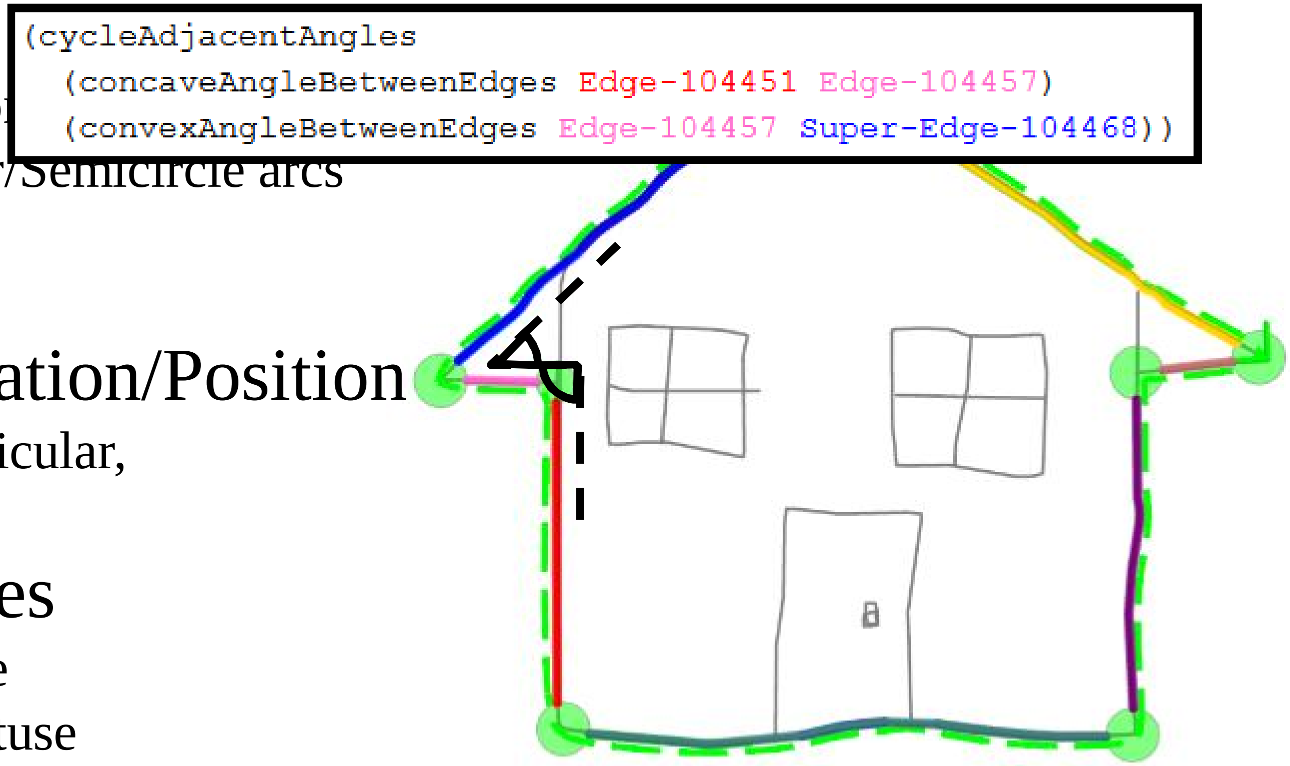
- Parallel, Perpendicular,
- Collinear

Corner Attributes

- Convex, Concave
- Right, Acute, Obtuse

Corner Relations

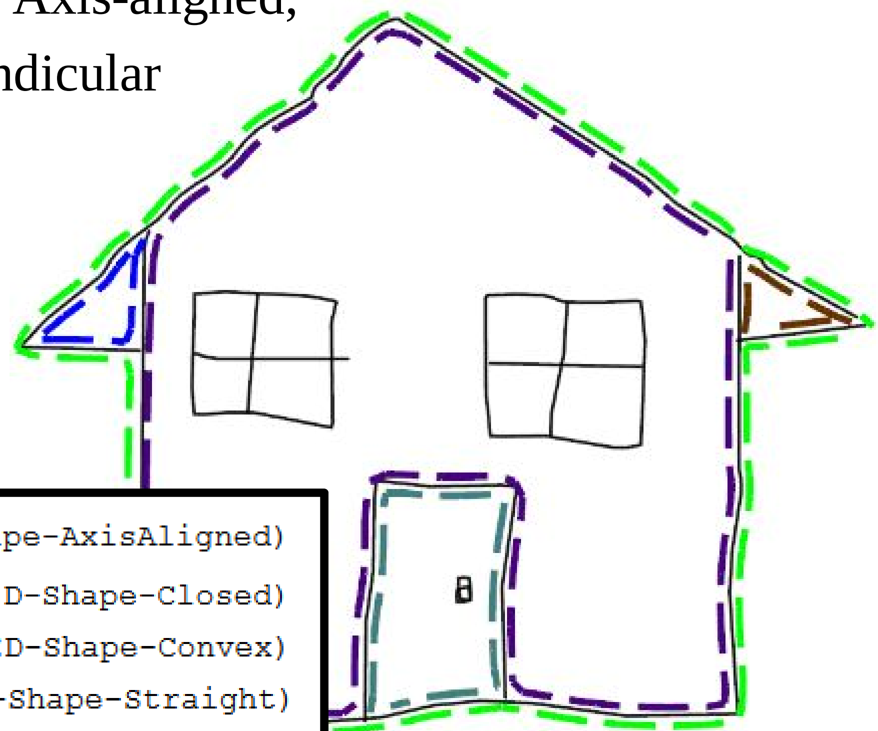
- Corner adjacency



Edge Cycle-Level Representations

Shape Attributes

- Edge-aggregated: Straight, Curved, Axis-aligned,
- Corner-aggregated: Convex, Perpendicular
- Closed, Partially-Closed, Open
- Major axis
- Axis of symmetry
- Relative area, edge-complexity



```
(isa EdgeCycle-61103 2D-Shape-AxisAligned)
(isa EdgeCycle-61103 2D-Shape-Closed)
(isa EdgeCycle-61103 2D-Shape-Convex)
(isa EdgeCycle-61103 2D-Shape-Straight)
(isa EdgeCycle-61103 2D-Shape-VerticalMajorAxis)
(areaTiny EdgeCycle-61103)
(edgeComplexityLow EdgeCycle-61103)
```

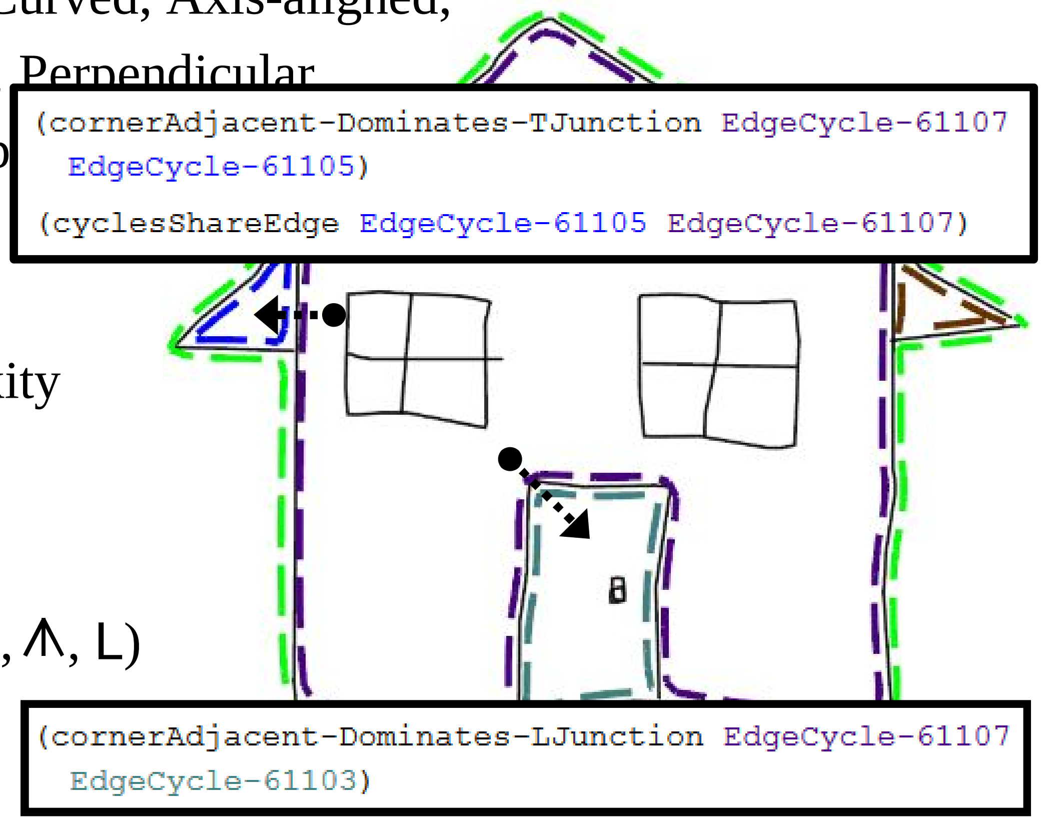
Edge Cycle-Level Representations

Shape Attributes

- Edge-aggregated: Straight, Curved, Axis-aligned,
- Corner-aggregated: Convex, Perpendicular
- Closed, Partially-Closed, Op
- Major axis
- Axis of symmetry
- Relative area, edge-complexity

Connection Relations

- Shared edge/junction
- Adjacent corner shape (T, Y, ⋀, L)



Edge Cycle-Level Representations

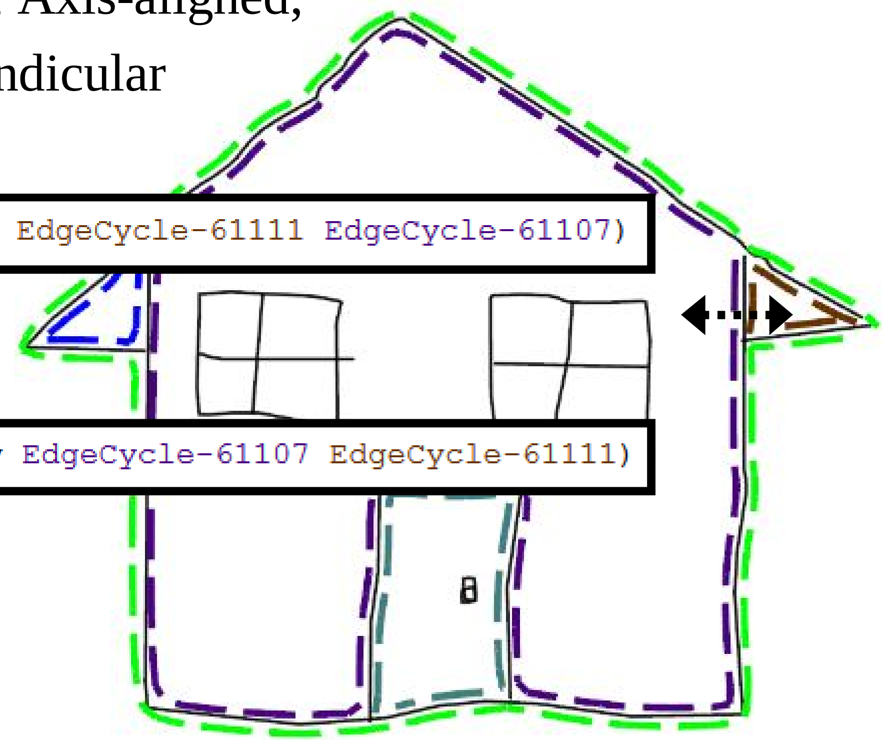
Shape Attributes

- Edge-aggregated: Straight, Curved, Axis-aligned,
- Corner-aggregated: Convex, Perpendicular
- Closed, Partially-Closed, Open
- Major axis
- Axis of symmetry
- Relative area, edge-complexity

Connection Relations

- Shared edge/junction
- Adjacent corner shape (T, Y, ⩚, L)

Positional Relations



Edge Cycle-Level Representations

Shape Attributes

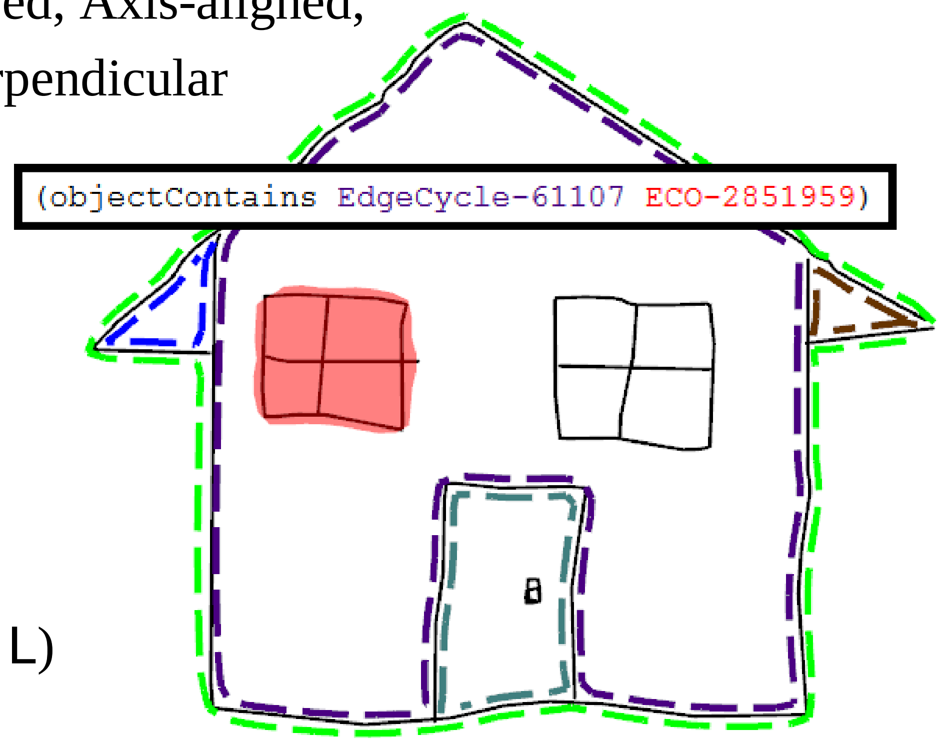
- Edge-aggregated: Straight, Curved, Axis-aligned,
- Corner-aggregated: Convex, Perpendicular
- Closed, Partially-Closed, Open
- Major axis
- Axis of symmetry
- Relative area, edge-complexity

Connection Relations

- Shared edge/junction
- Adjacent corner shape (T, Y, ⋀, L)

Positional Relations

Containment

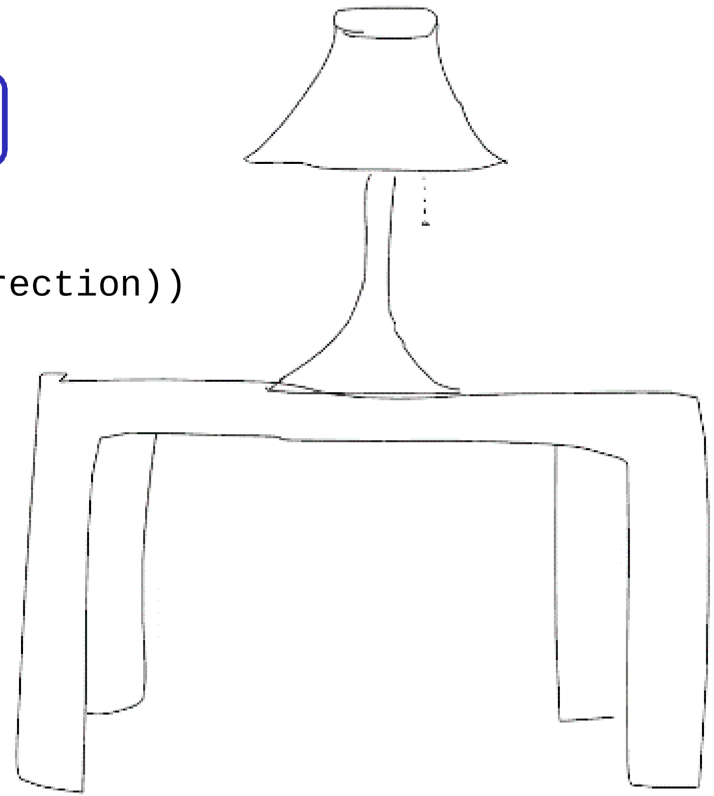


Surface Contact Detection

Edges in decompositions are used to compute a more stable contact edge or point between two glyphs

Query in the Subsketch context

```
(ist-Information BCase-3662865065
   (surfaceContactDirection Table TableLamp ?direction))
```

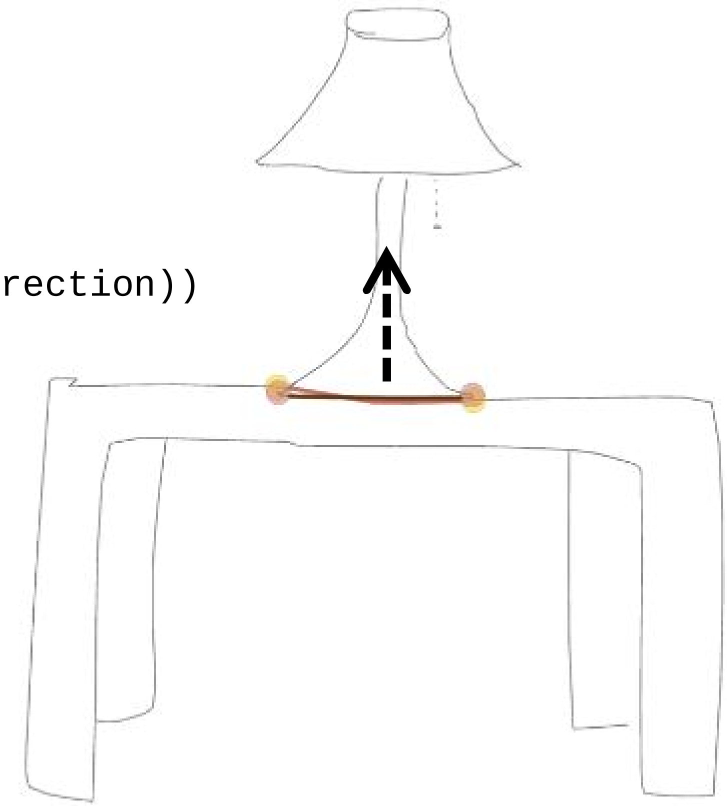


Surface Contact Detection

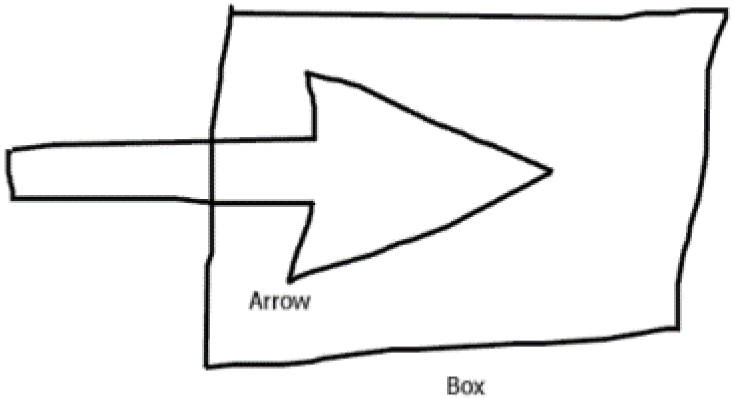
Edges in decompositions are used to compute a more stable contact edge or point between two glyphs

```
(ist-Information BCase-3662865065
   (surfaceContactDirection Table TableLamp ?direction))

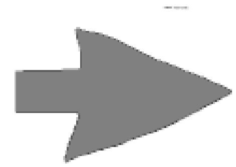
(surfaceContactDirection Table TableLamp Up)
```



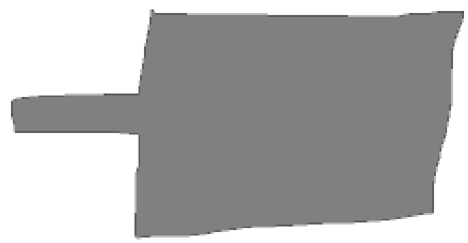
Generating New Glyphs from Visual Relationships



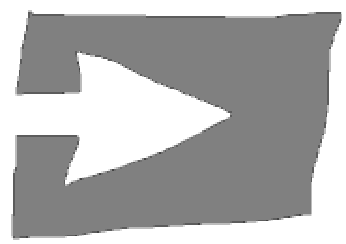
`glyphFromGlyphIntersection`



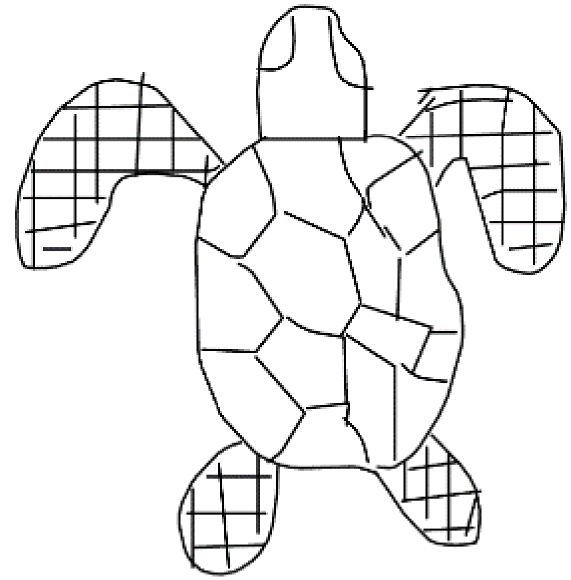
`glyphFromGlyphUnion`

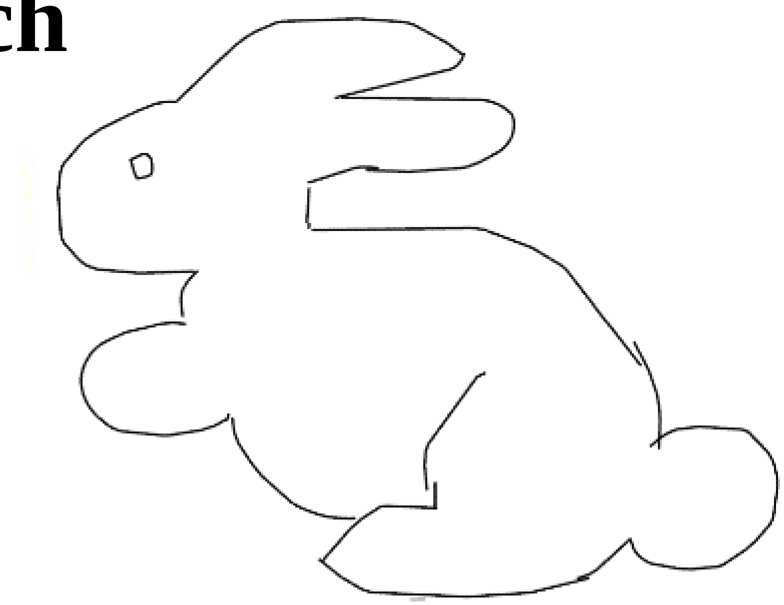


`glyphFromGlyphDifference`



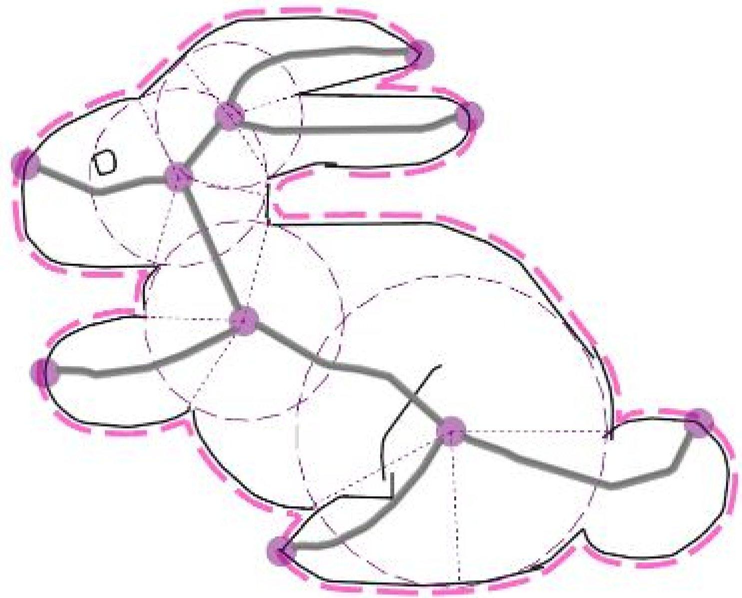
Experimental CogSketch





Medial Axis Transform (MAT)

1. The points on the interior of a closed shape that have more than one closest point on the exterior
2. The radius function *R*: For every point, the distance from the exterior



Medial Axis Transform (MAT)

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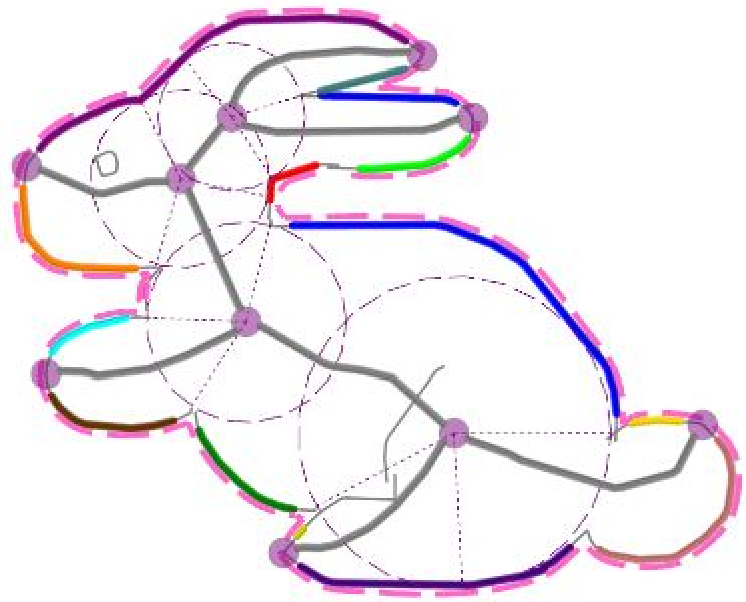

Sketched ink produces "hairy" MATs.

Filter using exterior segmentation

(Bai et al., 2007)

Medial Axis Transform (MAT)

1. The points on the interior of a closed shape that have more than one closest point on the exterior
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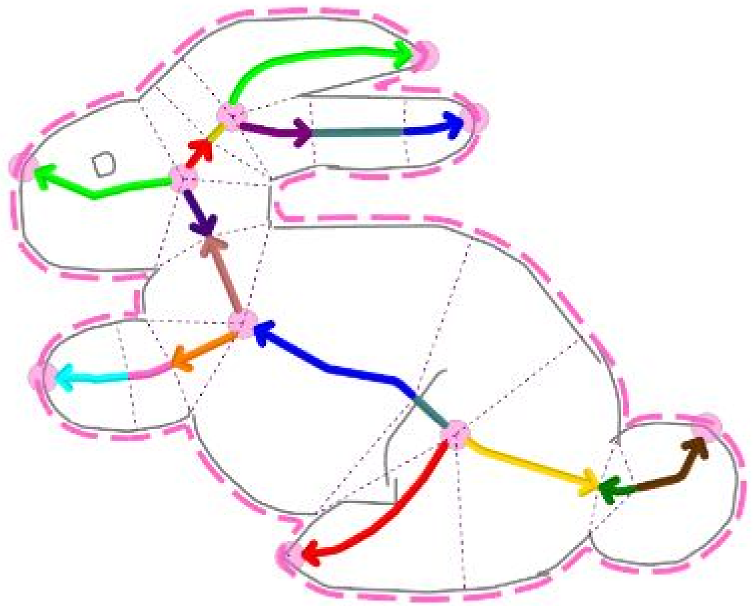


Sketched ink produces "hairy" MATs.

Filter using exterior segmentation

(Bai et al., 2007)

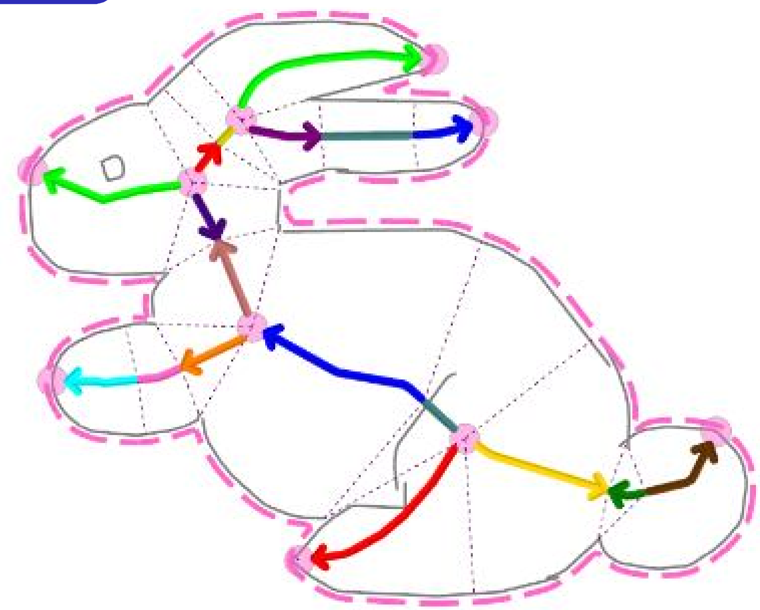
Shock graphs (Siddiqi et al. 1999) carve the MAT at qualitative changes in *R*

Querying for MAT Representations

Query in the context containing edge-cycle facts

```
(ist-Information (EdgeCycleFactsMtFn Rabbit)
  (medialAxisRepresentationsForEdgeCycle
  (PerimeterEdgeCycleFn ECO-3735956) ?angle-mod
    ?size-mod ?mat-mt ?edges ?n-facts)
```

Pass in an edge-cycle. Must be `2D-Shape-Closed` or `2D-Shape-PartiallyClosed`



Querying for MAT Representations

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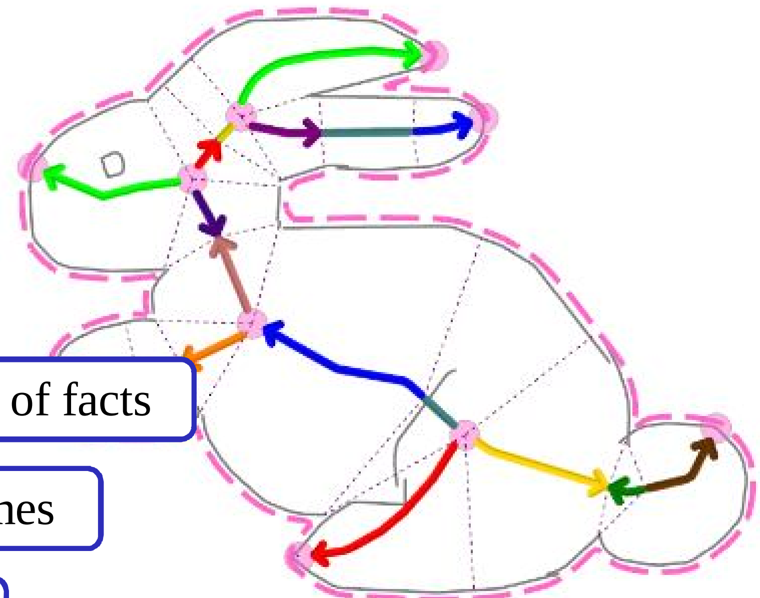
(ist-Information (EdgeCycleFactsMtFn Rabbit)
  (medialAxisRepresentationsForEdgeCycle
  (PerimeterEdgeCycleFn ECO-3735956) ?angle-mod
    ?size-mod ?mat-mt ?edges ?n-facts)
```



Gets bound to the number of facts

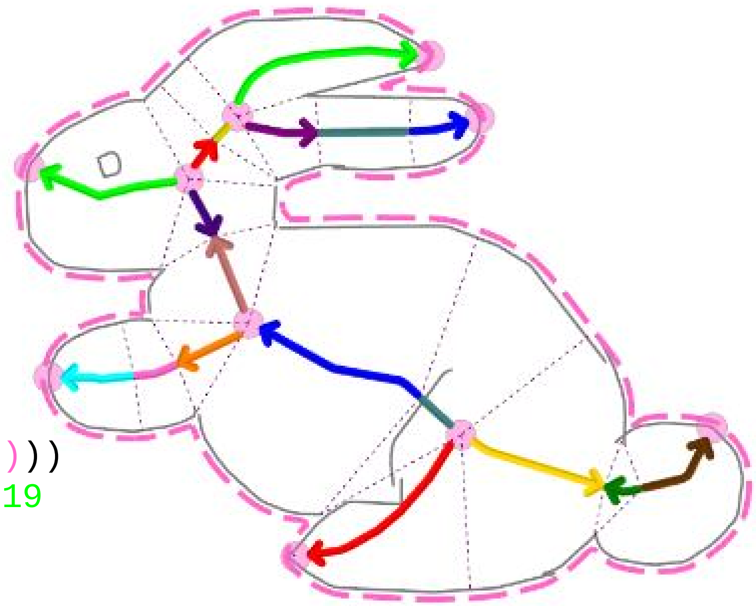
Gets bound to the list of MAT edge names

Gets bound to a microtheory containing the facts

Querying for MAT Representations

```
(ist-Information (EdgeCycleFactsMtFn Rabbit)
  (medialAxisRepresentationsForEdgeCycle
  (PerimeterEdgeCycleFn ECO-3735956) ?angle-mod
    ?size-mod ?mat-mt ?edges ?n-facts)

(medialAxisRepresentationsForEdgeCycle
  (PerimeterEdgeCycleFn ECO-3735956) 0 0
  (DirectedEdgeFactsMtFn
    (MedialAxisFn (PerimeterEdgeCycleFn ECO-3735956)))
  (TheSet MedialAxisEdge-106721 MedialAxisEdge-106719
    MedialAxisEdge-106717 MedialAxisEdge-106715
    MedialAxisEdge-106713 MedialAxisEdge-106711
    MedialAxisEdge-106709 MedialAxisEdge-106707
    MedialAxisEdge-106705 MedialAxisEdge-106703
    MedialAxisEdge-106701 MedialAxisEdge-106699
    MedialAxisEdge-106697 MedialAxisEdge-106695
    MedialAxisEdge-106693 MedialAxisEdge-106691
    MedialAxisEdge-106689 MedialAxisEdge-106687) 267)
```

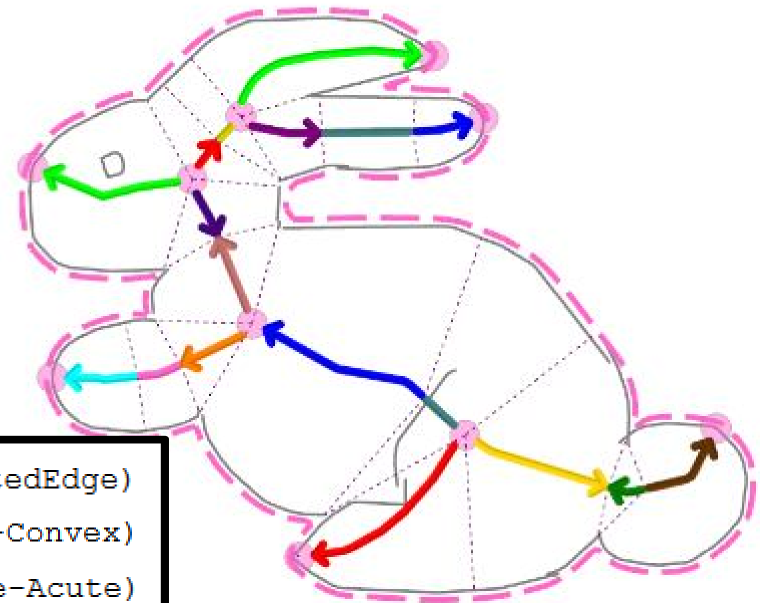


MAT Representations

Standard Edge Attributes

Edge Radius Attributes

- Directed/Undirected ($R' <\!/\!\approx 0$)
- Concave/Linear/Convex ($R'' >\!/\!\approx\!/\!< 0$)
- Obtuse/Right/Acute ($R' >\!/\!\approx\!/\!< -1$)
- Source/Sink edge
- Relative thickness



```
(isa MedialAxisEdge-106689 DirectedEdge)
(isa MedialAxisEdge-106689 MedialAxisEdge-Convex)
(isa MedialAxisEdge-106689 MedialAxisEdge-Acute)
```

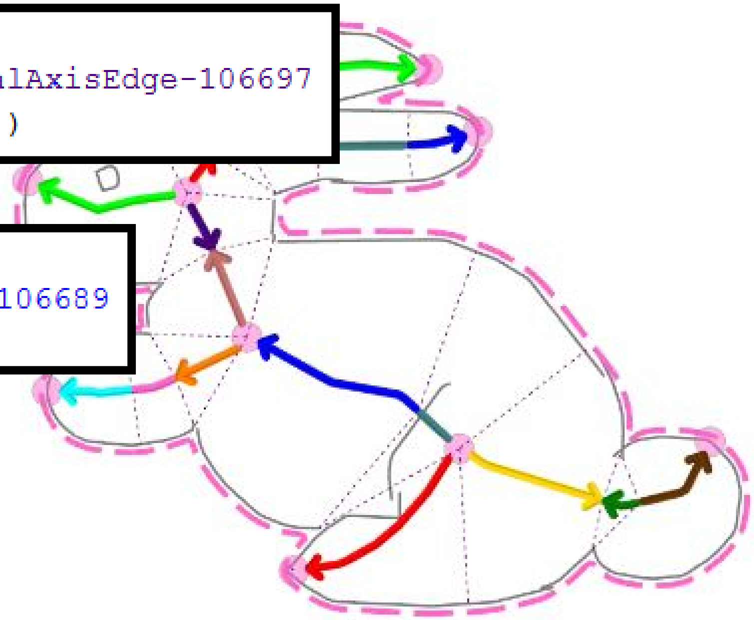
```
(isa MedialAxisEdge-106687 UndirectedEdge)
(isa MedialAxisEdge-106687 SourceEdge)
```

MAT Representations

- Standard Edge Attributes
- Edge Radius Attri…
  - Directed/Undirected
  - Concave/Linear/Convex ($R'' >/\approx/< 0$)
  - Obtuse/Right/Acute ($R' >/\approx/< -1$)
  - Source/Si…
  - Relative t…
- Connection Radius Relations
  - Weakly/Strongly directed connection
  - Source/Sink connection

```
(sinkConnection
  (elementsConnected MedialAxisEdge-106697
   MedialAxisEdge-106699))
```

```
(stronglyDirectedConnection
  (directedConnection MedialAxisEdge-106689
   MedialAxisEdge-106699))
```



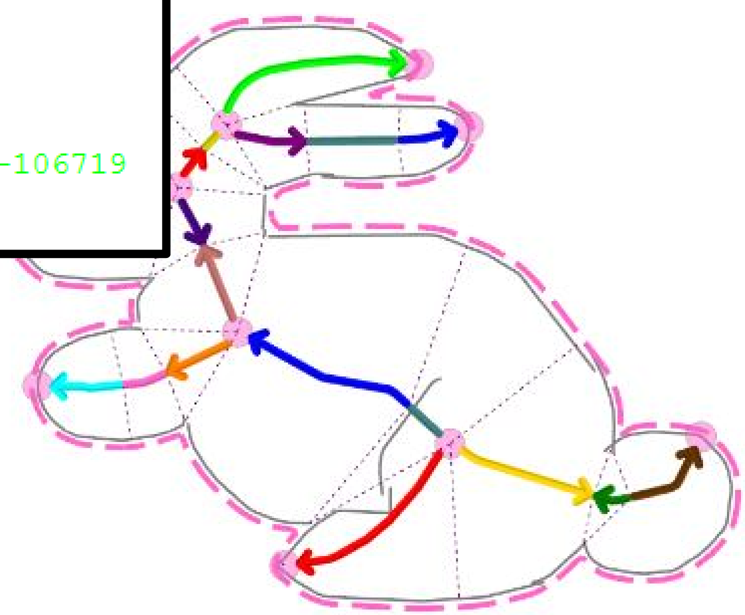
MAT Representations

Standard Edge Attributes

Edge

```
(acuteCorner
  (elementsConnected MedialAxisEdge-106719
   MedialAxisEdge-106713))
 (clockwiseNeighborAtJunction MedialAxisEdge-106719
  MedialAxisEdge-106713)
```

- Dir
- Co
- Obt
- Source/Sink edge
- Relative thickness



Connection Radius Relations

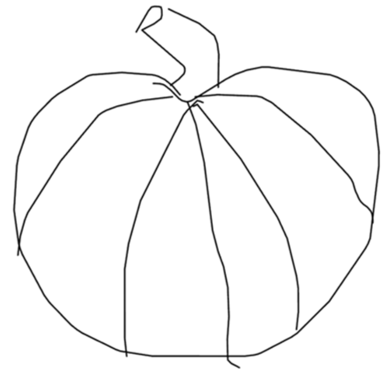
- Weakly/Strongly directed connection
- Source/Sink connection

Connection Shape Relations

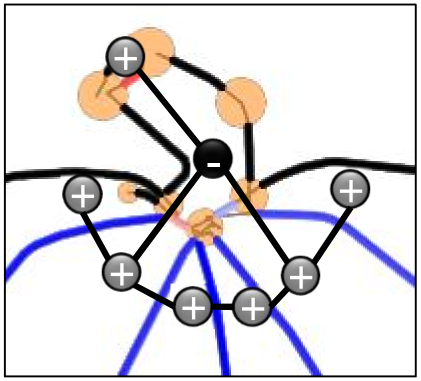
- Obtuse/Right/Acute/Straight corner
- Clockwise edge ordering

Texture Detection

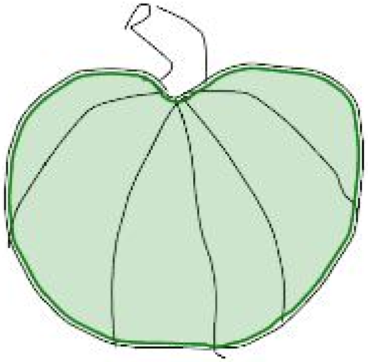
Ising Model: Given local grouping preferences (disagreement costs), finds globally optimal graph cut



- Built on edge-cycle adjacency graph



- Disagreement costs
  - Real-valued (**affinity** or **anti-affinity**)
  - Computed from normalized perceptual similarities between edge-cycles along multiple dimensions
    - E.g. orientation, area, curvature



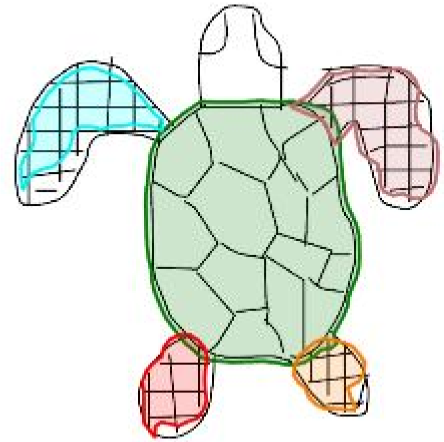
Details in (McLure et al. 2015)

Texture Representations

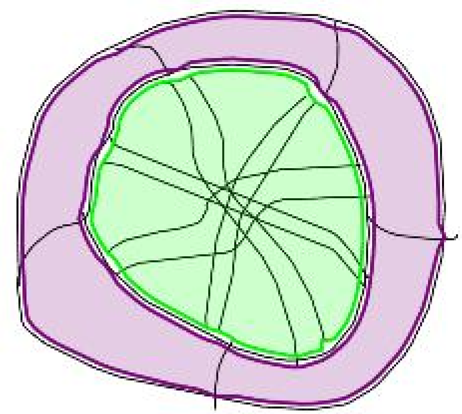
Textures are regions, which have perimeters and possibly holes

- Perimeter and holes are edge-cycles
- Perimeter and holes replace the grouped edge-cycles at the edge-cycle level of representation

Query predicate:
`edgeCycleRepresentationsFor-Textured`



~2500 facts → ~250 facts



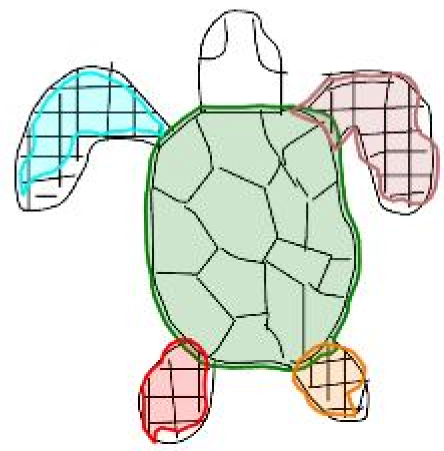
~1000 facts → ~40 facts

Texture Representations

Texture region is reified

Tied to perimeter and holes with relations.

Attributes are assigned based on which dimensions of perceptual similarity correlate with the grouping

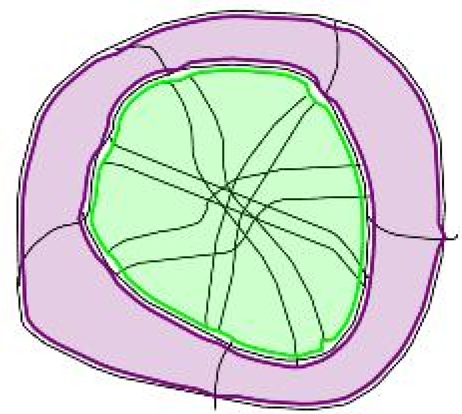


~2500 facts → ~250 facts

```
(hasHole EdgeCycle-Texture-3848276
  (TextureHoleFn EdgeCycle-Texture-3848276 0))
```

```
(hasPerimeterEdgeCycle EdgeCycle-Texture-3848276
  (PerimeterEdgeCycleFn ECO-3847663))
```

```
(isa EdgeCycle-Texture-3848276 PerceptualTexture-CycleSize)
```



~1000 facts → ~40 facts

Querying for an analogy

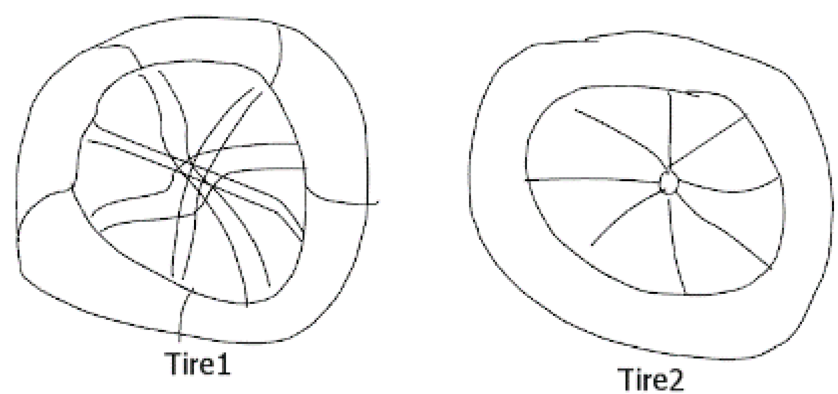
Query in the subsketch context

```
(ist-Information Bcase-3663043853
  (matchBetween
    (WMCaseFn (EdgeCycleFactsMtFn Tire1))
    (WMCaseFn (EdgeCycleFactsMtFn Tire2))
    (TheSet)
    ?match))
```

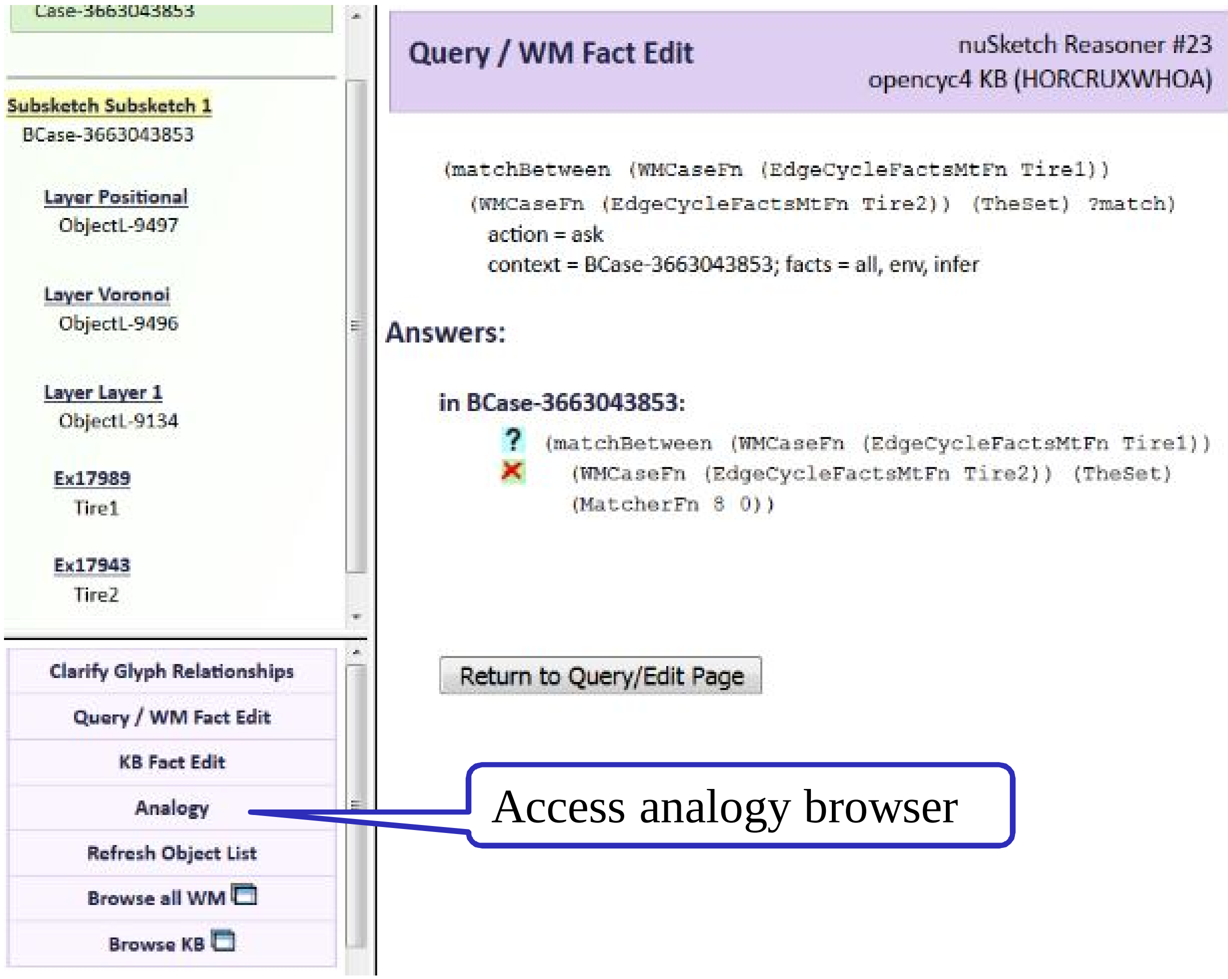
Two microtheories to compare

Match constraints (here, an empty set)

Gets bound to a match name

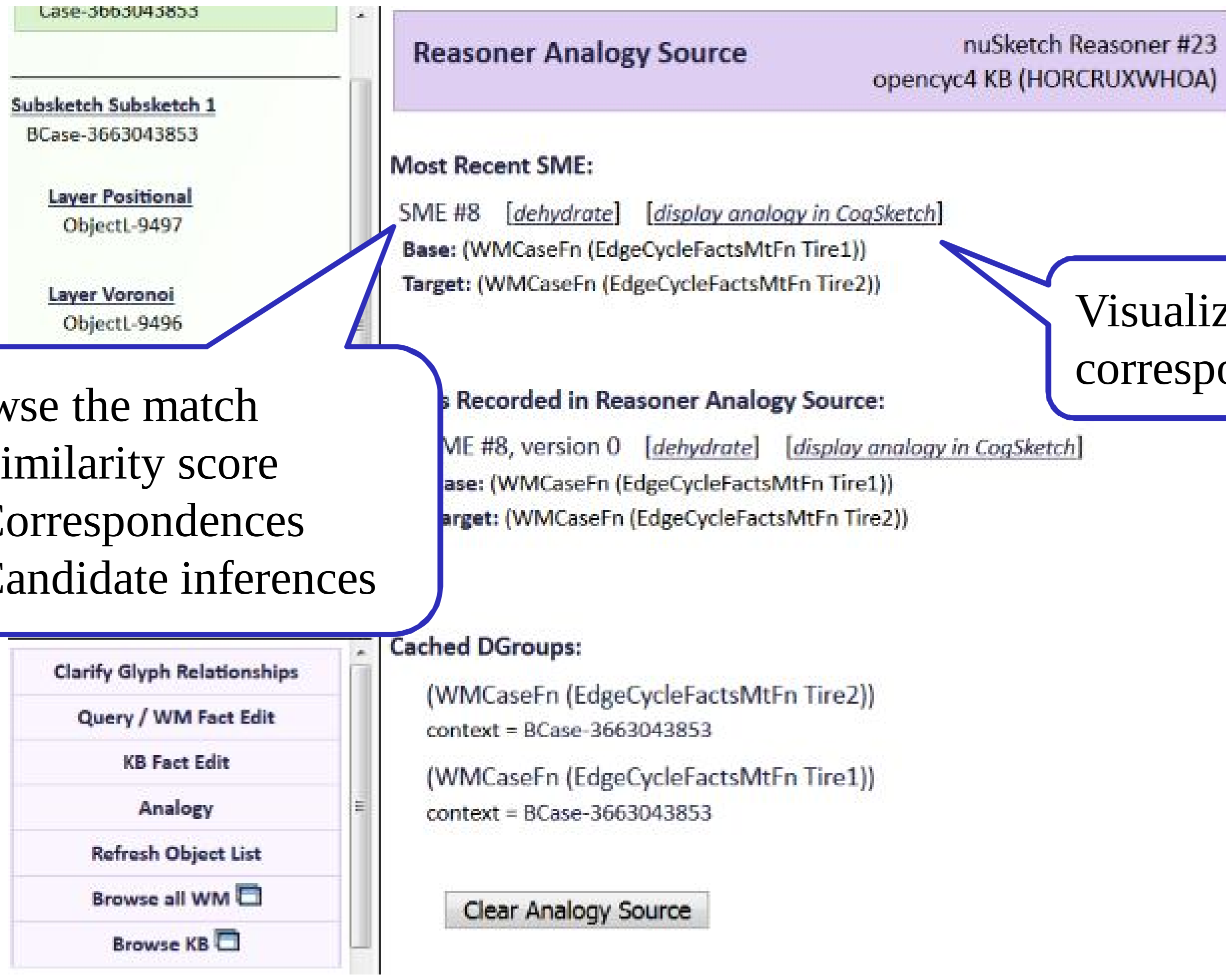


The Analogy Browser



Access analogy browser

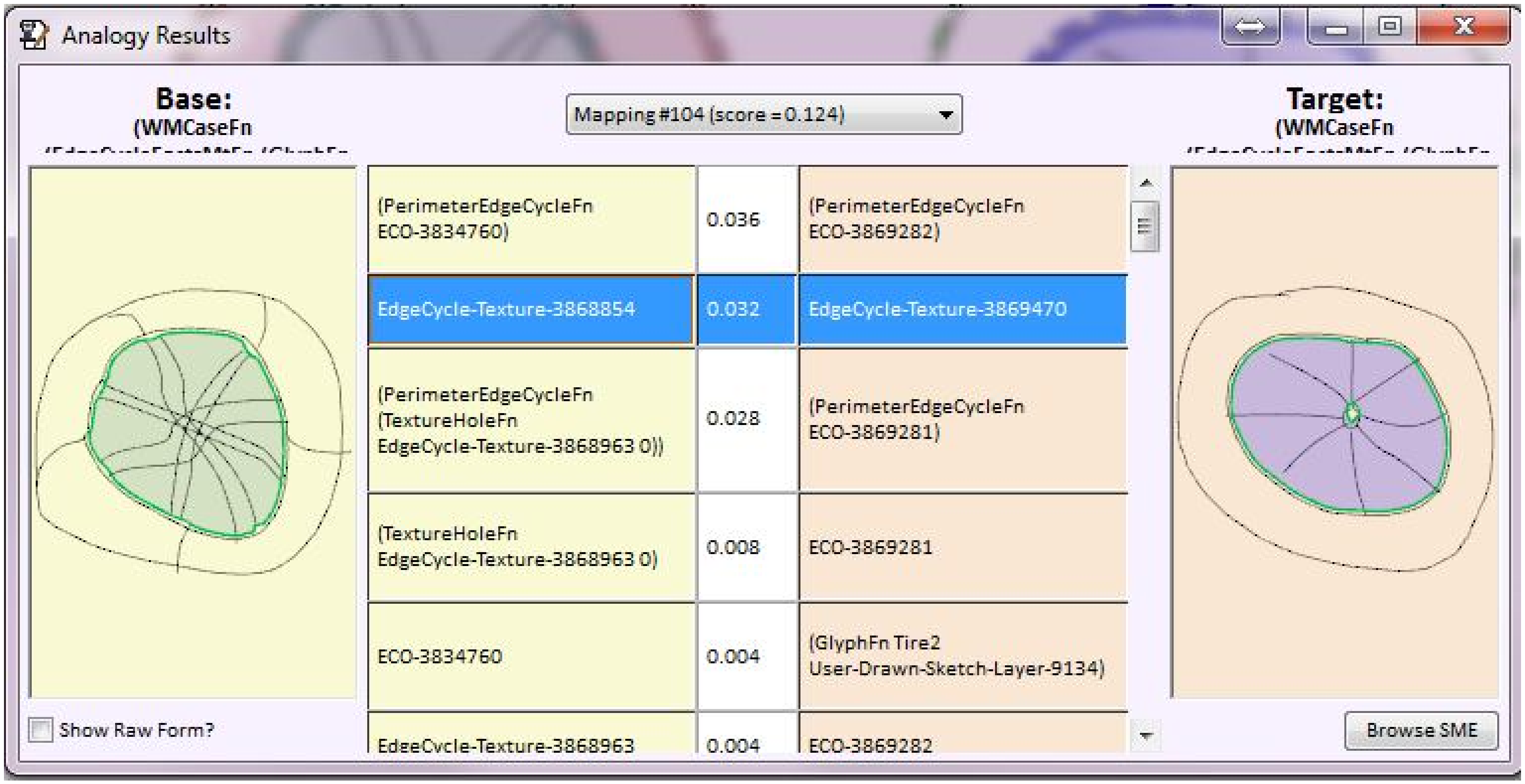
The Analogy Browser



Browse the match
- Similarity score
- Correspondences
- Candidate inferences

Visualize the correspondences

The Analogy Display



Questions?

Perceptual Sketchpad

Perceptual Sketchpad Motivation

- Facility for experimenting with expressive representation of shapes
  - Decomposing glyphs
  - Modeling human shape comparisons
- Still experimental, hence separate subsystem
  - Not all CogSketch users need it
  - Much has now been integrated into educational worksheets

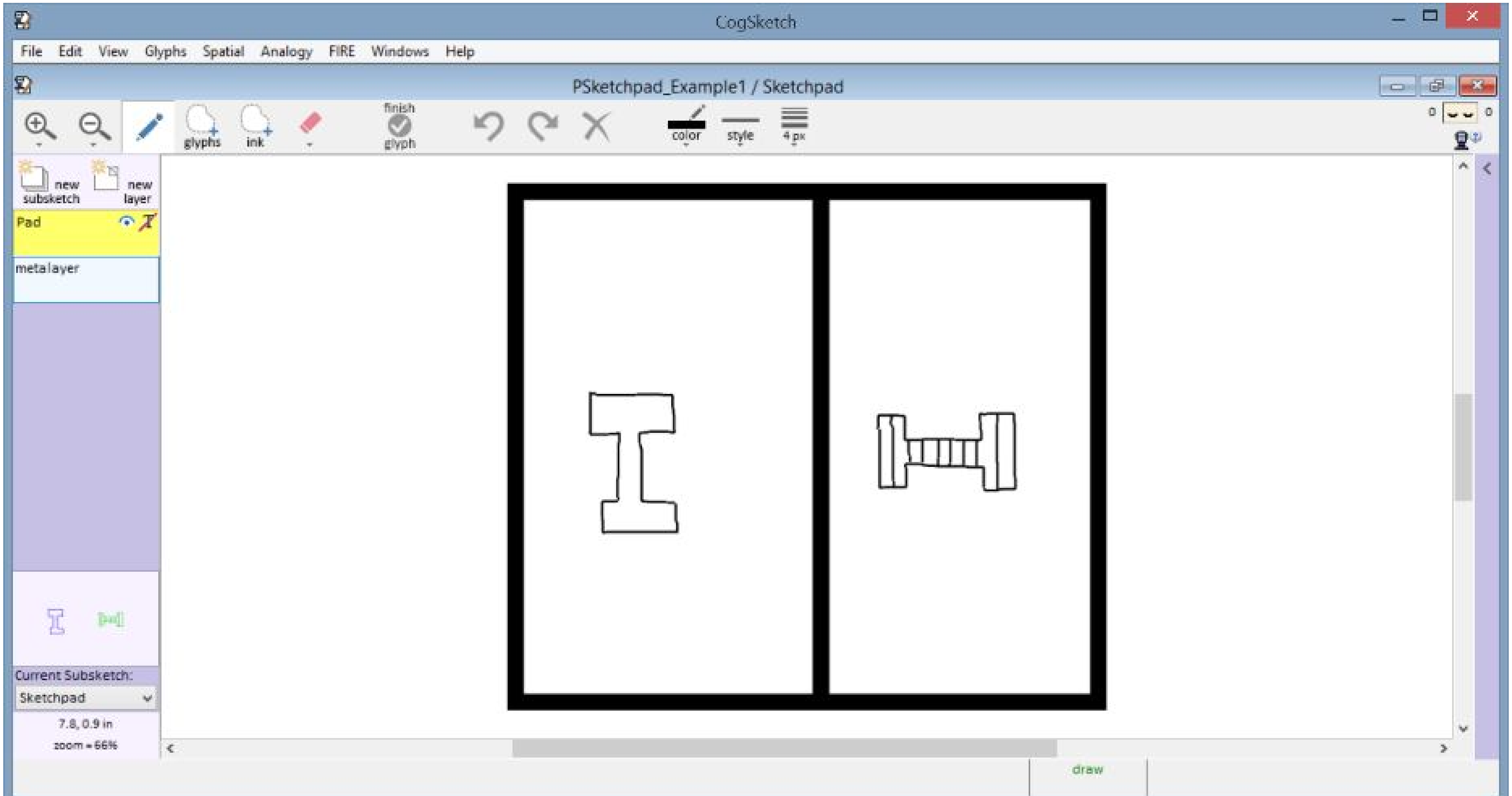
Using the Perceptual Sketchpad

- CogSketch comes with a Perceptual Sketchpad demo
  - Choose “New Perceptual Sketchpad” from the File Menu

OR

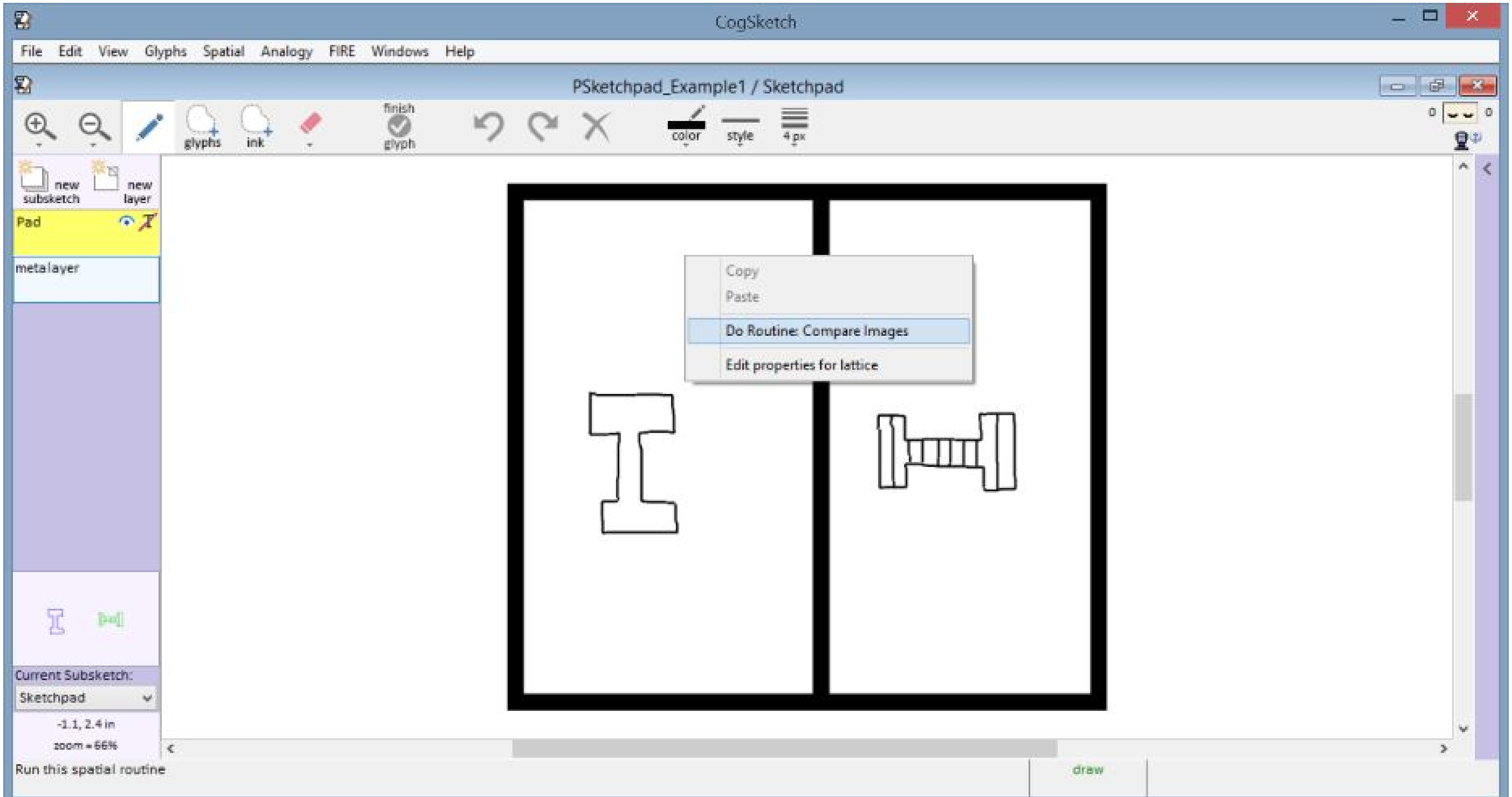
  - Open one of the examples from the sketches directory
    - PSketchpad_Example1
    - PSketchpad_Example2

Using the Perceptual Sketchpad

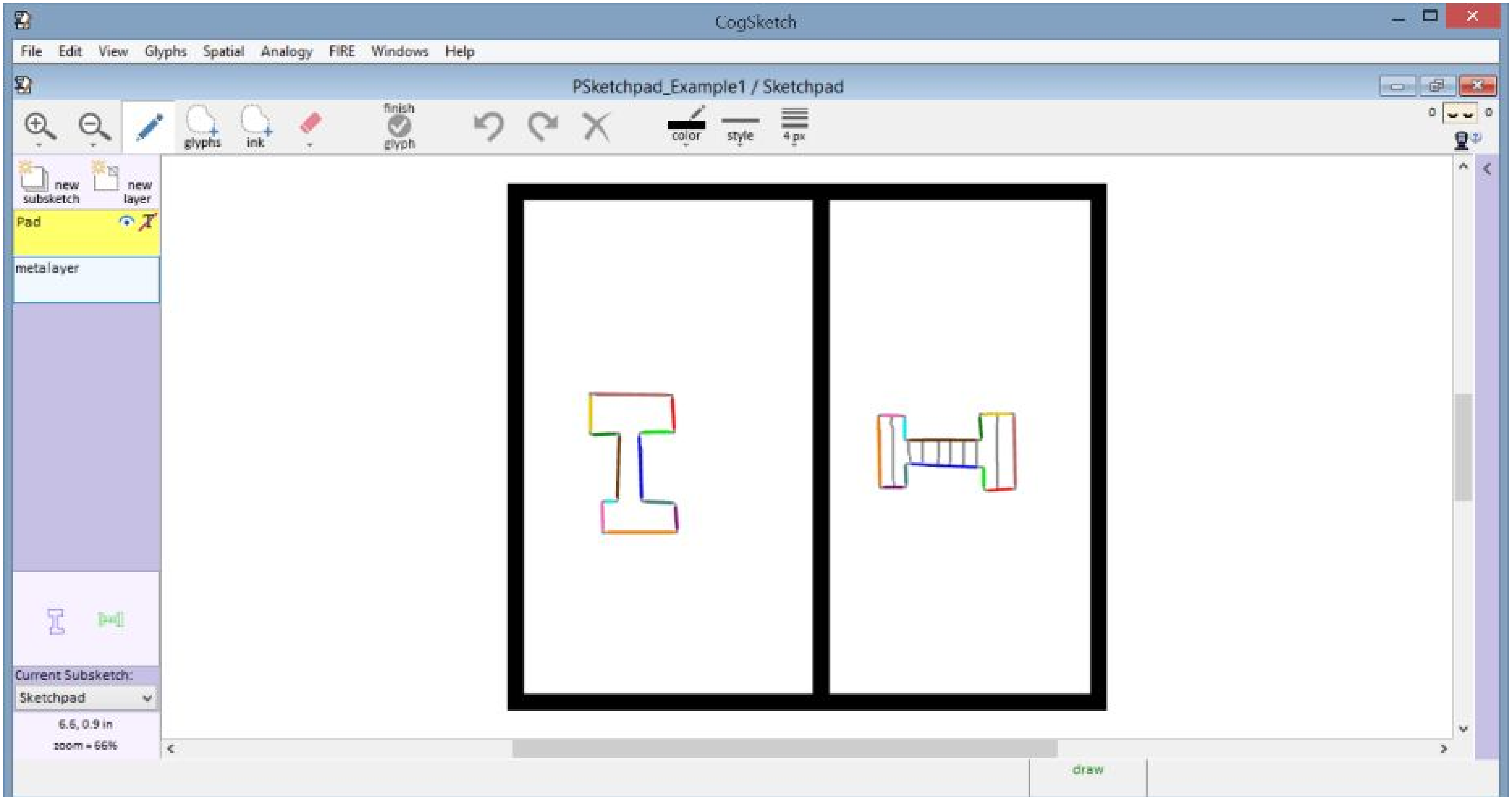


PSketchpad_Example1

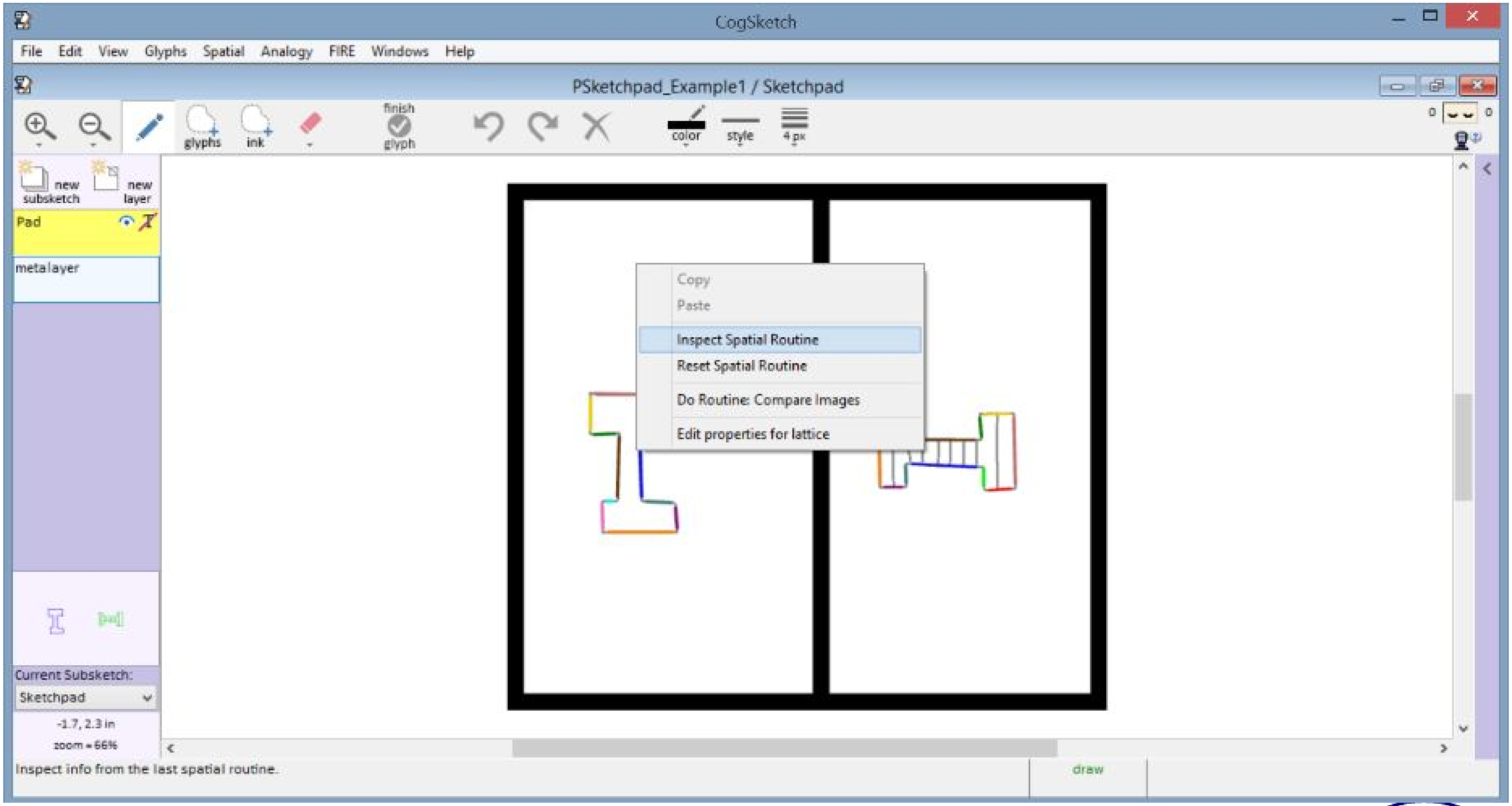
Using the Perceptual Sketchpad



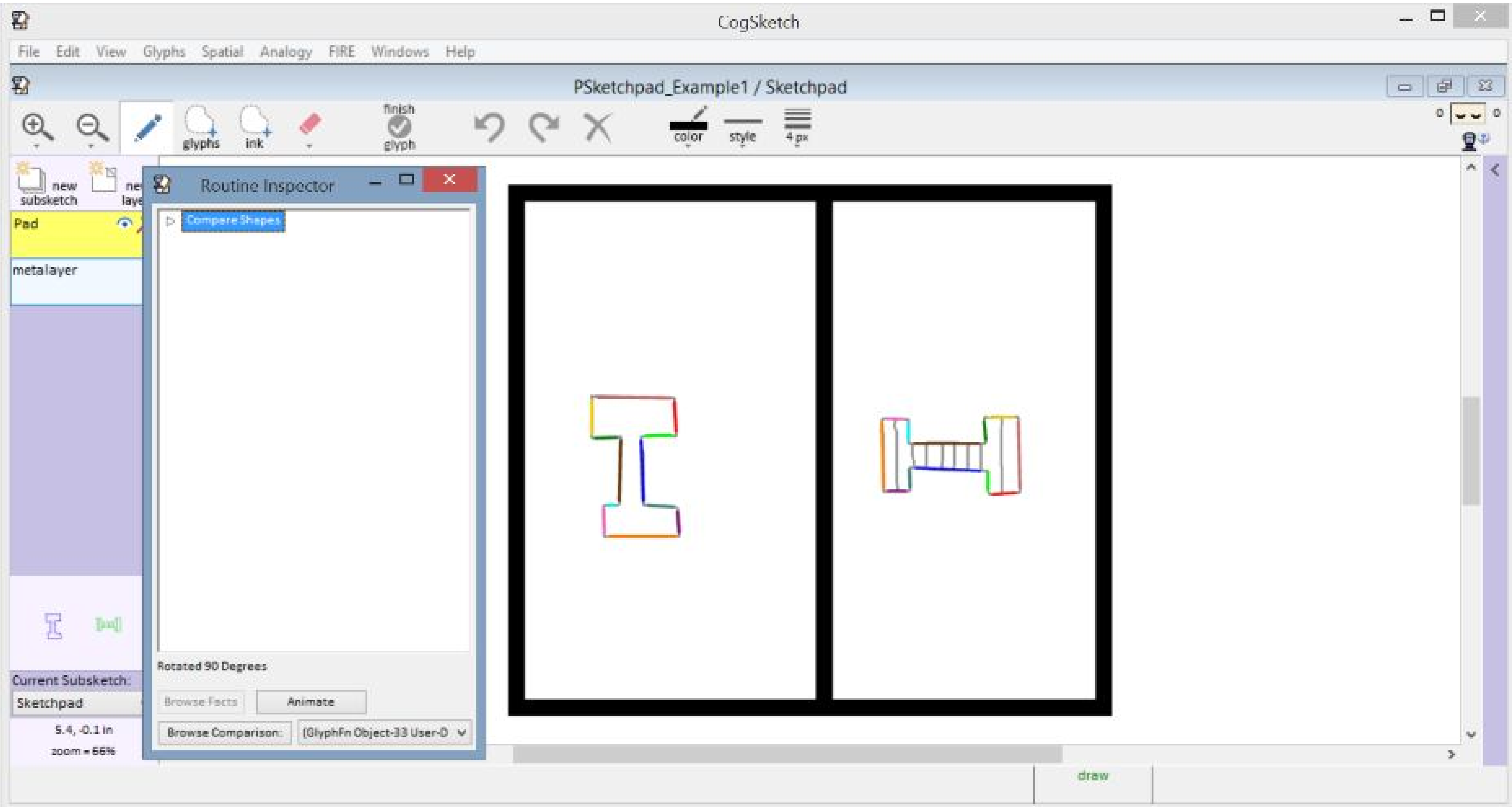
Using the Perceptual Sketchpad



Using the Perceptual Sketchpad



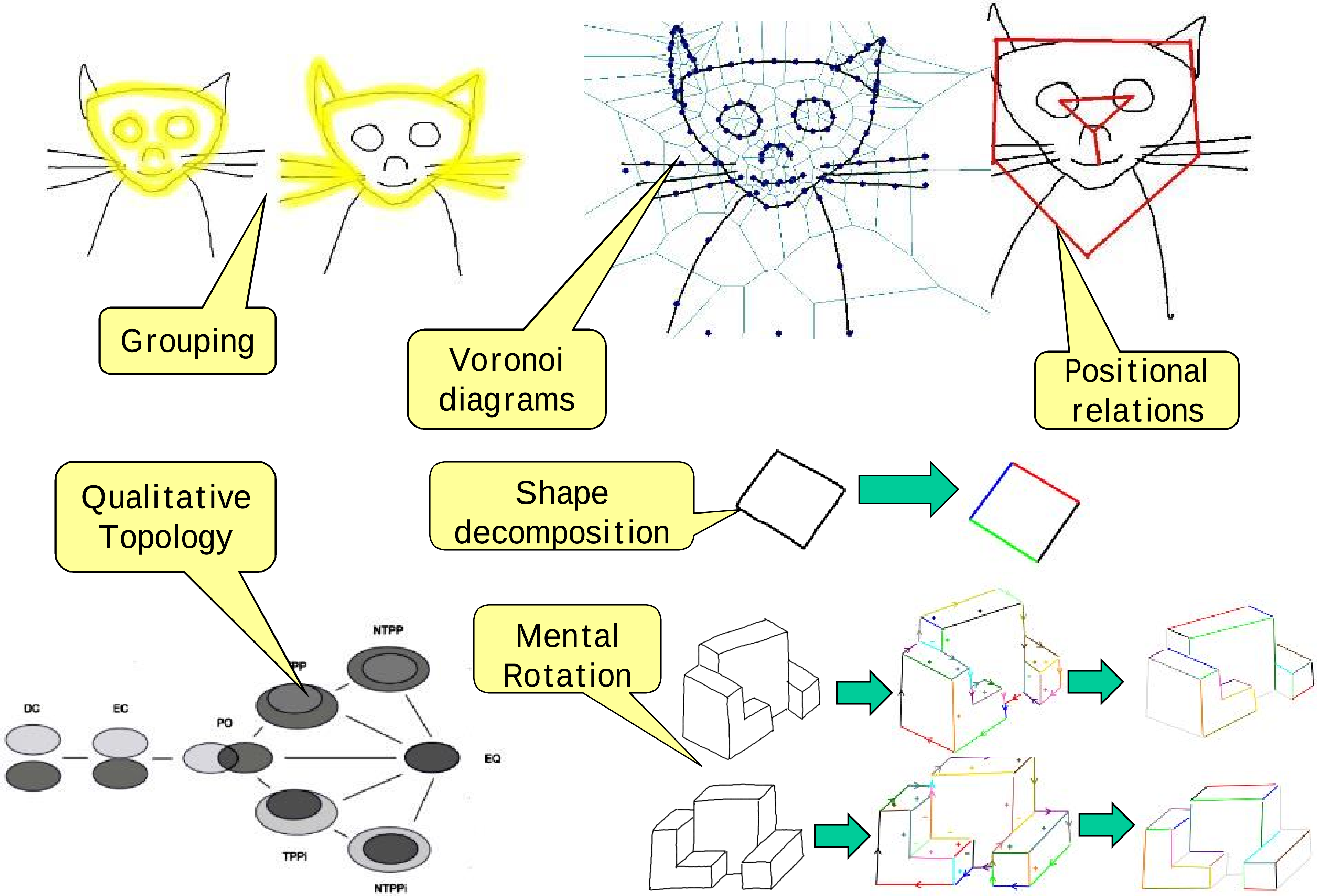
Using the Perceptual Sketchpad



Using the Perceptual Sketchpad

- If there is one glyph in each entry
  - Edge-level representations will be used
- If there are multiple glyphs
  - Glyph-level representations will be used
- Elements will be color-coded to indicate correspondences
  - Right-click and choose “Reset Spatial Routine” to remove colors

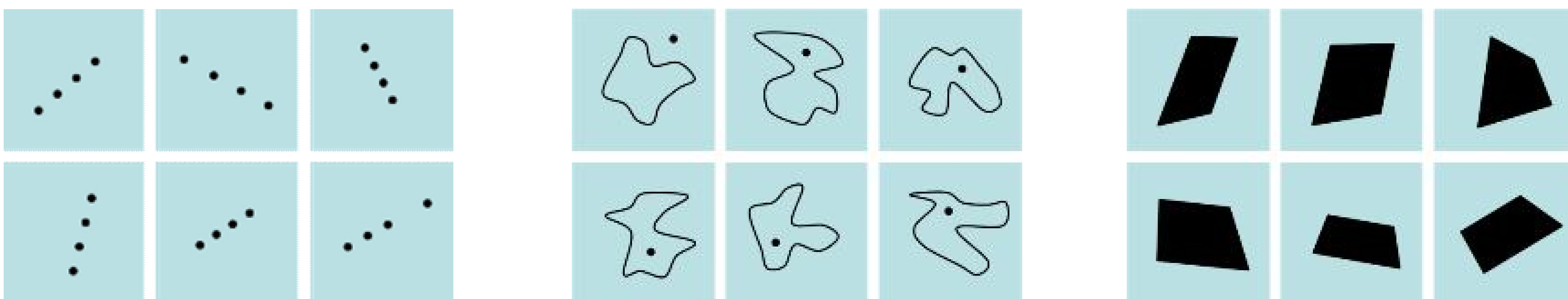
Some CogSketch spatial computations



Hierarchical Representations in Psychology

Images can be represented at different levels in a spatial hierarchy

Spatial reasoning requires identifying the appropriate level



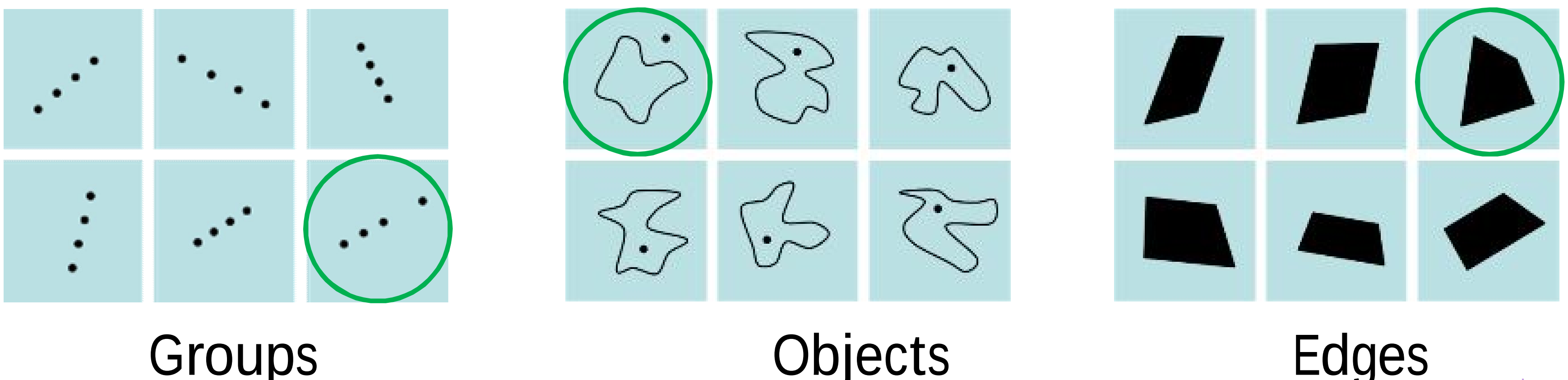
Groups | Objects | Edges

(Marr & Nishihara, 1978; Palmer, 1977; Hochstein & Ahissar, 2002)

Hierarchical Representations in Psychology

Images can be represented at different levels in a spatial hierarchy

Spatial reasoning requires identifying the appropriate level



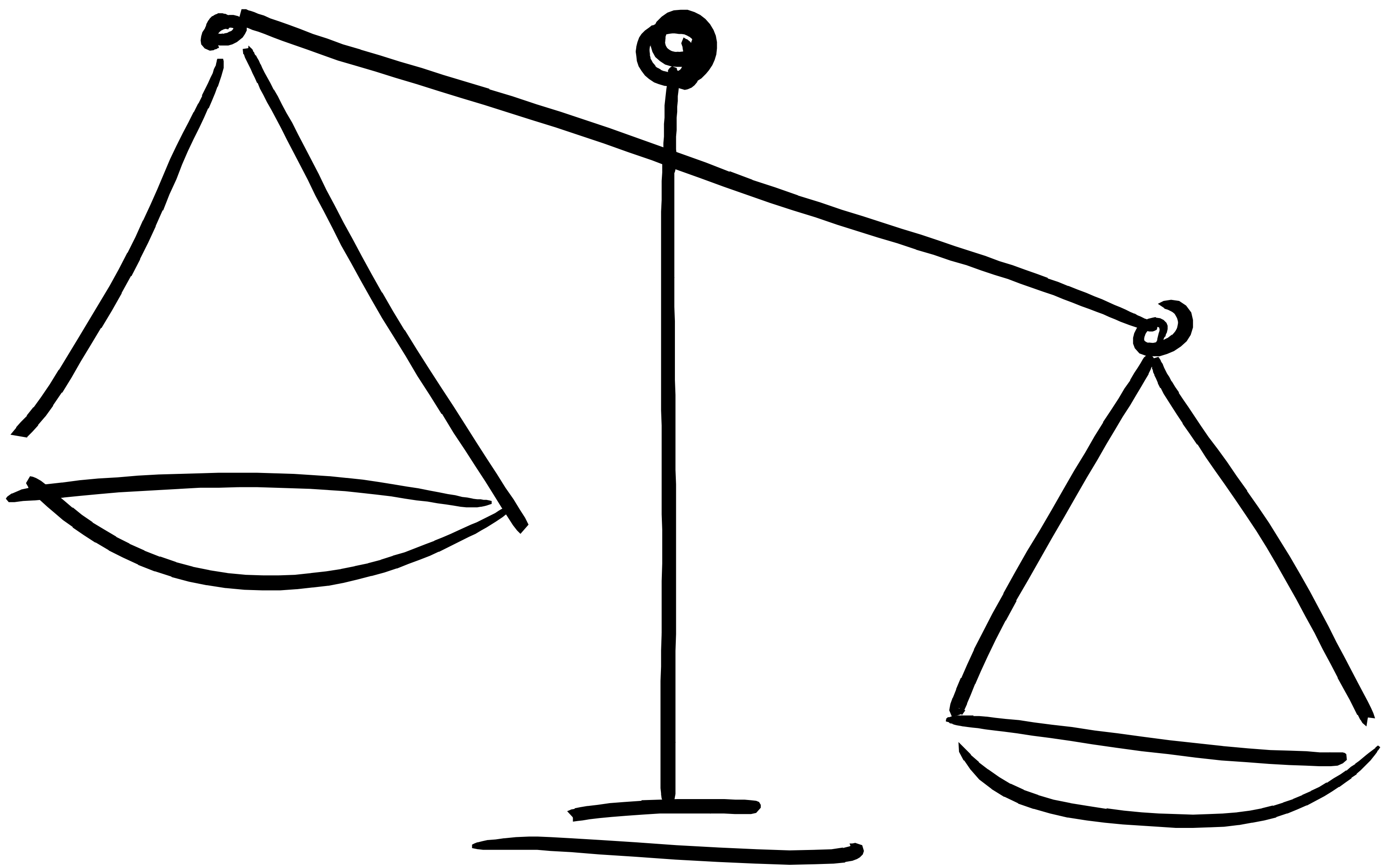
(Marr & Nishihara, 1978; Palmer, 1977; Hochstein & Ahissar, 2002)

CogSketch and Education

Tutorial

AAAI 2016

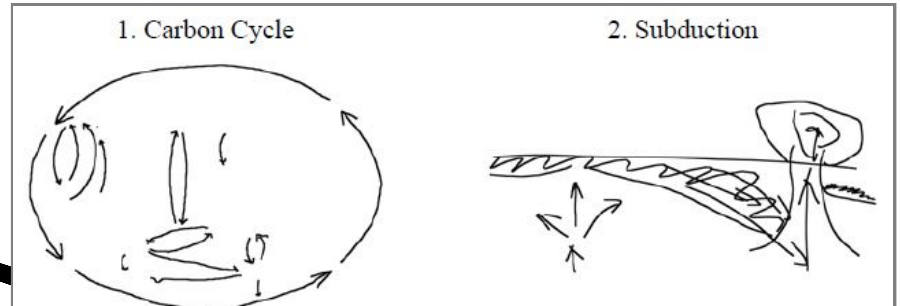
Sketching for Learning in Science



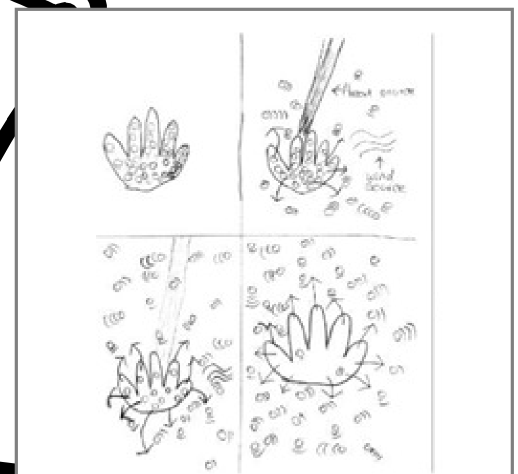
Sketching for Learning in Science

Powerful tool for Learning

- Increases engagement
- Easier spatial reasoning
- Multi-modal reasoning

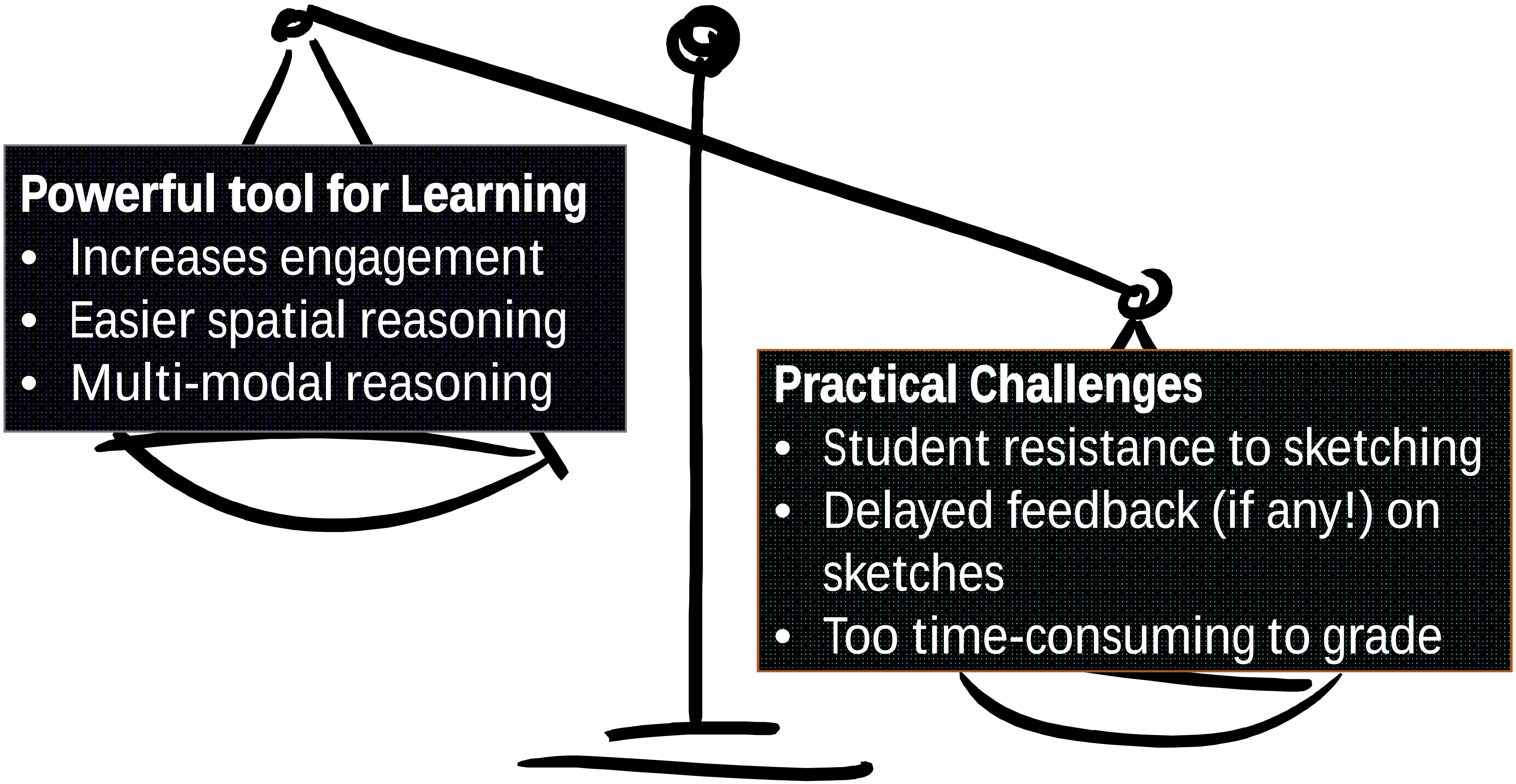


Jee et al. 2009



Ainsworth et al. 2011

Sketching for Learning in Science



Benefits of Intelligent Tutoring Systems

Each challenge can be at least partially addressed by a sketch-based intelligent tutoring system (SBITS)

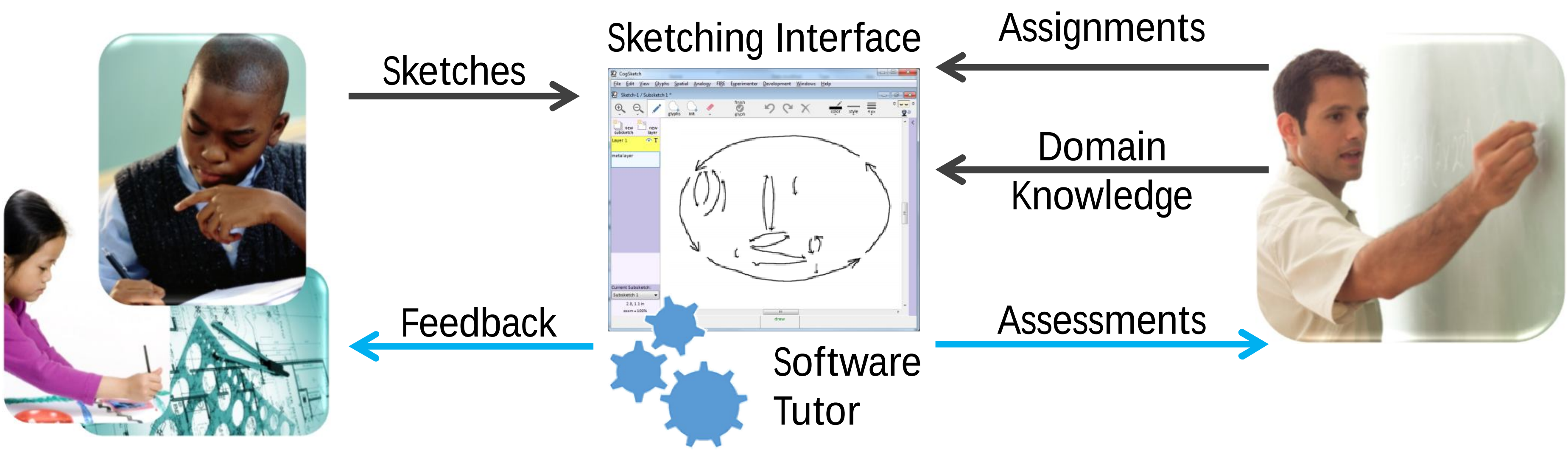
Practical Challenges of Sketching

- Student resistance to sketching
- Delayed feedback (if any!) on sketches
- Too time-consuming to grade

- Safe environment for students to practice, make mistakes, learn
- Timely, on-the-spot feedback
- Automated assessment

CogSketch as a Platform for sketch-based educational software

Eventually, like a calculator, but with automated feedback and assessment



Our vision: sketch understanding software for helping students learn could be widely available within 3-5 years.

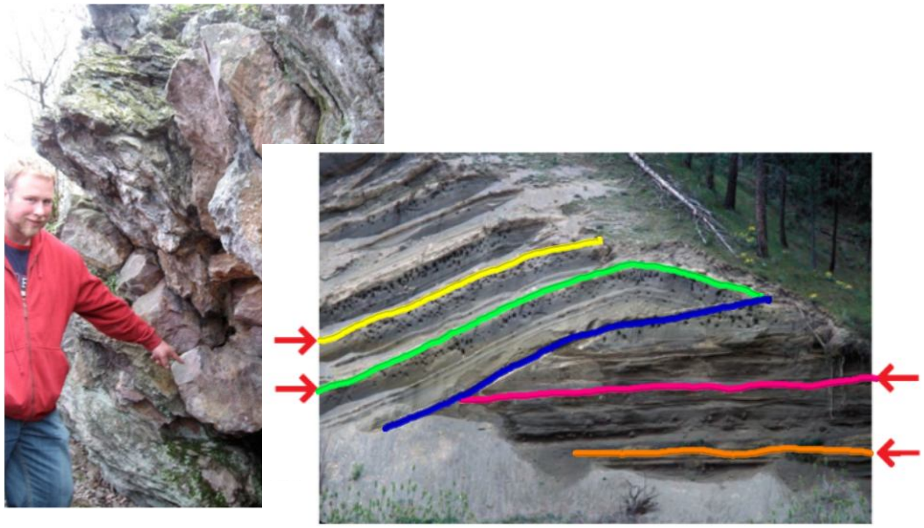
Sketch-based Intelligent Tutoring: Technical Challenges

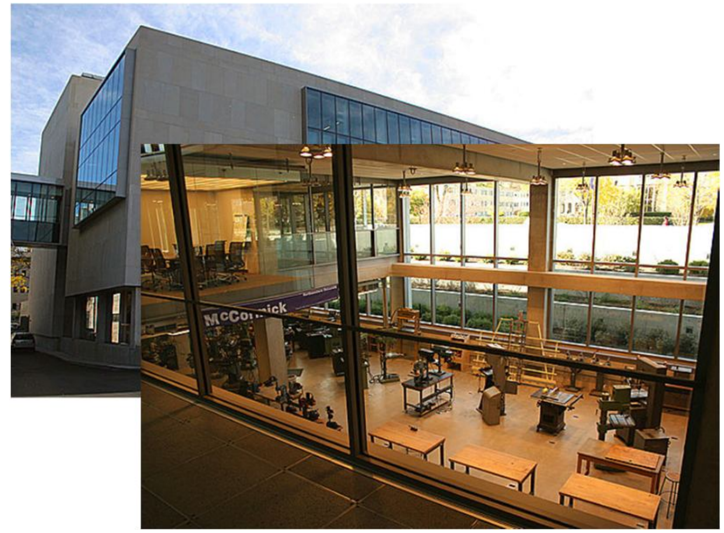
- Sketch Understanding
  - Visual Processing
  - Qualitative Spatial Reasoning
  - Visual-conceptual reasoning
  - Domain knowledge
- Intelligent tutoring
  - Natural interaction
  - Teaching knowledge
  - Student modeling
  - Domain knowledge

via CogSketch

Two approaches:
Domain-specific
Domain-general

Current CogSketch Education Projects

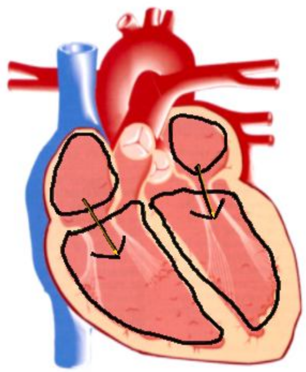




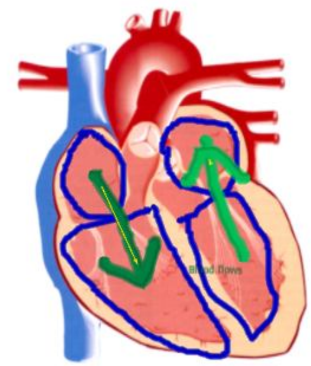
	Sketch Worksheets	Design Coach
Problem	Many STEM fields require learning **spatial layouts and terminology**, but students do not get timely feedback on sketching exercises.	Students have trouble using **sketches to communicate their ideas**.
Idea	Develop software to coach students on sketching exercises	Develop software to coach students on their design sketches and explanations
Domain	Potentially any	Engineering Design
People	Maria Chang, Jeff Usher	Jon Wetzel

Sketch Worksheets:
domain-general, model-based tutoring
(Yin et al. 2010)

Teacher's Solution



Student's Solution



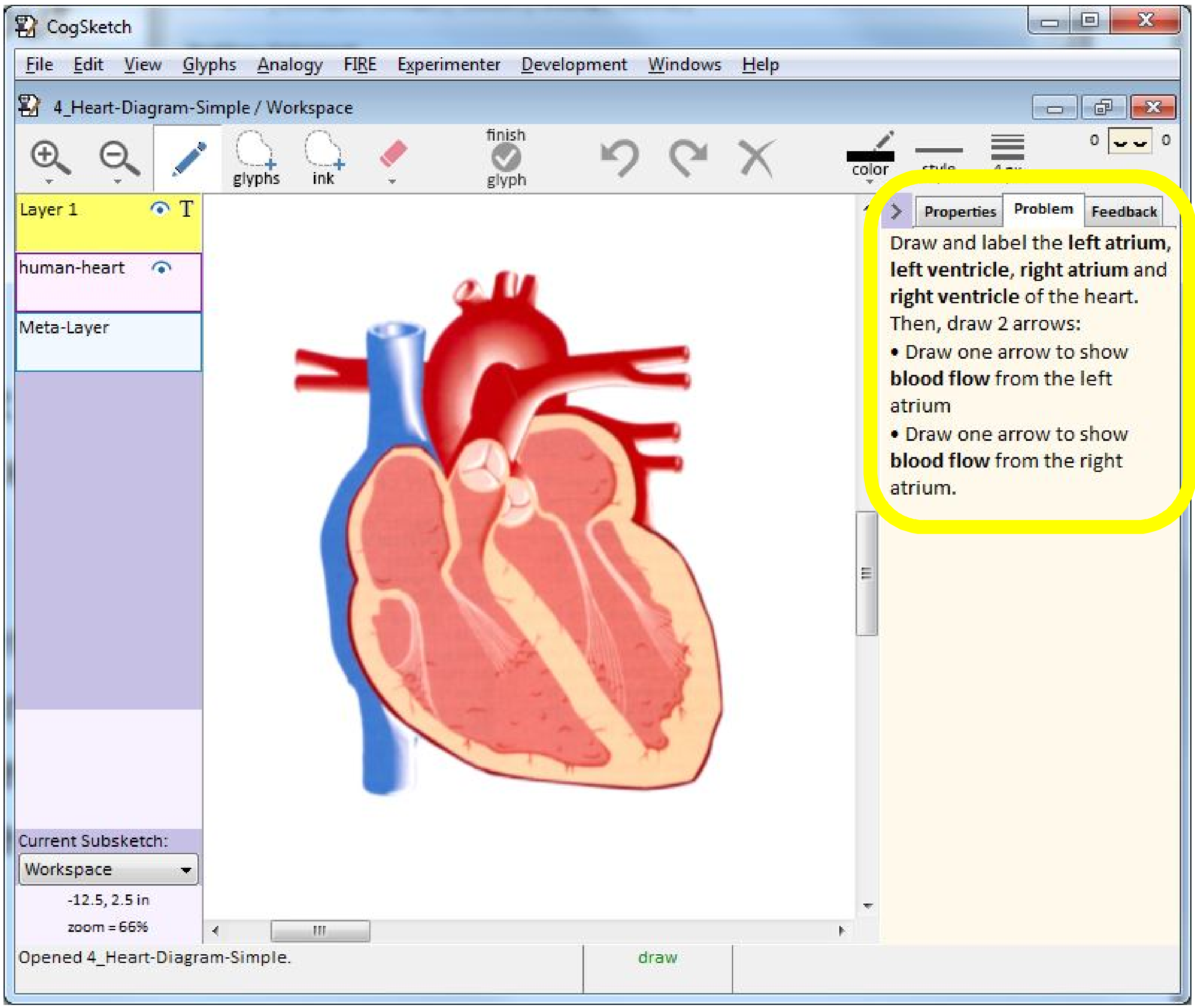
Structure-Mapping Engine

Differences between sketches +
Pre-determined correctness criteria

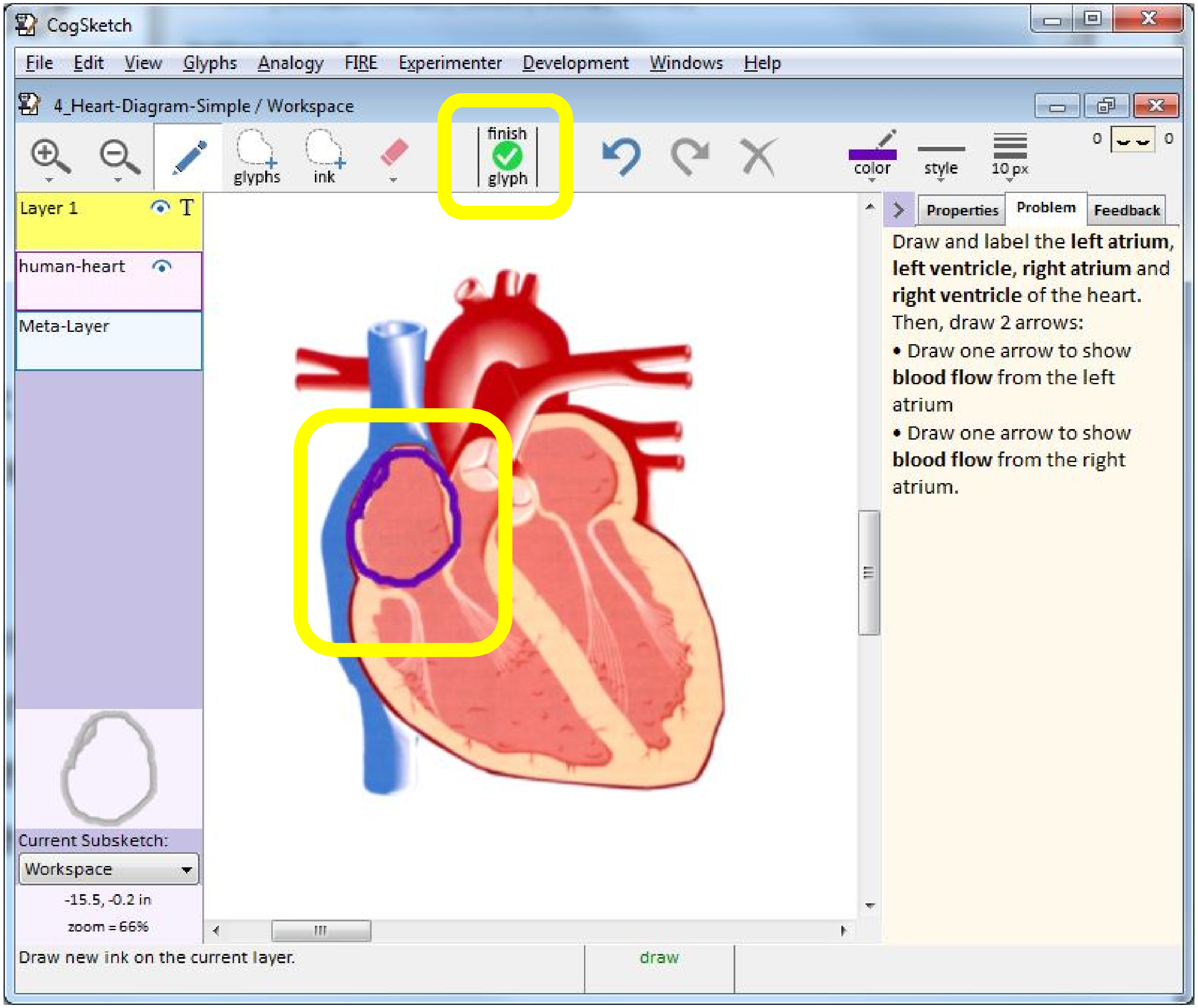
Feedback to Student:
"The left atrium pumps blood out through a valve. Where does that blood go?"

- Mimic traditional paper and pencil worksheets
- Provides on-demand feedback to students
- Platform for instructors to create *their own* worksheets

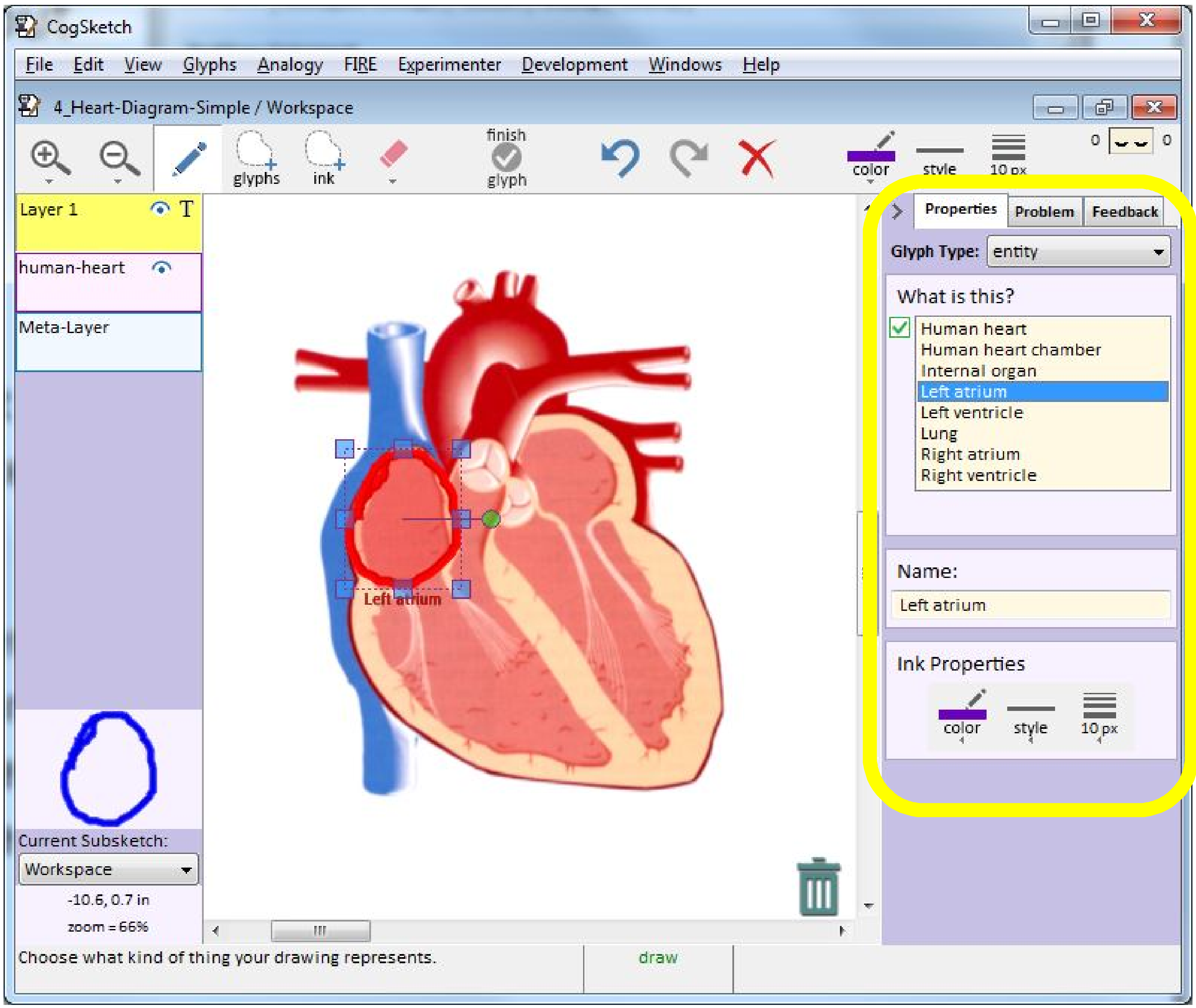
Worksheet Example – Instructions



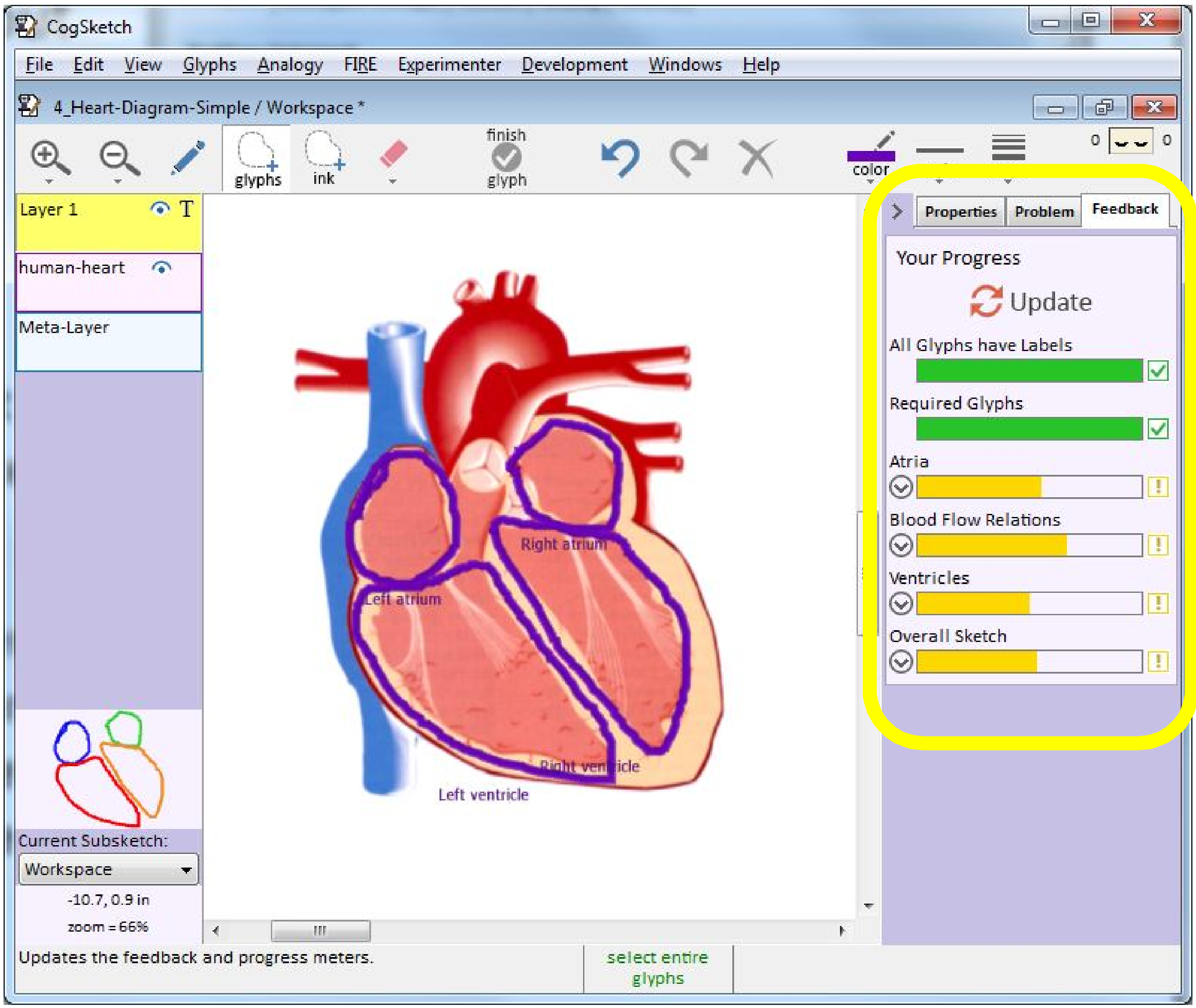
Worksheet Example – Draw, Finish Glyph



Worksheet Example – Label Glyph

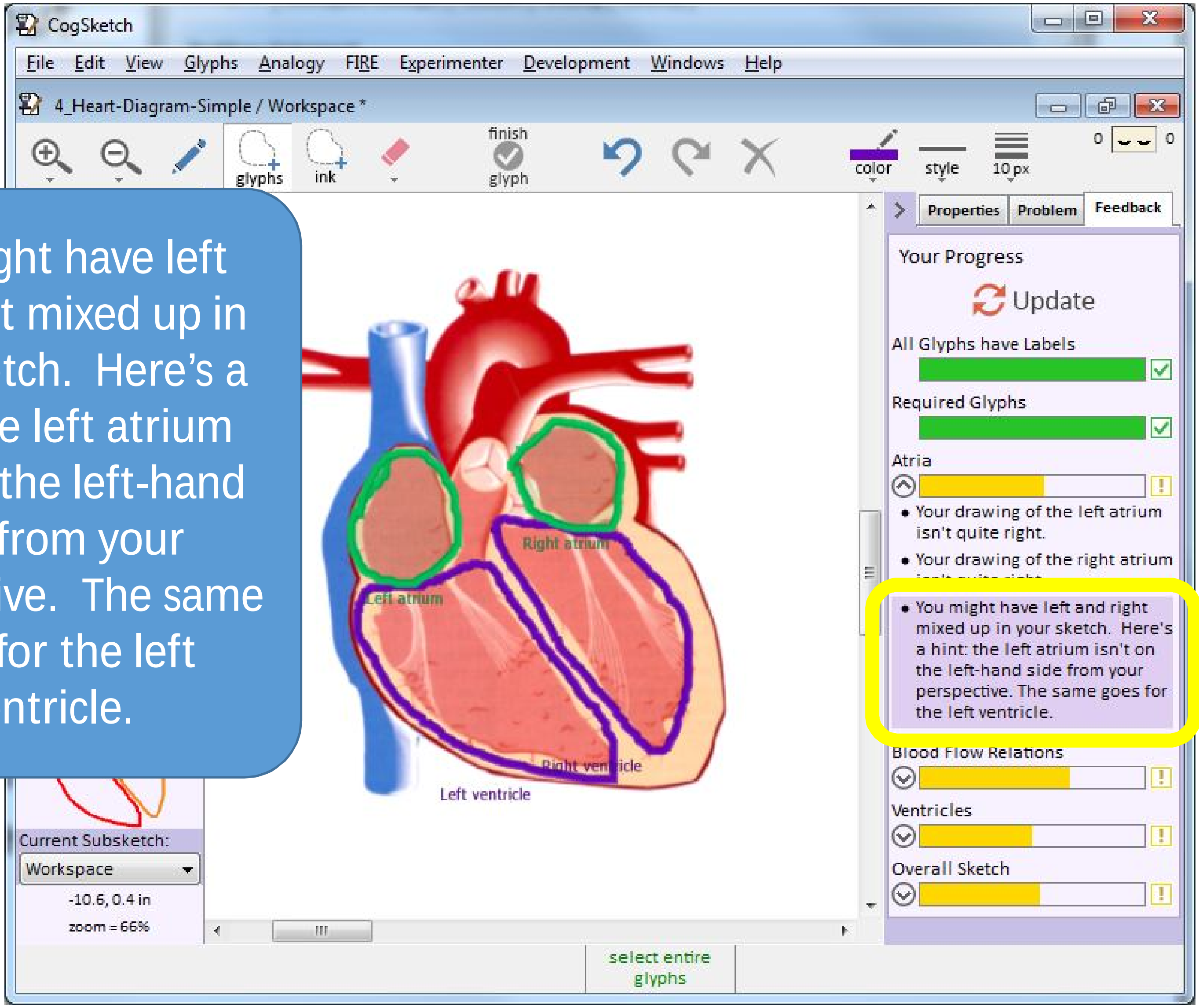


Worksheet Example – Request Feedback

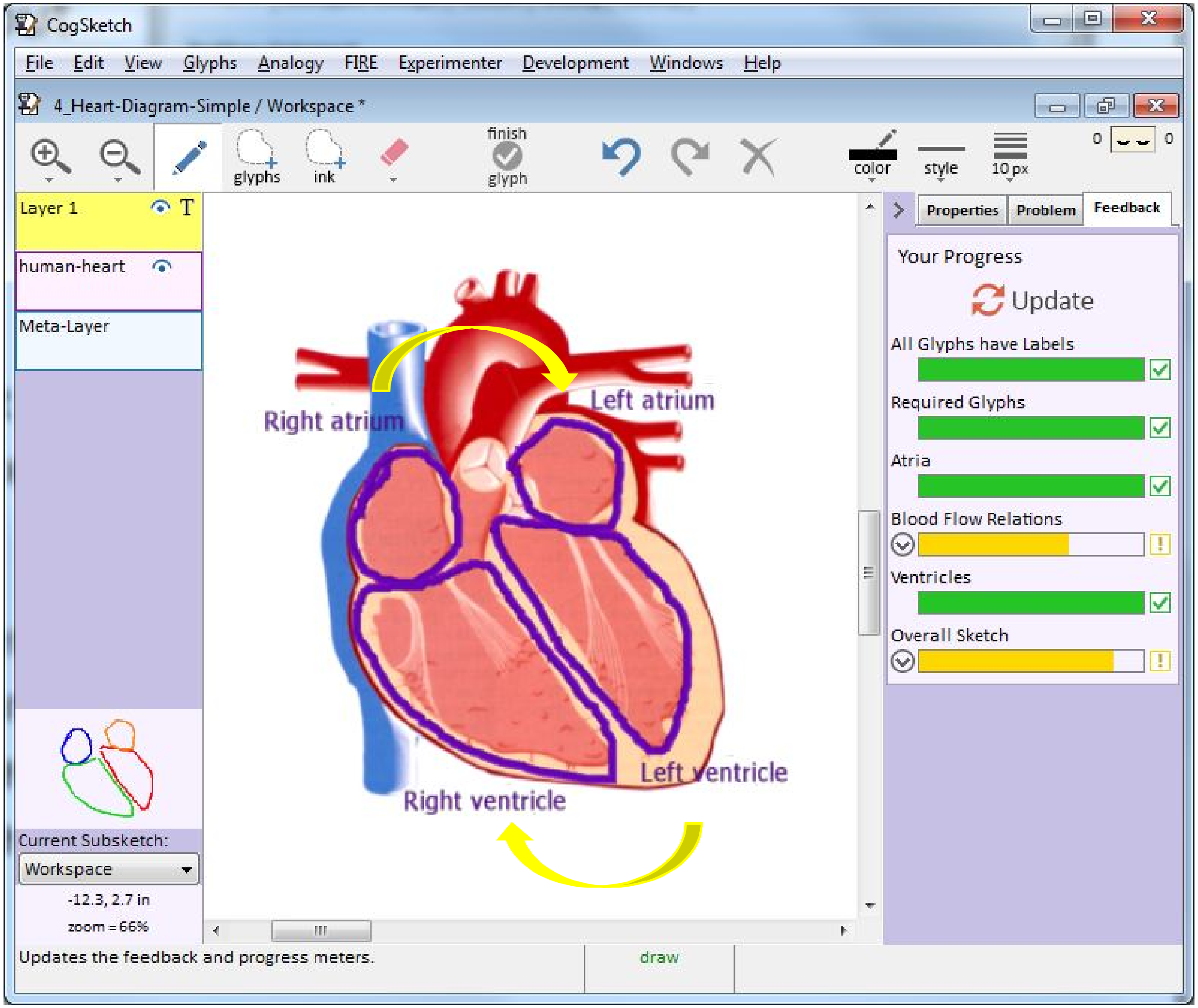


Worksheet Example – Drill down

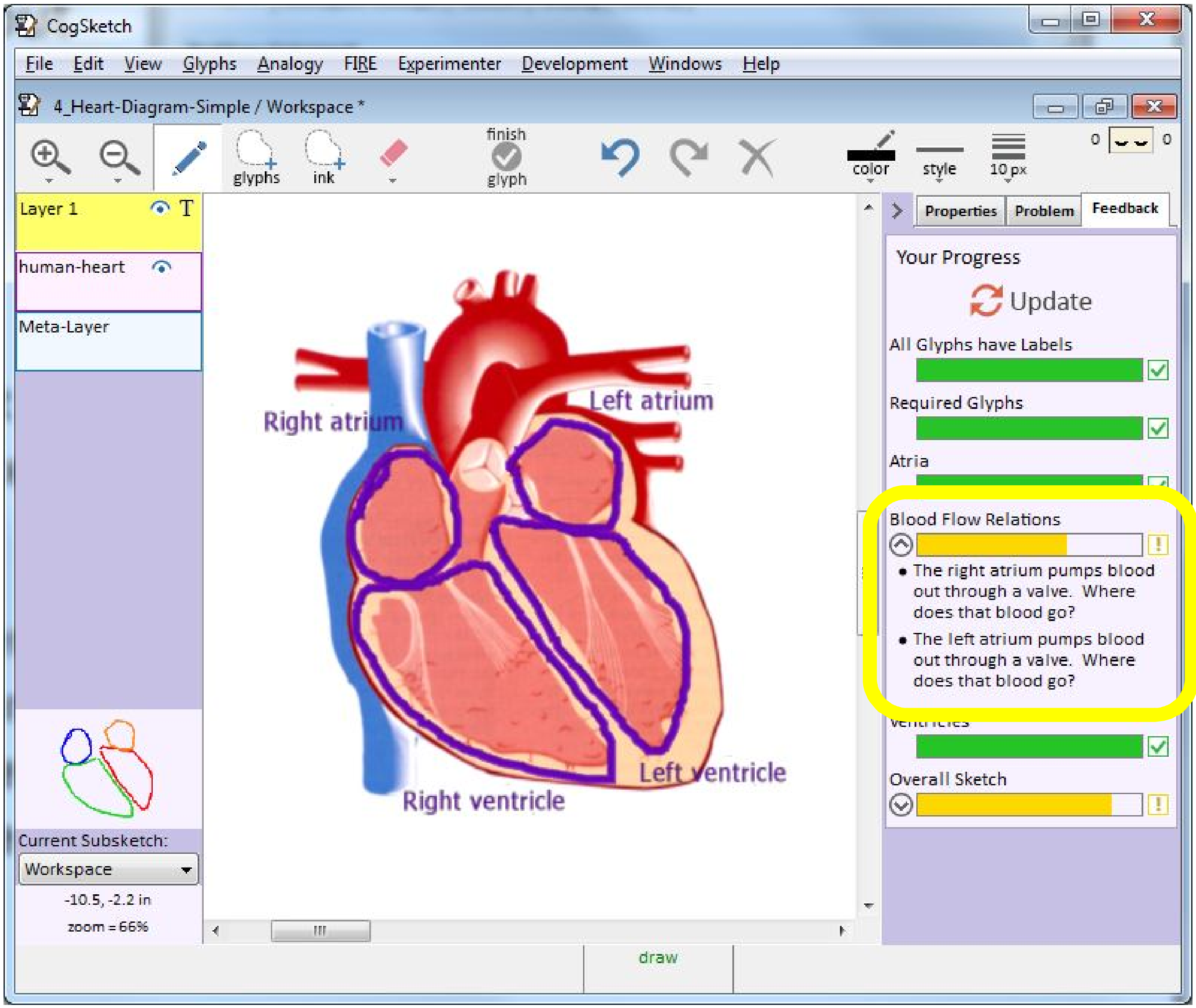
You might have left and right mixed up in your sketch. Here's a hint: the left atrium isn't on the left-hand side from your perspective. The same goes for the left ventricle.



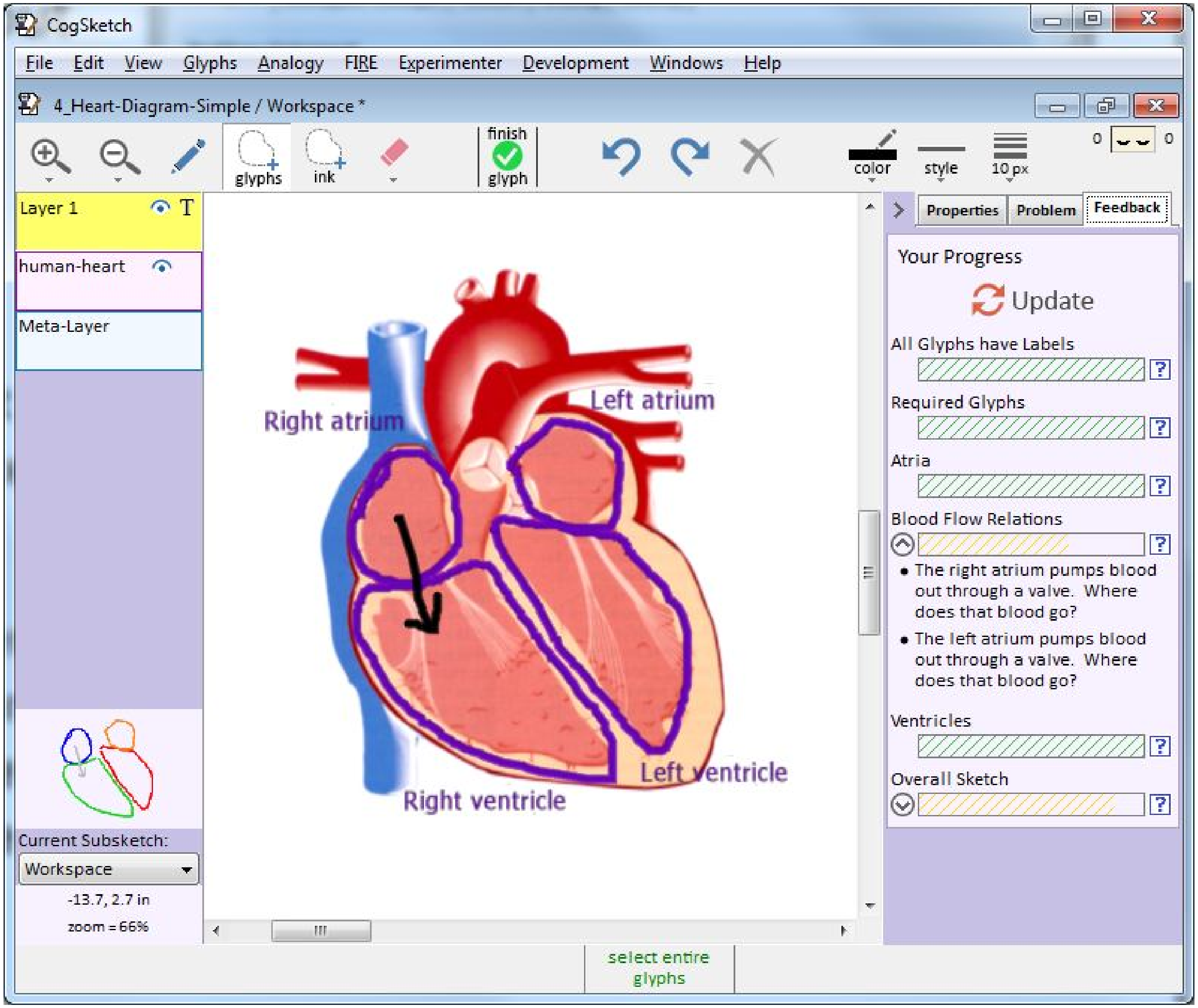
Worksheet Example – Revision



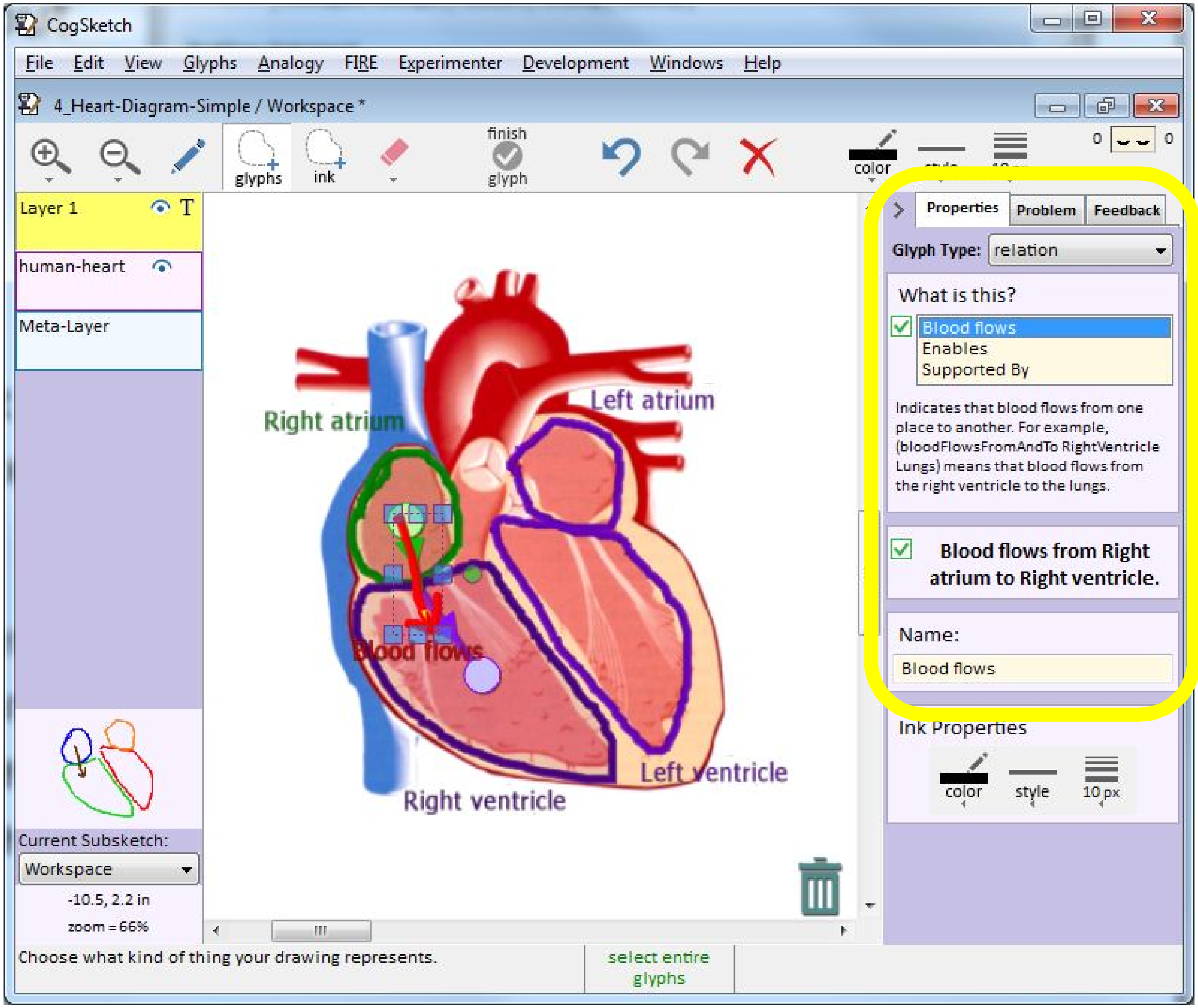
Worksheet Example – Drill Down



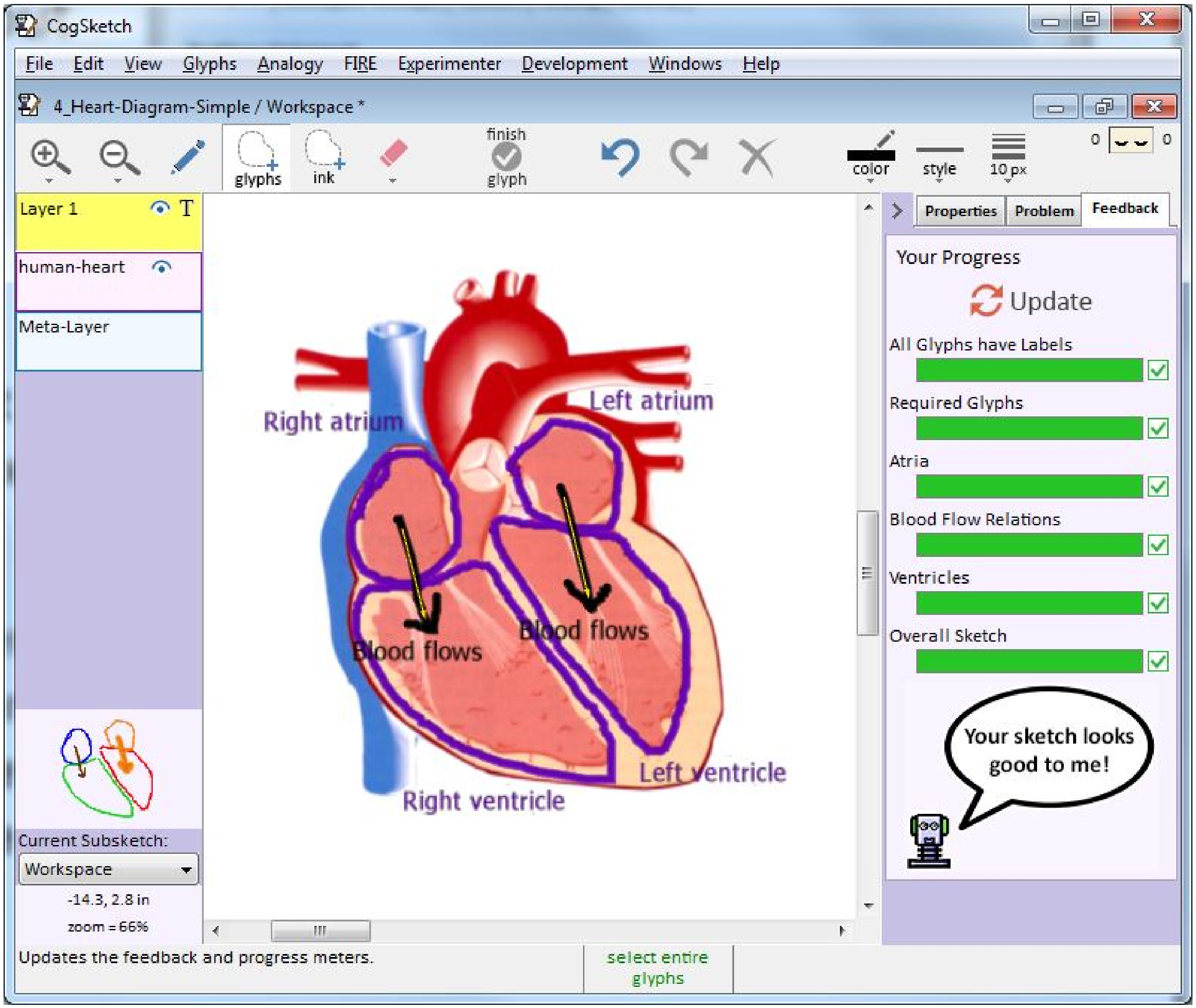
Worksheet Example – Blood flow arrows



Worksheet Example – Blood flow arrows

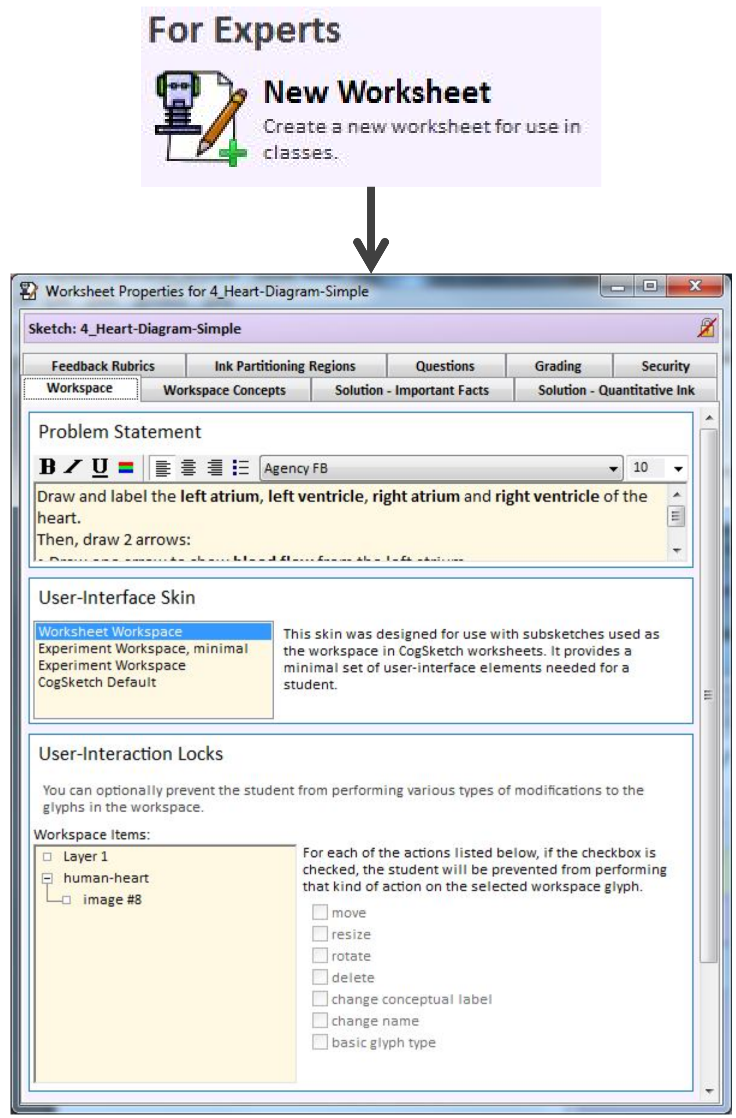


Worksheet Example – Completed



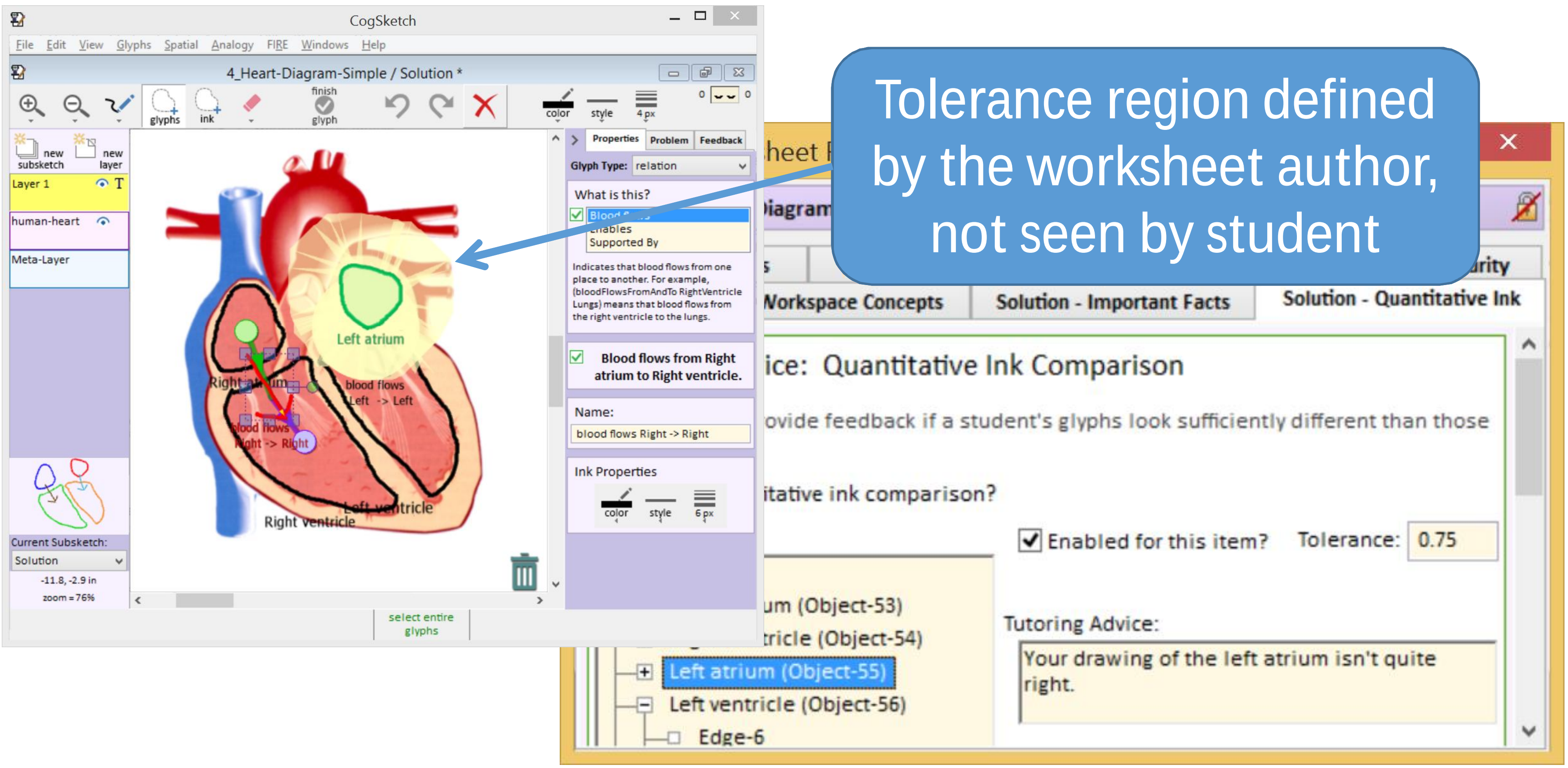
How to Create a Worksheet from Scratch

- Authoring environment for setting up worksheet properties
  - Problem statement, relevant concepts, skin
  - Solution Sketch
  - Correctness Criteria & Feedback
    - Quantitative ink constraints
    - Important qualitative spatial and conceptual facts
  - Grading
  - Password protection



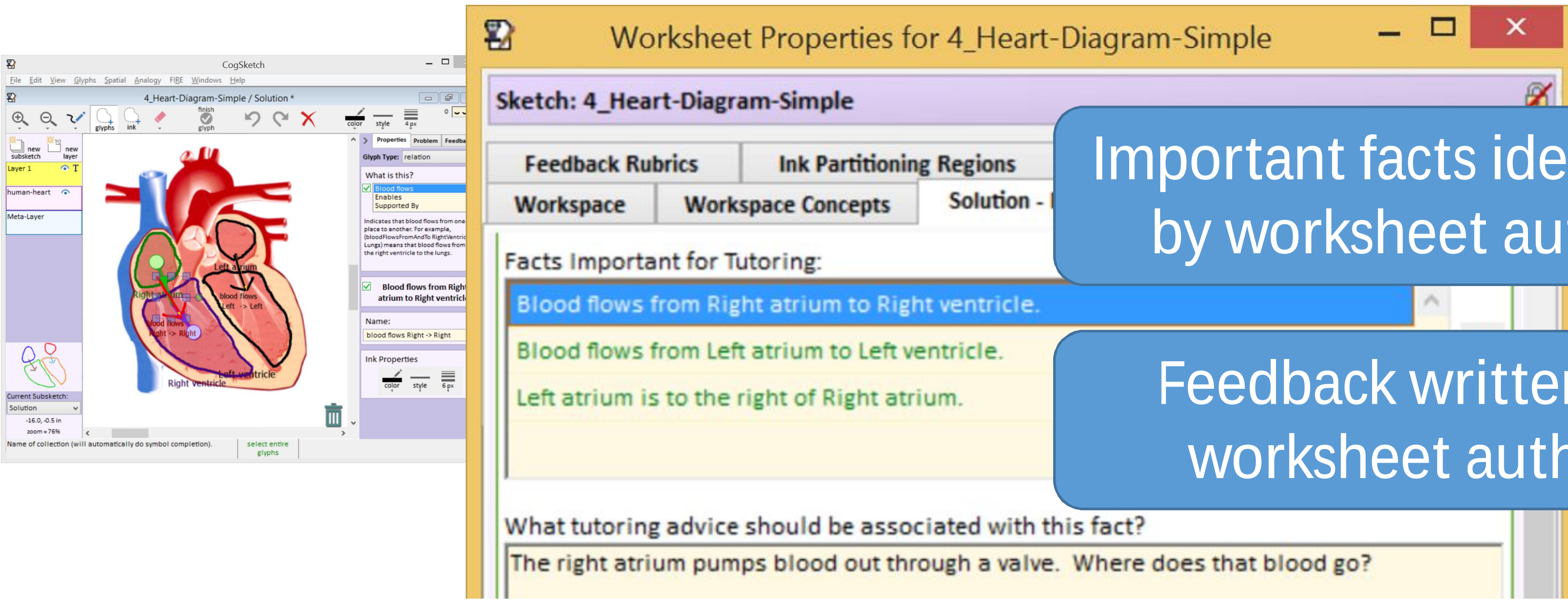
Quantitative Ink Differences

Rough overlap between student glyph(s) and teacher glyph(s), for when absolute location matters



Qualitative Spatial and Conceptual Differences

Sketch facts automatically generated by CogSketch, browsed by worksheet author



Important facts identified by worksheet author

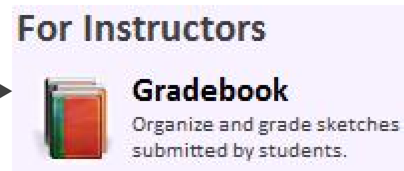
Feedback written by worksheet author

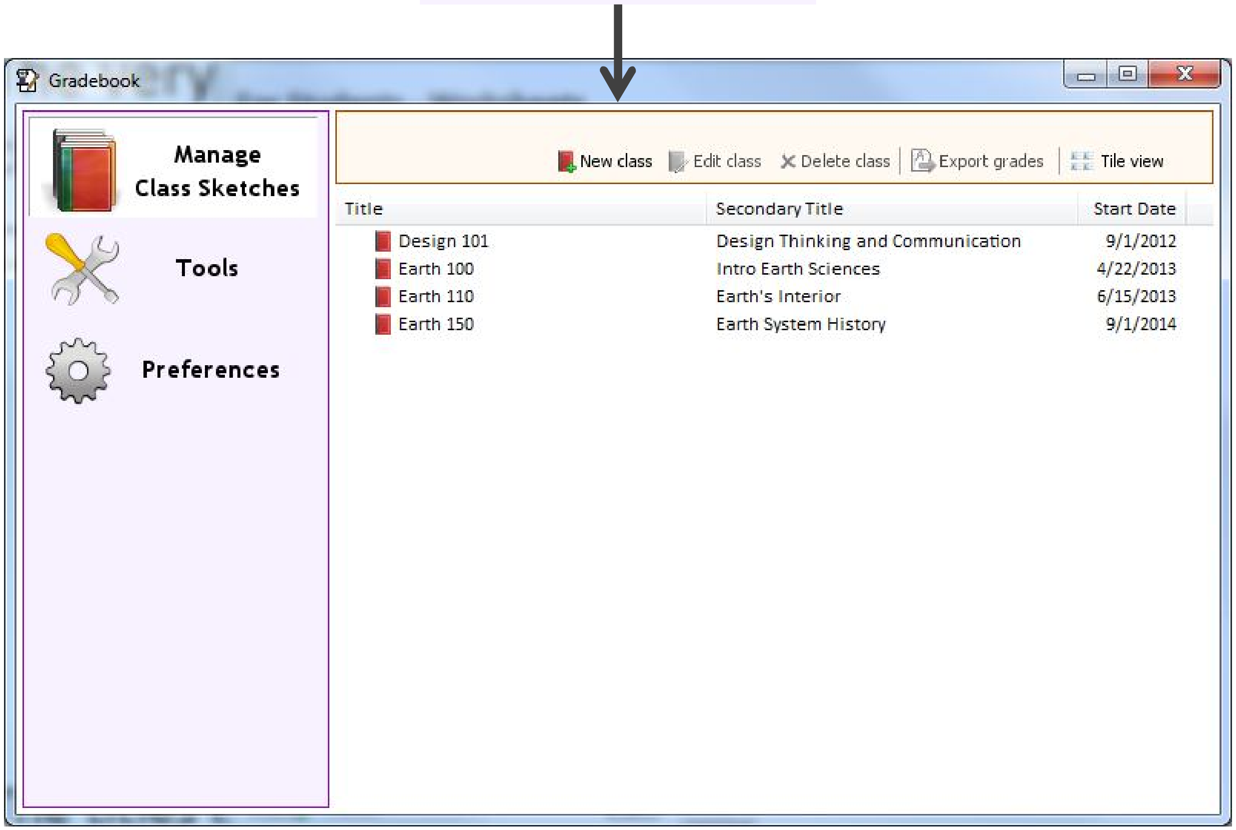
Important facts that are missing or different in student sketch trigger feedback

Gradebook

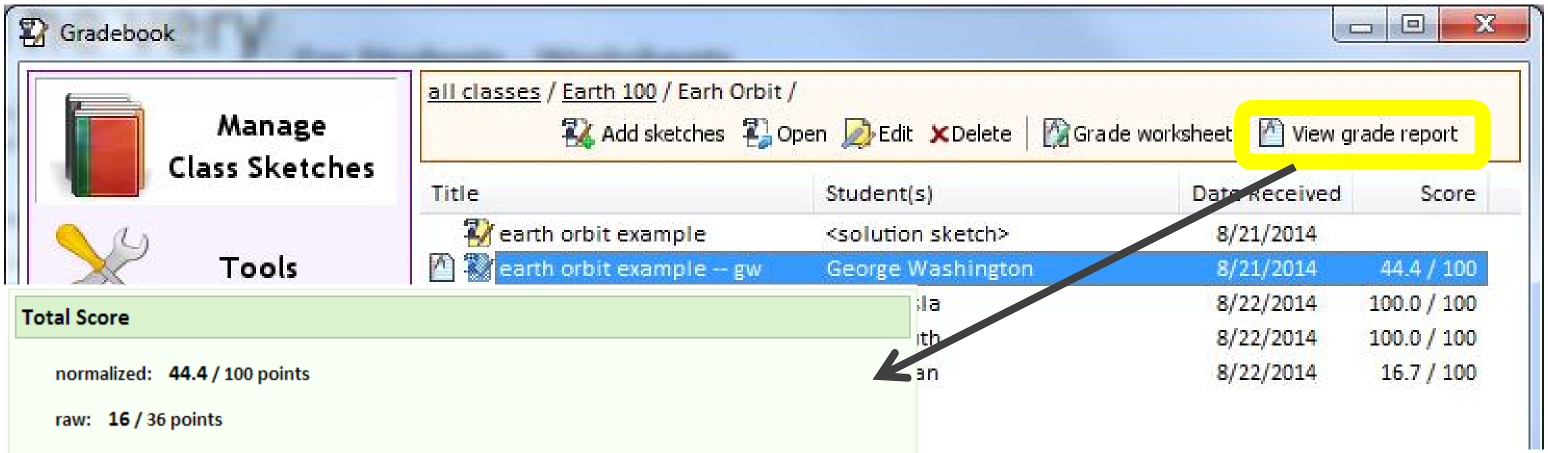
- Tool for organizing and grading sketches submitted by students.

From start screen





Gradebook: grade reports



Total Score

normalized: **44.4 / 100 points**

raw: **16 / 36 points**

Scoring Details

Missing Glyphs

For each of the glyphs listed below, points are awarded if the student has included the glyph in their sketch.

Student Score: 10 / 10 points

- [5 points] Orbit
- [5 points] Sun

Scoring details, including what advice would be given to the student's final sketch

Non-Quantitative Facts Important for Tutoring

The following are the facts marked as important for tutoring that don't mention quantitative values. Points are awarded if the tutor doesn't find anything wrong with the corresponding facts in the student's sketch.

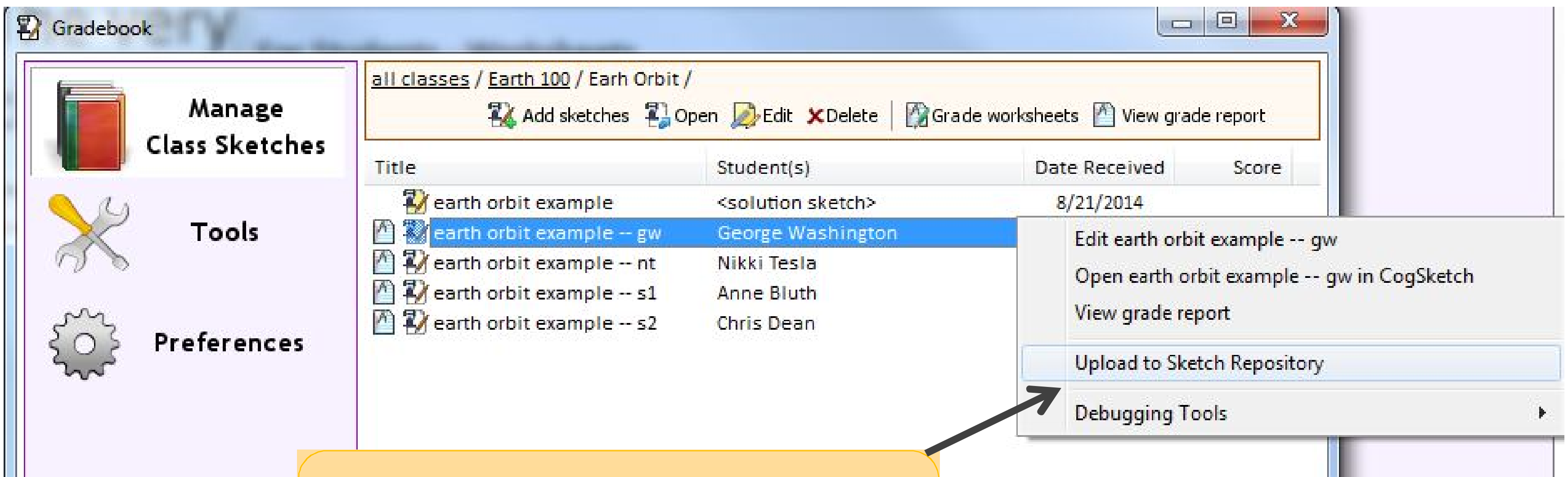
Student Score: 0 / 20 points

- [0 points]

  Correct Answer would be:
  ```
  (objectContains "Orbit" "Sun")
  ```
  Student had the following similar facts:
  ```
  (objectContains "orbit" "my home")
  ```
  Tutor Says: Shouldn't the Earth orbit around the Sun?

Sending Sketches to the CogSketch Team

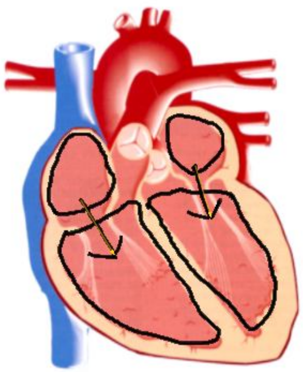
- Sketches **anonymized on-site** to protect privacy
- Anonymized sketches can be used for
  - Cognitive science experiments/analyses
  - Helping us to improve the software and user experience



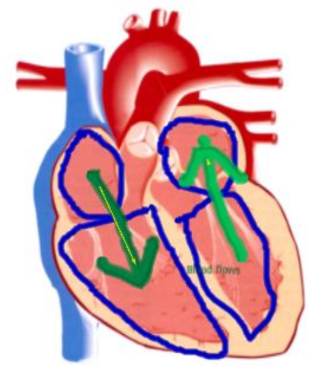
Right-click on a sketch to anonymously send it back to us

Sketch Worksheets:
domain-general, model-based tutoring
(Yin et al. 2010)

Teacher's Solution



Student's Solution



Structure-Mapping Engine

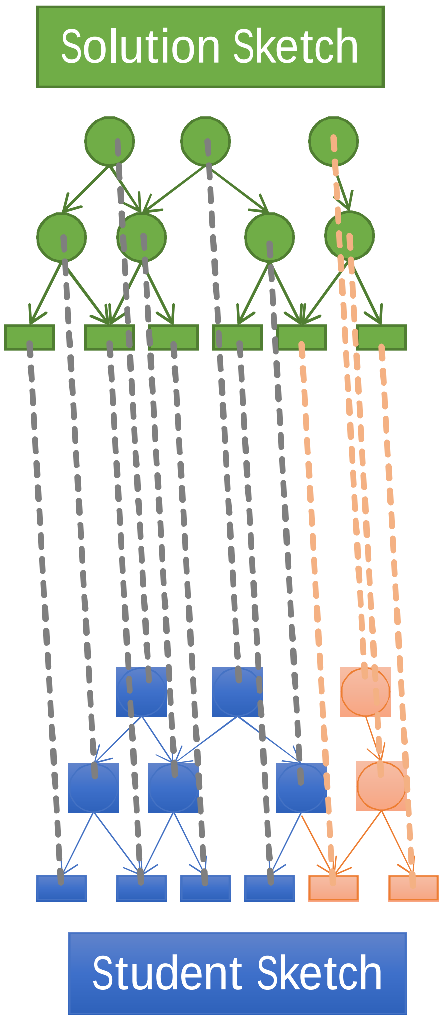
Differences between sketches +
Pre-determined correctness criteria

Feedback to Student:
"The left atrium pumps blood out through a valve. Where does that blood go?"

How does the comparison, feedback generation work?

Structure Mapping Engine (SME)

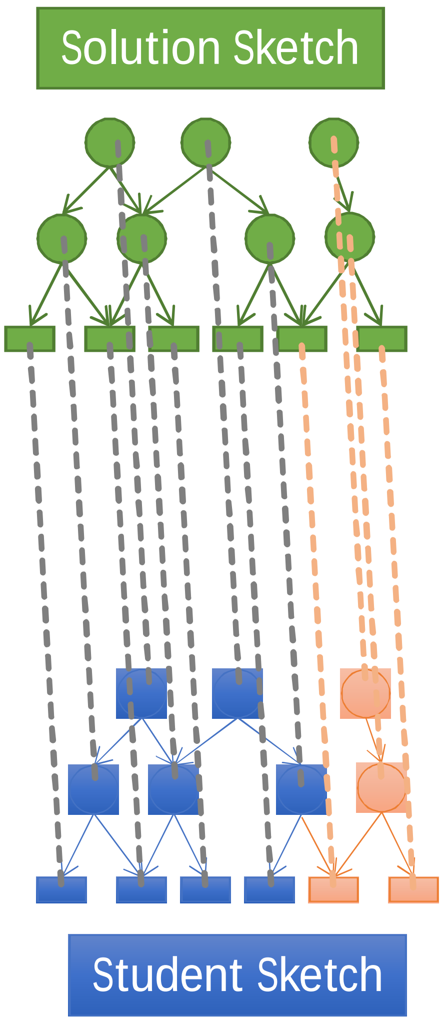
(Falkenhainer et al. 1989; Forbus et al. 1994)

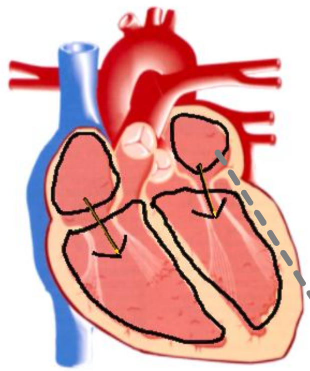


- Takes two structured descriptions (base, target)
- Produces one or more mappings:
  - Correspondences, e.g. student's right atrium corresponds to teacher's right atrium
  - Candidate inferences, e.g. an important fact in the solution is missing from the student's sketch
- Enables feedback for
  - Quantitative ink differences
  - Qualitative spatial or conceptual differences

Structure Mapping Engine (SME)

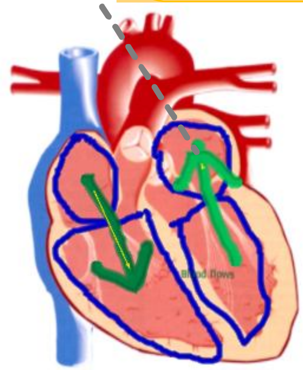
(Falkenhainer et al. 1989; Forbus et al. 1994)





For a given student glyph, does absolute location matter?

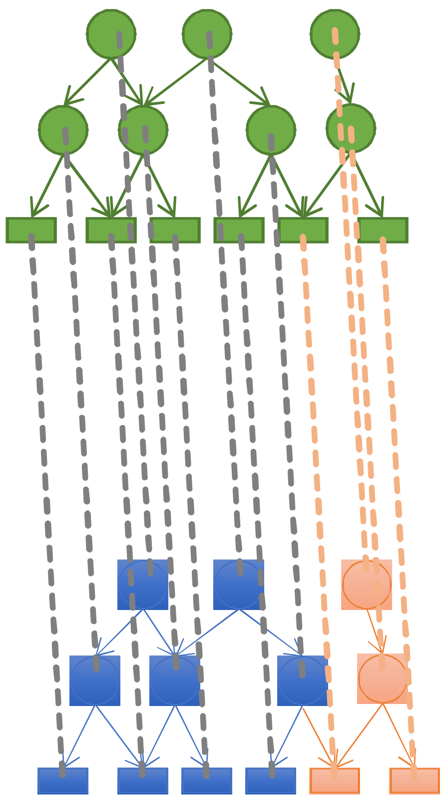
SME correspondence indicates the corresponding solution glyph and the corresponding tolerance region



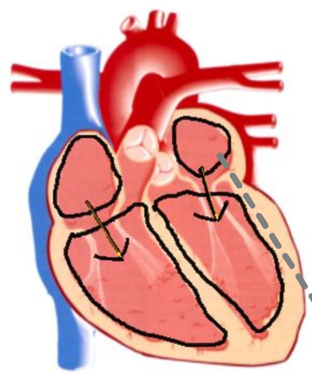
Structure Mapping Engine (SME)

(Falkenhainer et al. 1989; Forbus et al. 1994)

Solution Sketch



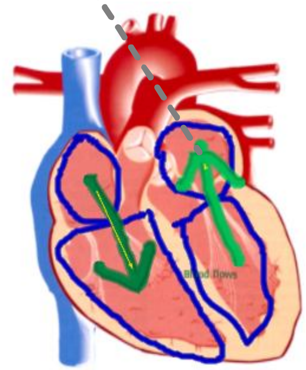
Student Sketch



Are there any important qualitative differences?

Important fact:
Blood flows
from *left atrium*
to *left ventricle*

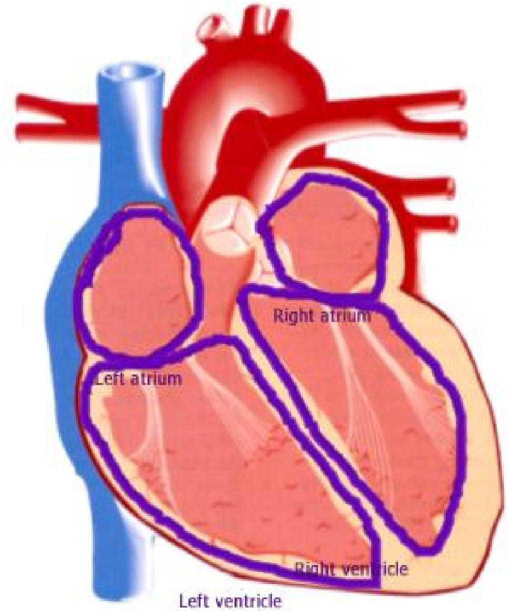
SME candidate inference indicates an important difference



Important fact:
Blood flows
from *~~left ventricle~~*
to *~~left atrium~~*

Match Constraints

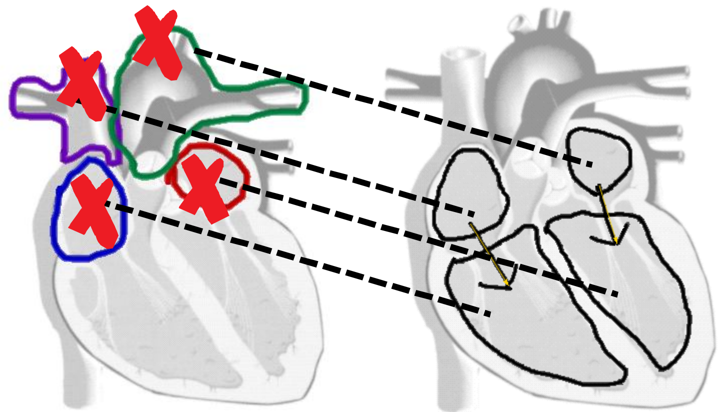
- *Partition constraints*
  - If two entities correspond to each other, they must have identical attributes
  - Prevents matches suggested by spatial arrangement, but incorrect because of labels
- *Quantitative ink constraints*
  - When multiple matches are possible, favor ones that satisfy quantitative ink constraints

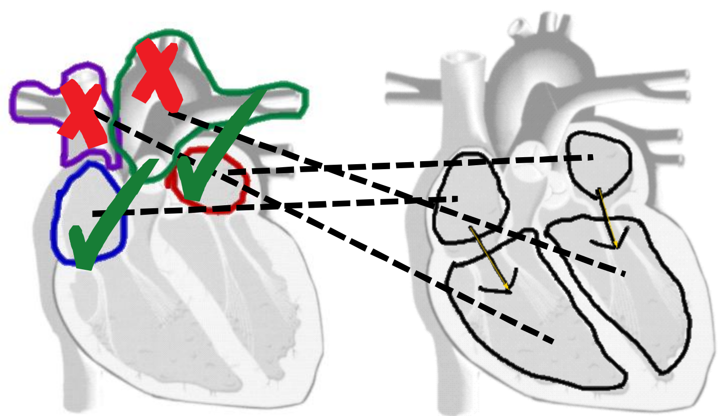


Visually, this looks correct, but what if the student has left and right mixed up?
Labels matter!

Match Constraints

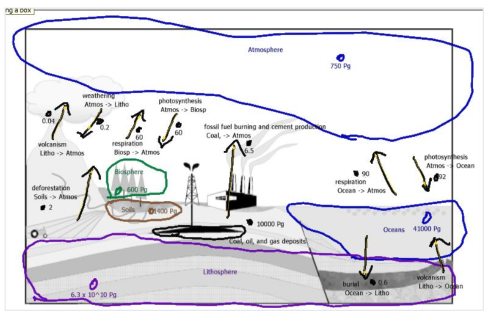
- *Partition constraints*
  - If two entities correspond to each other, they must have identical attributes
  - Prevents matches suggested by spatial arrangement, but incorrect because of labels
- *Quantitative ink constraints*
  - When multiple matches are possible, favor ones that satisfy quantitative ink constraints

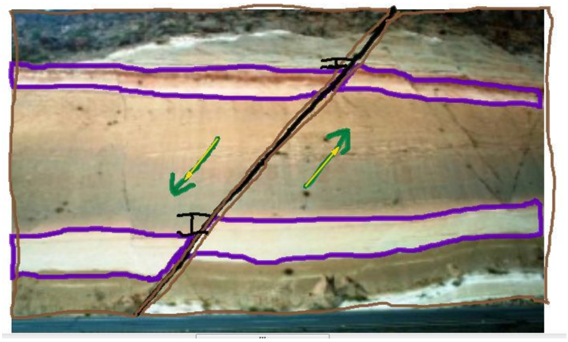


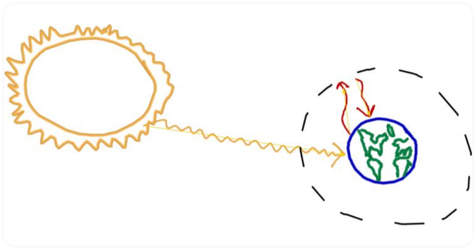


Worksheet Pilot Studies

- Objectives
  - Gather data needed to improve representations, algorithms, and user experience
  - Understand how to make worksheets practical in classrooms and for homework assignments







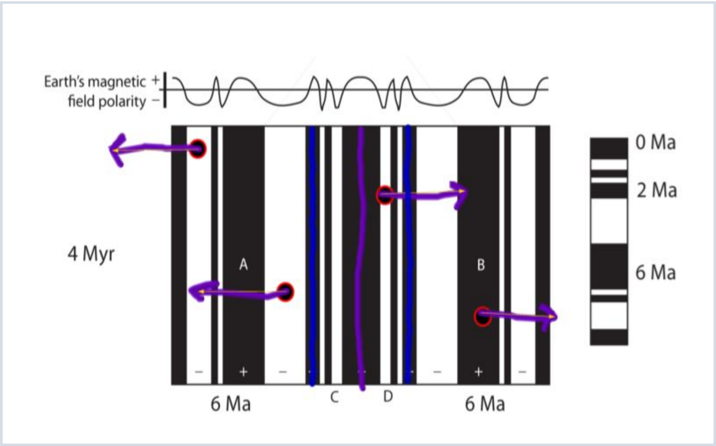
Northwestern University, Earth 201, Profs. Brad Sageman, Fall 2009

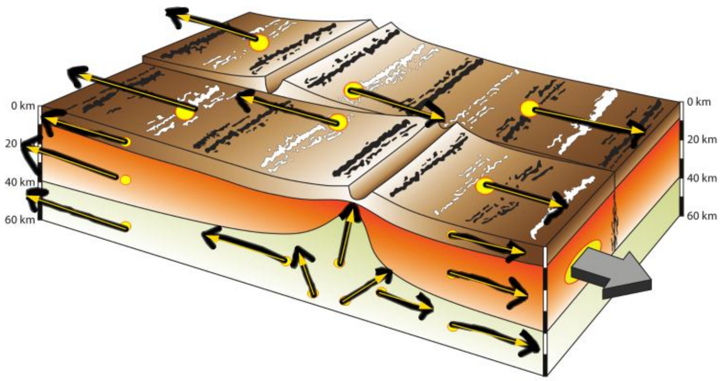
- Extra credit assignment: fault identification worksheets (3); 10 students
- Mandatory homework assignment: carbon cycle worksheet; 28 students

Northwestern University, Earth 201, Prof. Andrew Jacobson, Spring 2011

- Mandatory homework assignment: fault identification worksheets (3); 40 students
- Extra credit assignment: carbon cycle and greenhouse worksheets; 27 students

Worksheet Pilot Studies (cont'd)

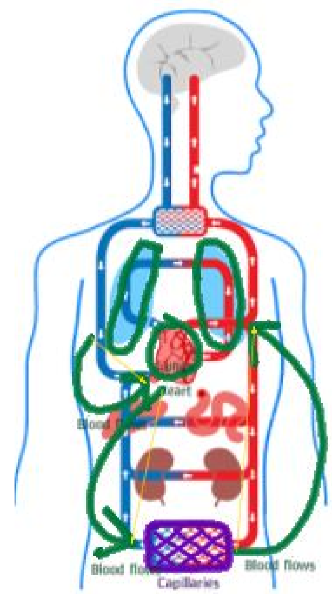




- Spring 2011, Carleton College, Geo 110
  - Four plate tectonics worksheets as part of in-class group activity
  - 1 hour lab section
  - 2-4 students per laptop
  - Students completed CogSketch tutorial and completed on average 2 worksheets per group in < 1 hour
  - Students had never seen/used CogSketch before

Worksheets in the Classroom – Evidence of Learning Gains

- Westampton Elementary School 5th graders, n = 50
- Four worksheets on circulatory system function, after lesson
  - Self-paced, 1 hour time limit
  - 70% of students completed all four
- Three measures of circulatory system understanding
  - Heart chamber identification (fill in the blanks on diagram)
  - Blood flow order (list order on diagram)
  - Flow of oxygen (multiple choice questions)



Significant learning gains on 2 out of 3 measures

*Collaborators: Brian Miller (Towson University), Jennifer Cromley (Temple University)

Worksheets in the Classroom – What did the 5th graders think?

CogSketch survey Likert-style scale-item responses

Question	*M*	*SD*
CogSketch was easy to learn by practicing with the person, cat, and dog.	5.06	1.42
I liked using CogSketch.	5.87	1.71
CogSketch is easy to use.	5.13	1.52
I would feel comfortable using a CogSketch for a class assignment.	5.65	1.89
CogSketch helped me learn about the circulatory system.	5.60	1.75

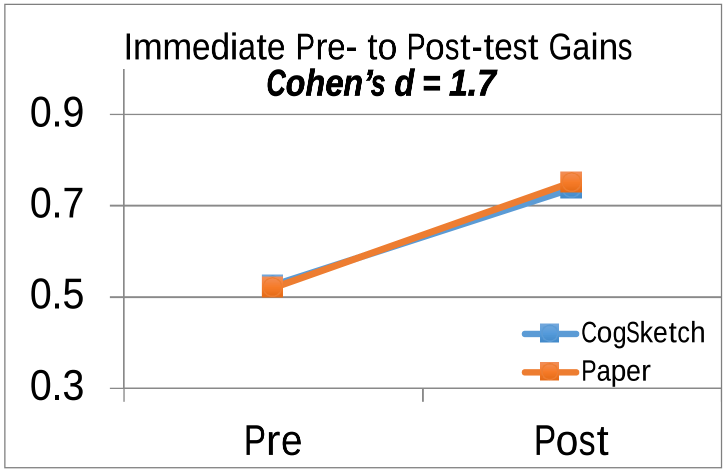
Note: all questions have a maximum score of 7

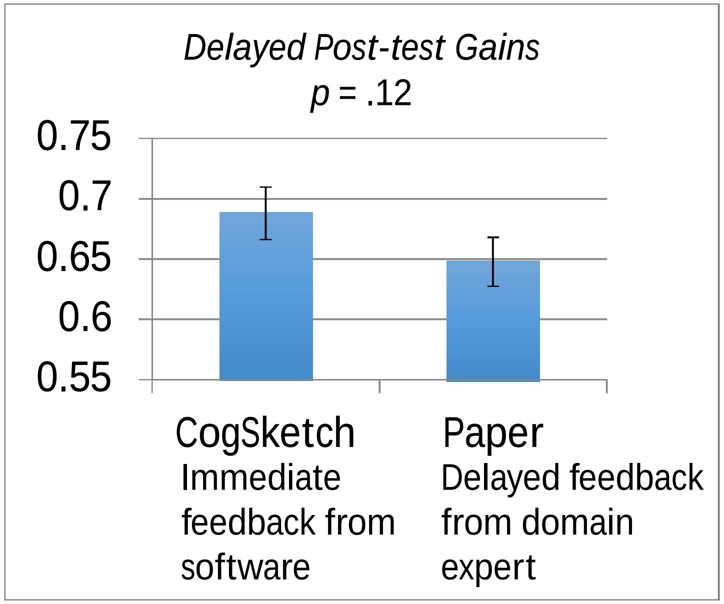
Worksheets in the Classroom – Undergraduate Geoscience at UW Madison

- Worksheets developed by domain expert: Bridget Garnier (geoscientist and instructor, *not a computer scientist*)
- Two groups
  - CogSketch group (n = 64) used CogSketch worksheets, received immediate, on-demand feedback from tutor
  - Paper group (n = 93) did identical exercises on paper, received detailed feedback from Bridget Garnier 1 week later
- Note: in real classrooms, students **do not** receive paper worksheets because they are too time consuming to grade!
- Pre-test prior to completing worksheet
- Immediate post-test after completing worksheet
- Delayed post-test (covering all 16 topics) at end of semester

Worksheets in the Classroom – Undergraduate Geoscience Results

- All students made large, significant learning gains from pre- to immediate post-test
  - 12/16 worksheets: no difference
  - 3/16 worksheets: CogSketch better than paper
  - 1/16 worksheets: paper better than CogSketch
- Further analyses needed to understand what makes some worksheets more/less effective than others
- Overall, **no significant difference** between CogSketch and paper on delayed-post tests
- Paper condition ≠ business as usual!



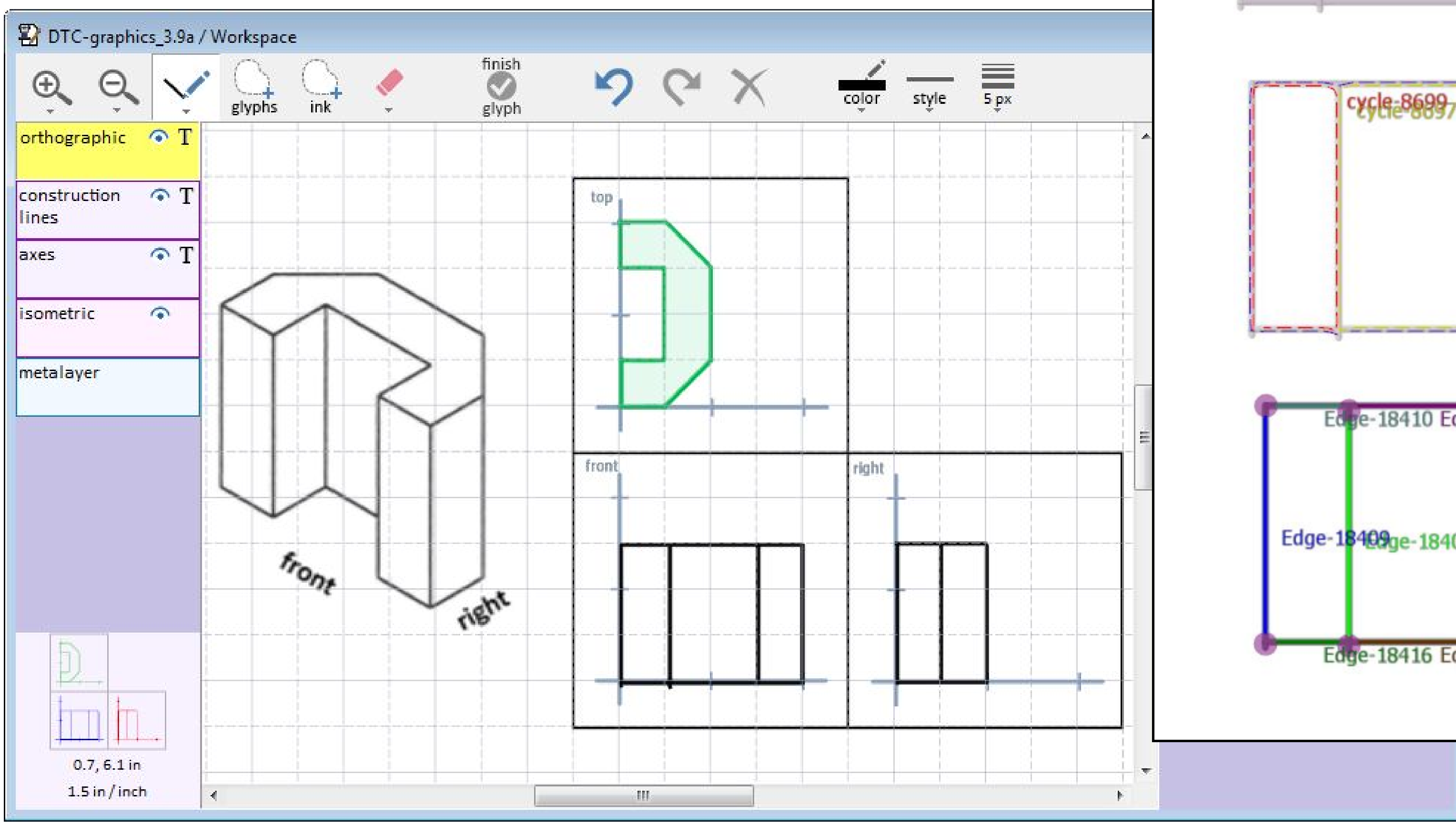


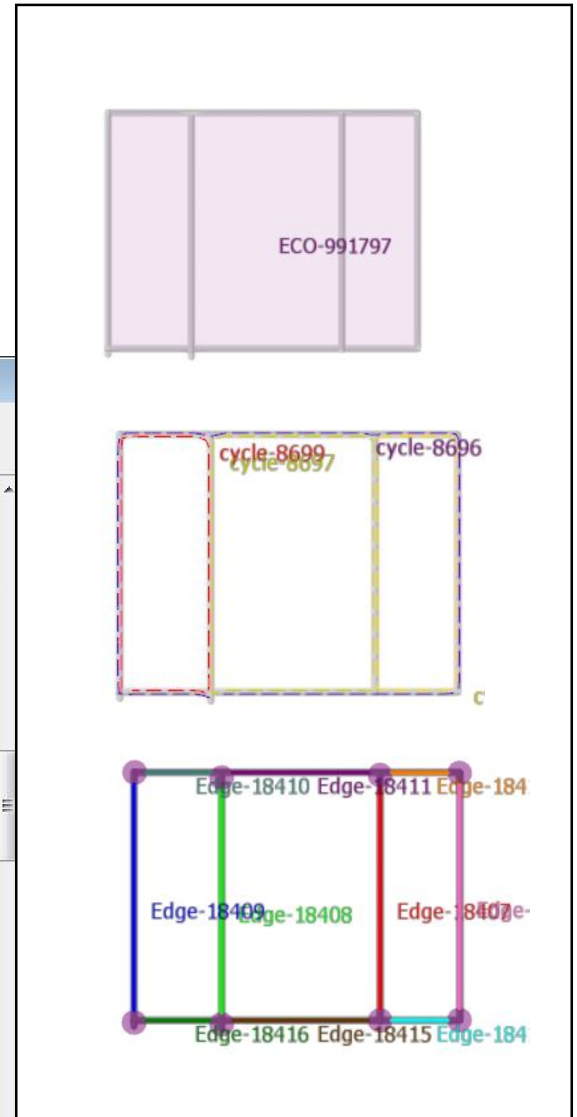
CogSketch potential:

Enabling instructors to give effective sketching assignments that are too impractical to implement on paper.

Design Thinking and Communication

Orthographic Projection Sketches



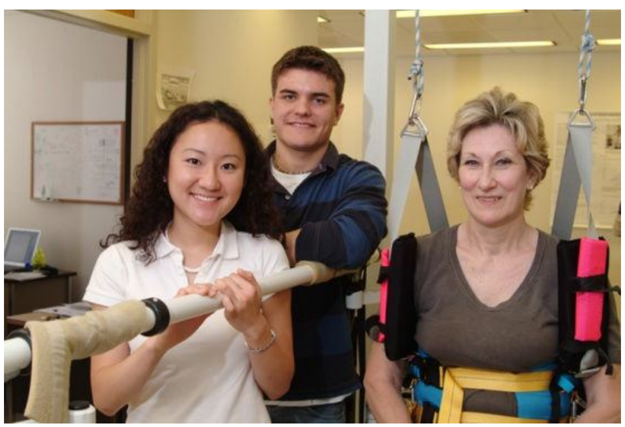


Worksheets: Technical Lessons

- Two types of spatial representations go a long way
  - Qualitative positional and topological relations
  - Quantitative ink constraints
- But, for things like orthographic projection, more detailed representations needed
- Tight constraints on analogical mapping are necessary, since the variance of student drawings is huge
- Lower entry-barriers to authoring key to scaling up

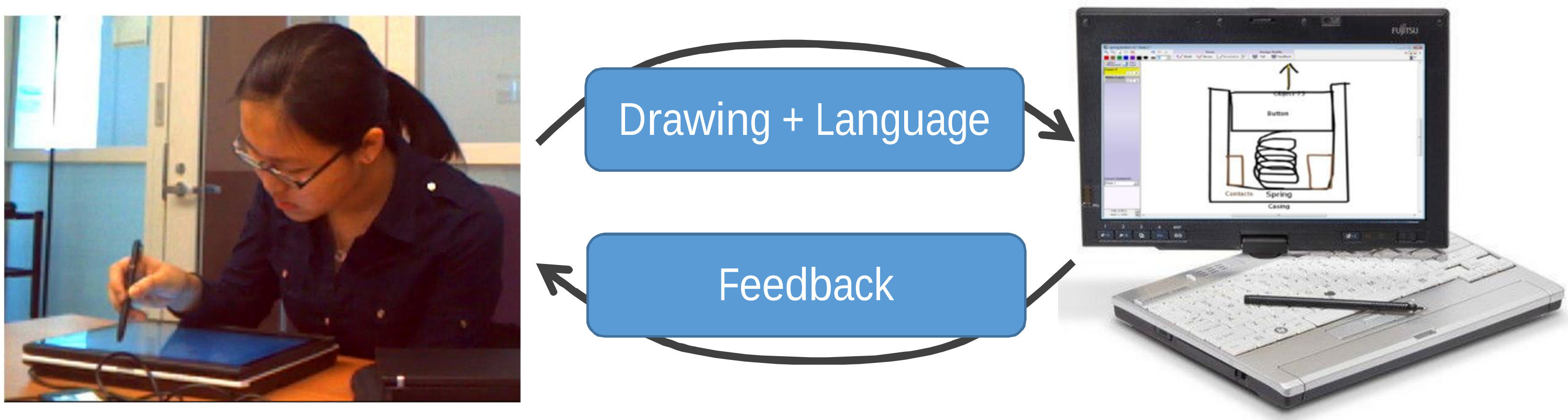
Design Coach: Setting and Problem

Design Thinking and communication course at Northwestern University



Problem: students have trouble using sketches to communicate

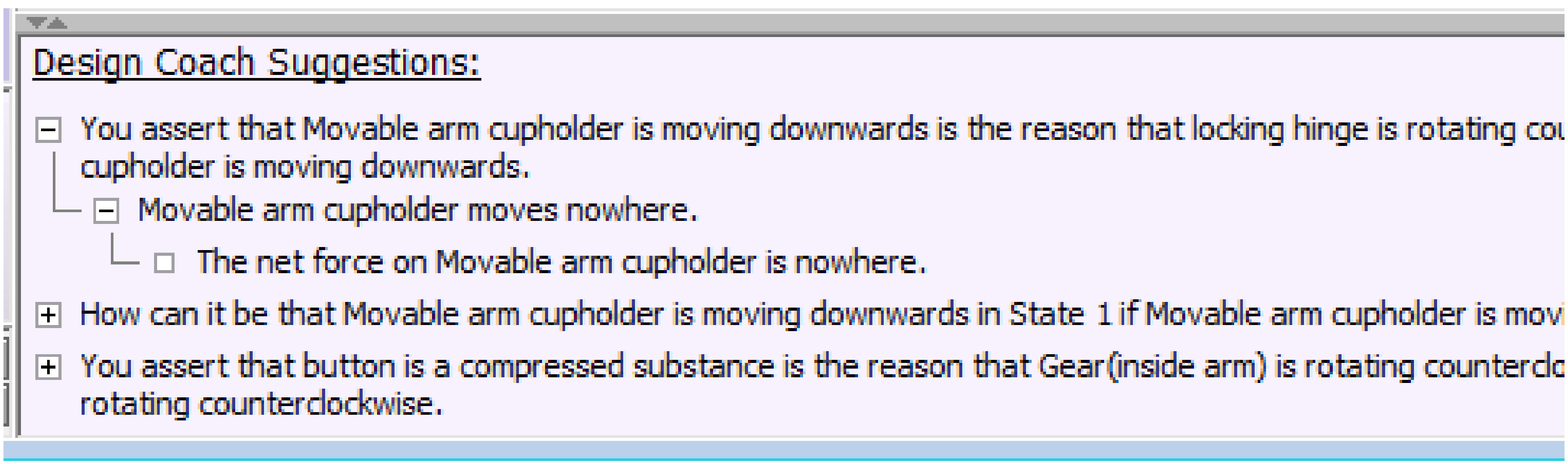
Design Coach: domain-specific, first principles-based tutoring



- For students to practice design explanation with sketching and language
  - Student supplements sketch with language-like input using restricted syntax templates
  - Qualitative reasoning allows coach to understand physical mechanisms, i.e. support forces, motion, springs, gears, pulleys, cords
  - Coach provides feedback when explanation is unclear
- Domain-specific (mechanics and design) knowledge enable more in-depth tutoring

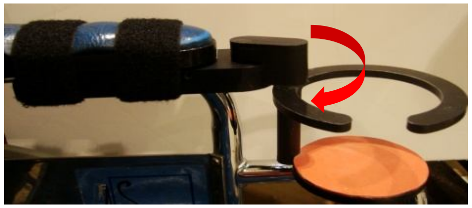
Giving Students Feedback

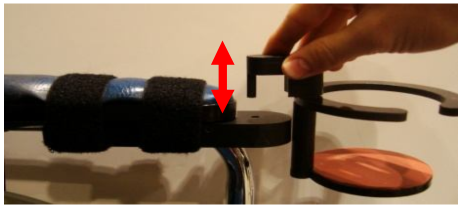
- Design Coach checks for
  1. Unexplained or impossible motions depicted in the sketch [Wetzel & Forbus, 2008]
  2. Unsupported or contradictory template-based sentences [Wetzel & Forbus, 2009]
  3. User input errors



Design Coach in the Lab and Classroom

- Design Coach activity
  - Design Thinking and Communication (DTC) students: Fall 2012, Winter 2013, and Fall 2013
  - Sketch and explain how a given device works
  - Devise a refinement and explain it to Design Coach
- Sketching Anxiety Survey
  - Based on math anxiety survey by Beilock et al. (2010)
  - Given pre- and post-activity
- Design Coach significantly reduced sketching anxiety in two out of three quarters

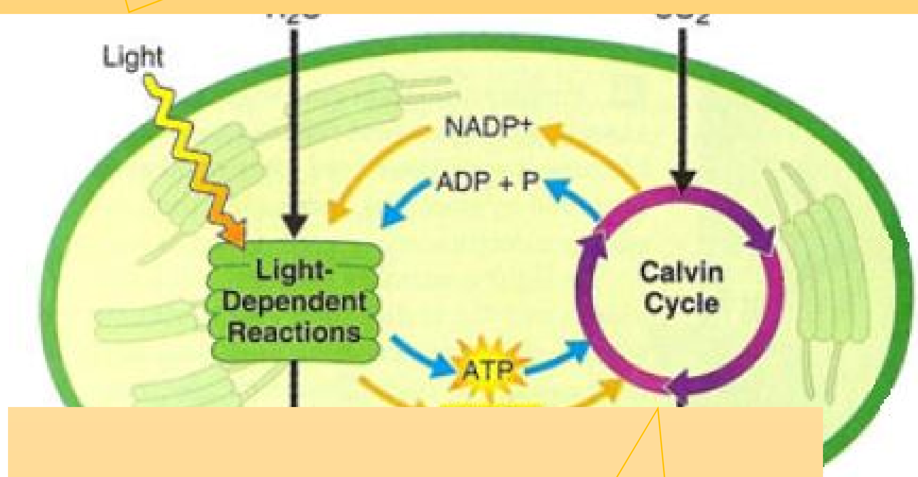




Sketching as an Assessment Tool (without immediate feedback)

- Simple tasks, e.g. copying, tracing can distinguish experts and novices
- Pilot study from Louis Gomez (UCLA) on copying biology process diagrams
  - 10 non-science majors
  - 10 pre-med students

Experts start at beginning of process

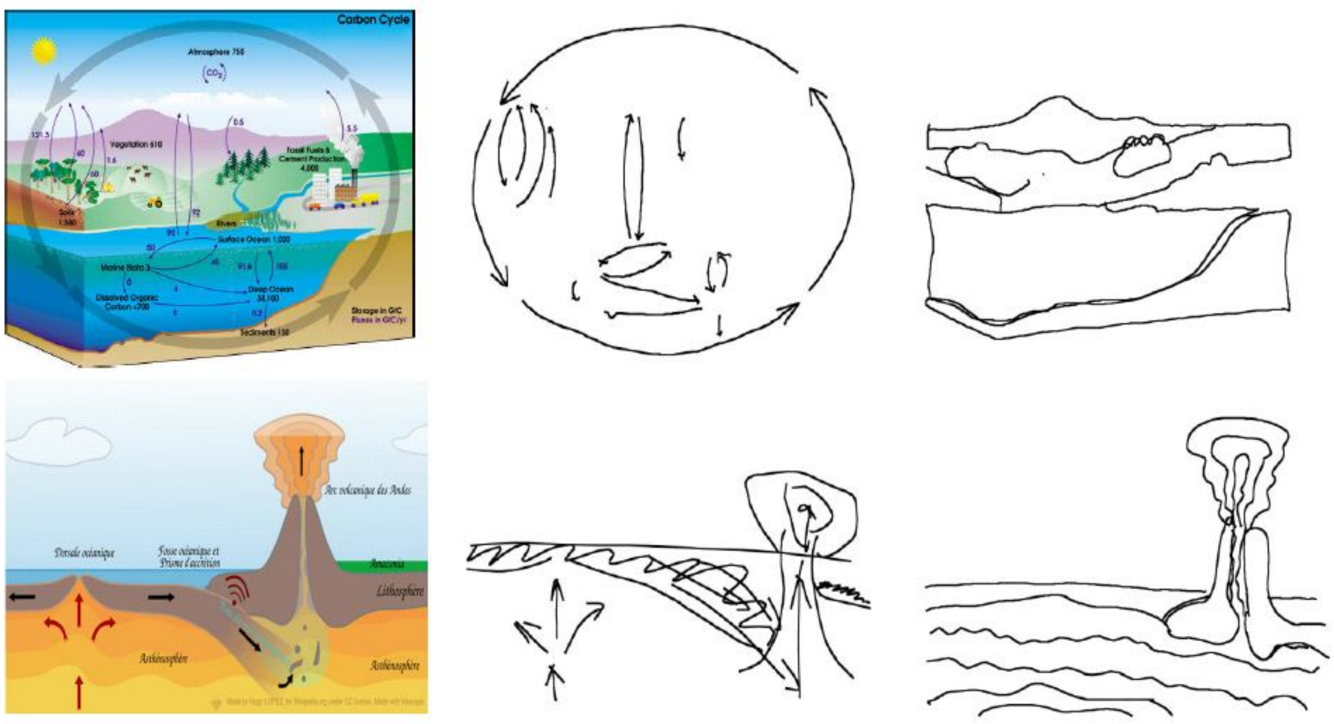


Novices start with visually salient features

Sketching as an Assessment Tool (without immediate feedback)

Jee et al. (2009): Geoscience undergrad/grad students include more relations compared to psychology undergrads

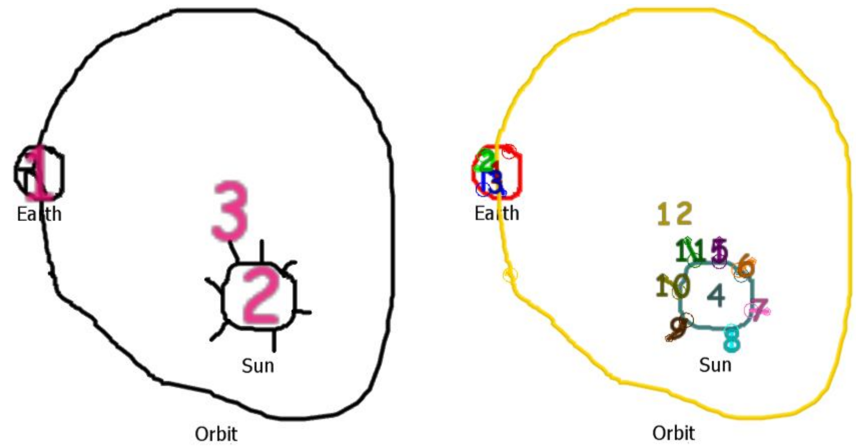
Geo Diagram | Geo Student sketch | Novice sketch

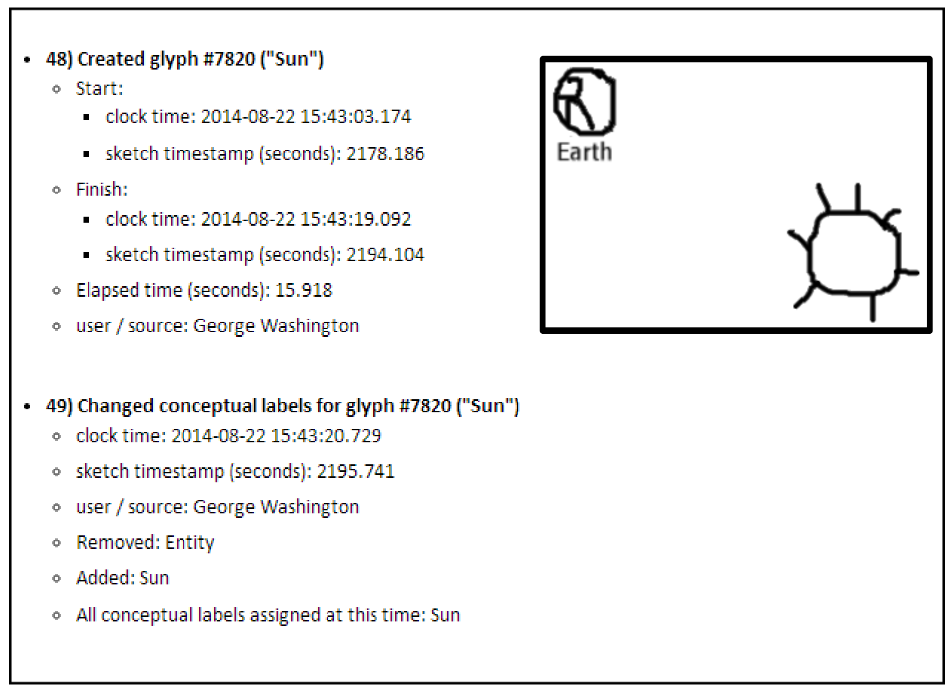


Other Analysis Tools

- Timing data
  - View glyph ordering
  - View ink stroke ordering
  - Sketch playback
- History data
  - Detailed history and ink data exported to comma separated values (*.csv) format
  - HTML reports detailing user actions with screenshots

Useful assessment data





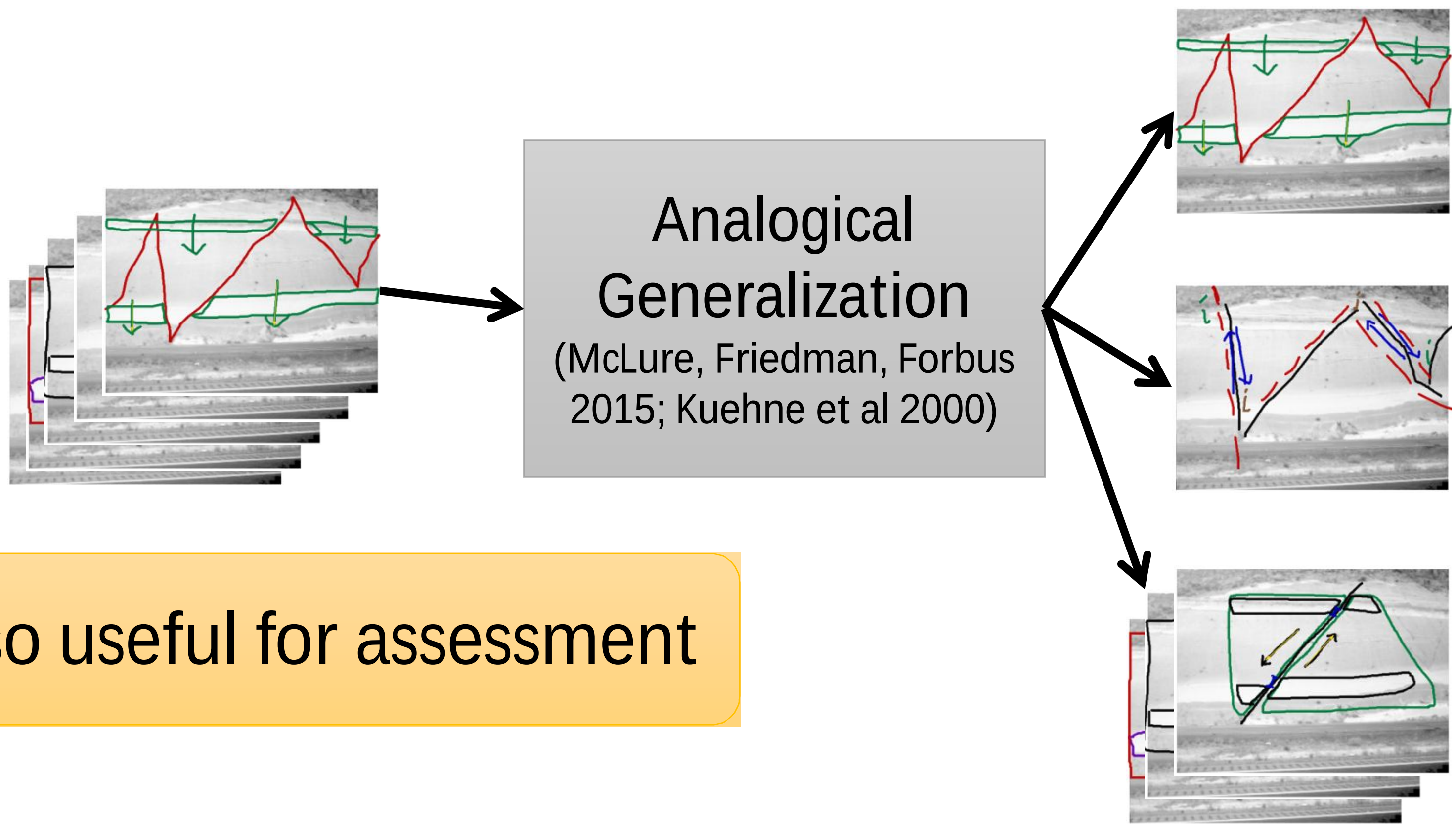
- 48) Created glyph #7820 ("Sun")
  - Start:
    - clock time: 2014-08-22 15:43:03.174
    - sketch timestamp (seconds): 2178.186
  - Finish:
    - clock time: 2014-08-22 15:43:19.092
    - sketch timestamp (seconds): 2194.104
  - Elapsed time (seconds): 15.918
  - user / source: George Washington

- 49) Changed conceptual labels for glyph #7820 ("Sun")
  - clock time: 2014-08-22 15:43:20.729
  - sketch timestamp (seconds): 2195.741
  - user / source: George Washington
  - Removed: Entity
  - Added: Sun
  - All conceptual labels assigned at this time: Sun

Analysis tools for the future

Sketch clustering for common answer patterns

(see Chang & Forbus 2014 *AI Magazine* for details)



Also useful for assessment

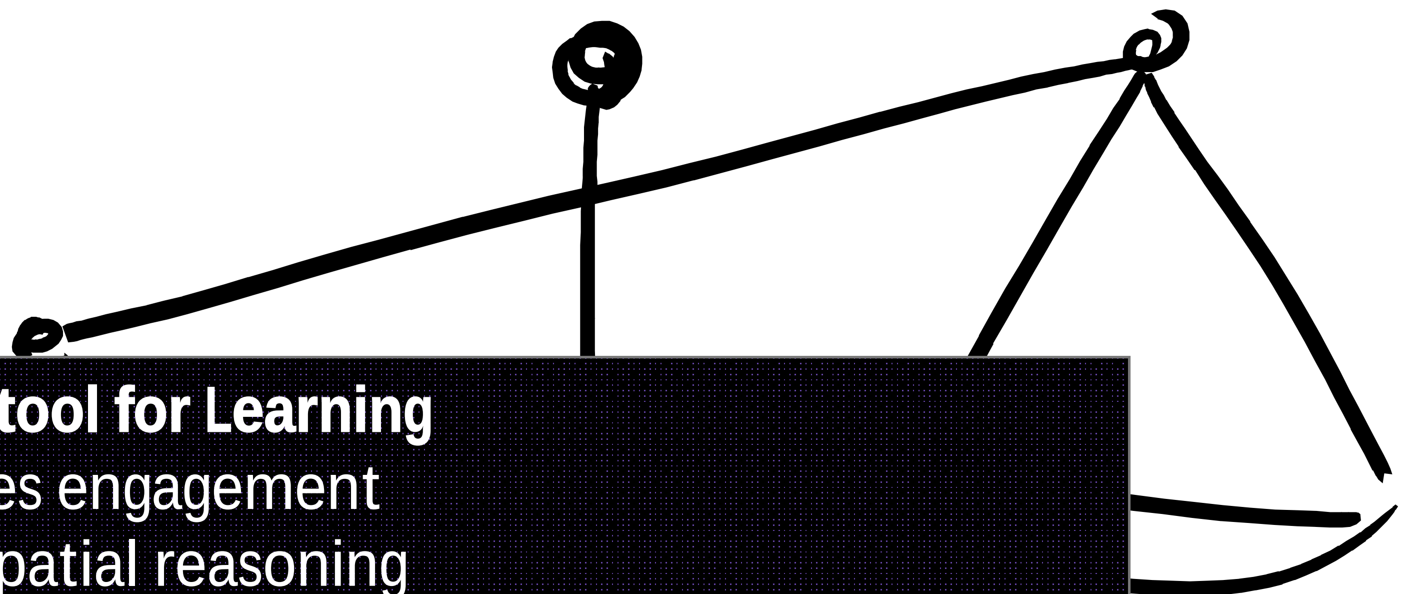
CogSketch and Education: Future Plans

- Further analyses of classroom data to determine best practices for developing worksheets and opportunities for improved tutoring
- Worksheet web exchange: online community for instructors to share worksheets
- Cloud-based version of CogSketch, potential for use on lightweight machines (e.g. Android devices, iPad)
- Continue to collaborate with domain experts and educators

Summary

- Worksheets are designed to help students learn spatial phenomena, especially layouts
  - In 5th grade science data, evidence of learning beyond that of regular instruction
  - In undergraduate geoscience data, just as good as paper with detailed delayed feedback
- Design Coach uses qualitative physical reasoning to help students with design explanations
  - Evidence that CogSketch can be combined with other AI techniques to provide sophisticated tutoring

Tip the scale!



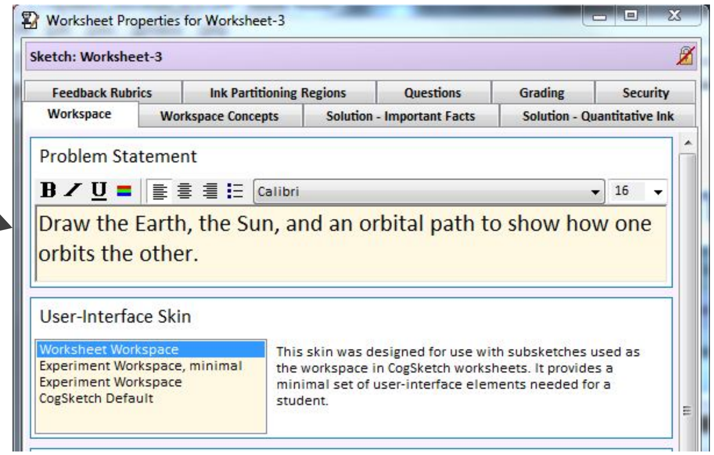
Powerful tool for Learning

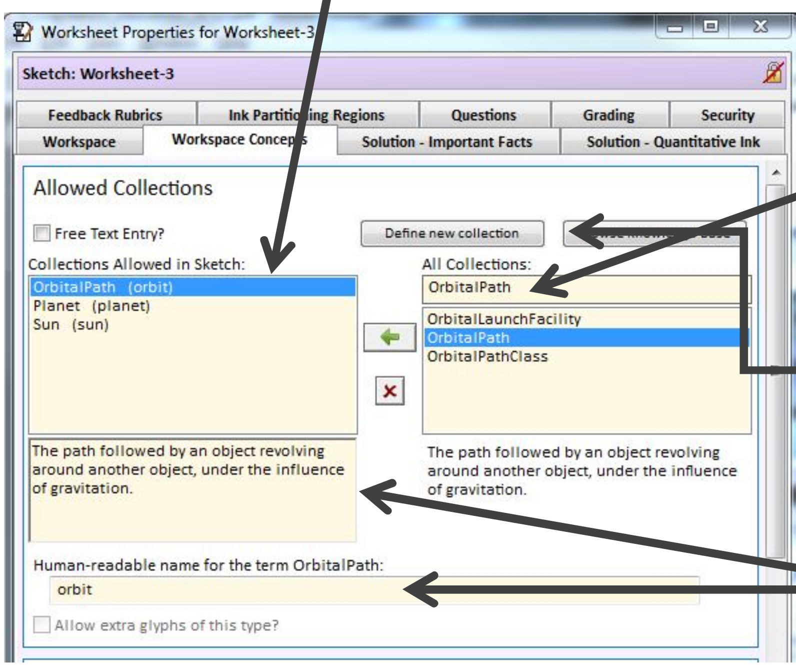
- Increases engagement
- Easier spatial reasoning
- Multi-modal reasoning
- **On-demand feedback from CogSketch**
- **Faster grading via CogSketch**
- **More sketching exercises for students learning about science**

Backup Slides

1. Set up the Workspace

- Problem statement, i.e. instructions for the student
- Workspace concepts, i.e. labels for student glyphs





Search the knowledge base for concepts and select the ones you want

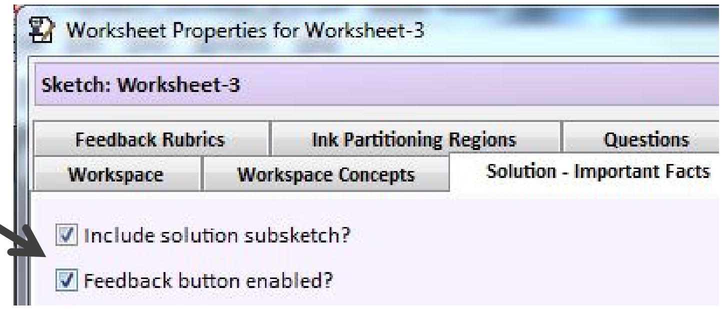
Don't see the concept you want? Define a new one for this worksheet.

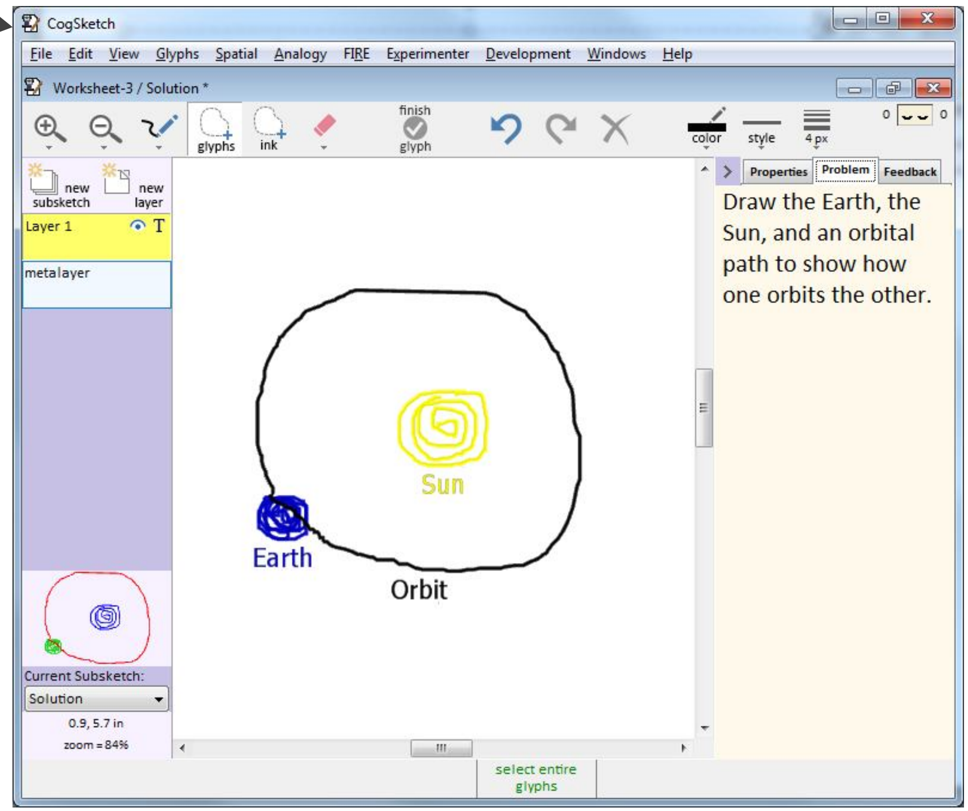
Define new collection

Edit name strings and descriptions, control over what the student sees

2. Draw Worksheet Solution

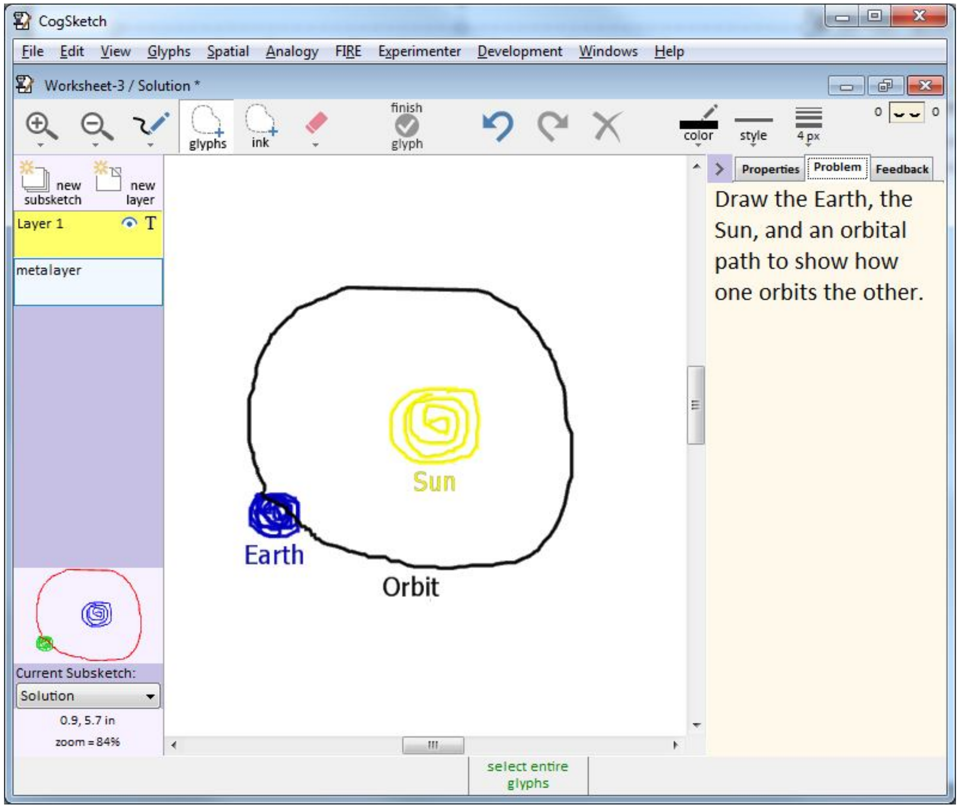
- Include solution sketch and feedback
- Draw and label solution into CogSketch
  - Draw the sun, label it *Sun*
  - Draw the Earth, label it *Planet*
  - Draw the Orbit, label it *Orbit*
  - Optional: change name strings, e.g. Planet → Earth





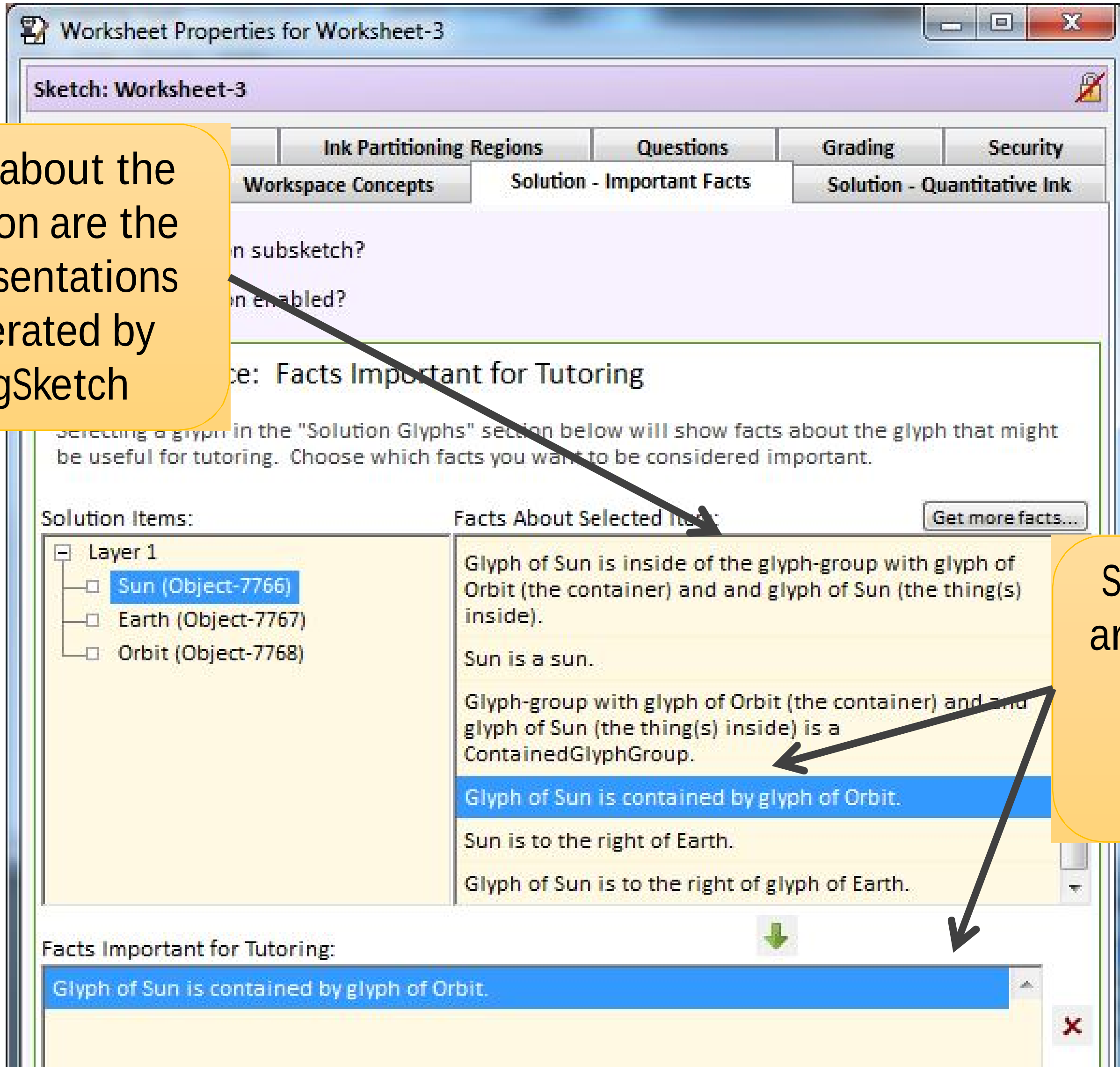
2. Draw Worksheet Solution

<Representations generated by cogsketch automatically>



3. Correctness Criteria & Feedback

Facts about the solution are the representations generated by CogSketch



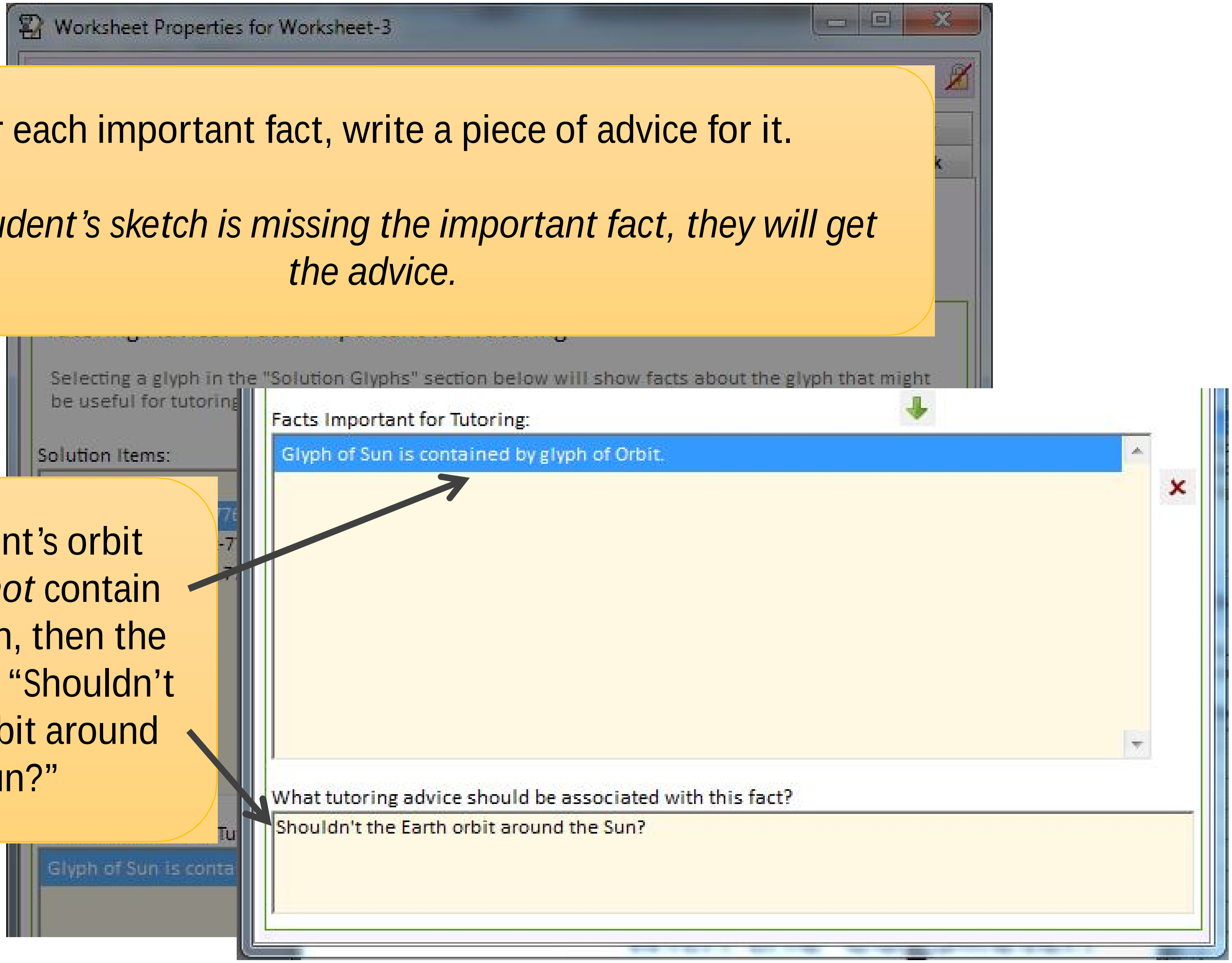
Select facts that are important for getting the worksheet correct

3. Correctness Criteria & Feedback

For each important fact, write a piece of advice for it.

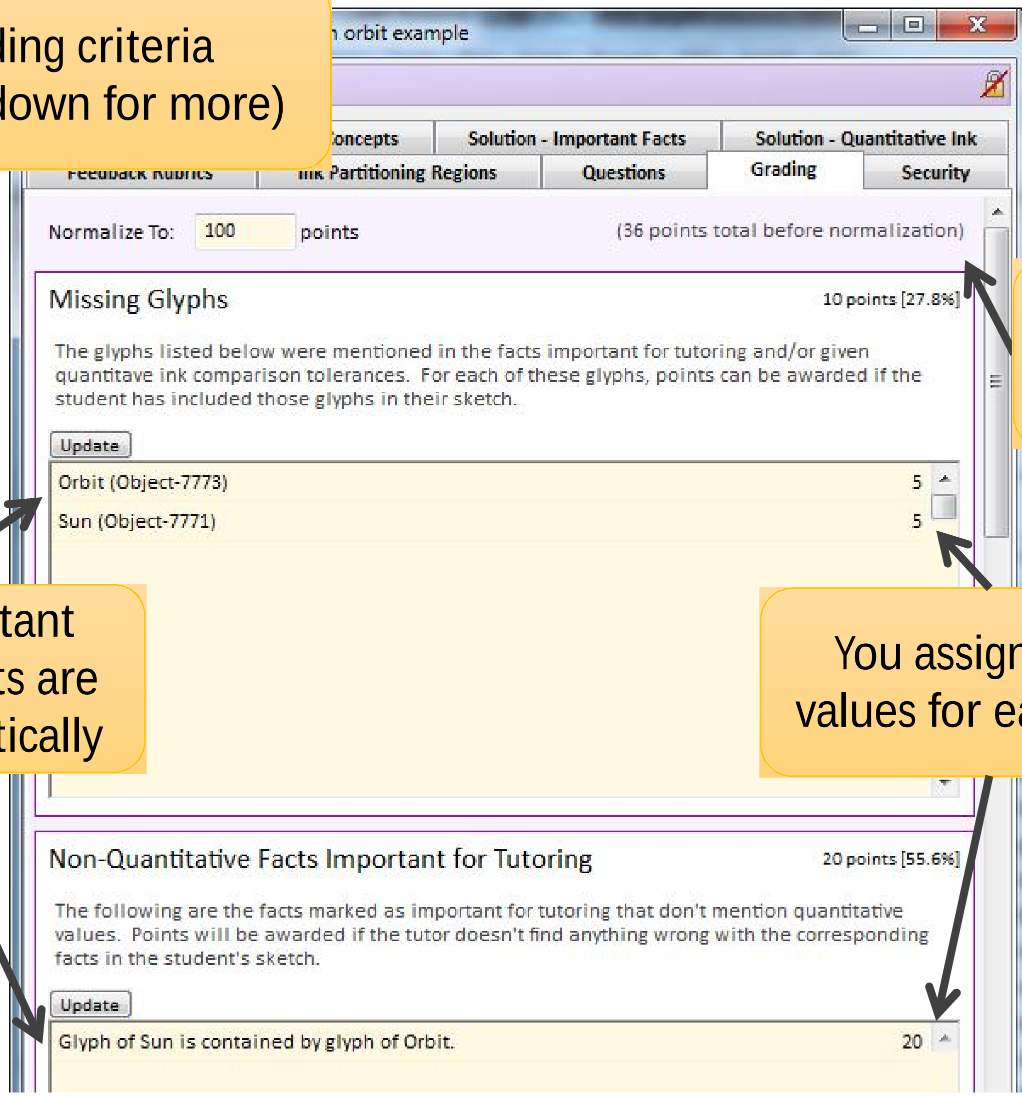
If the student's sketch is missing the important fact, they will get the advice.

If the student's orbit glyph does *not* contain the Sun glyph, then the tutor will say, "Shouldn't the Earth orbit around the Sun?"



4. Grading Rubrics

Multiple grading criteria available (scroll down for more)



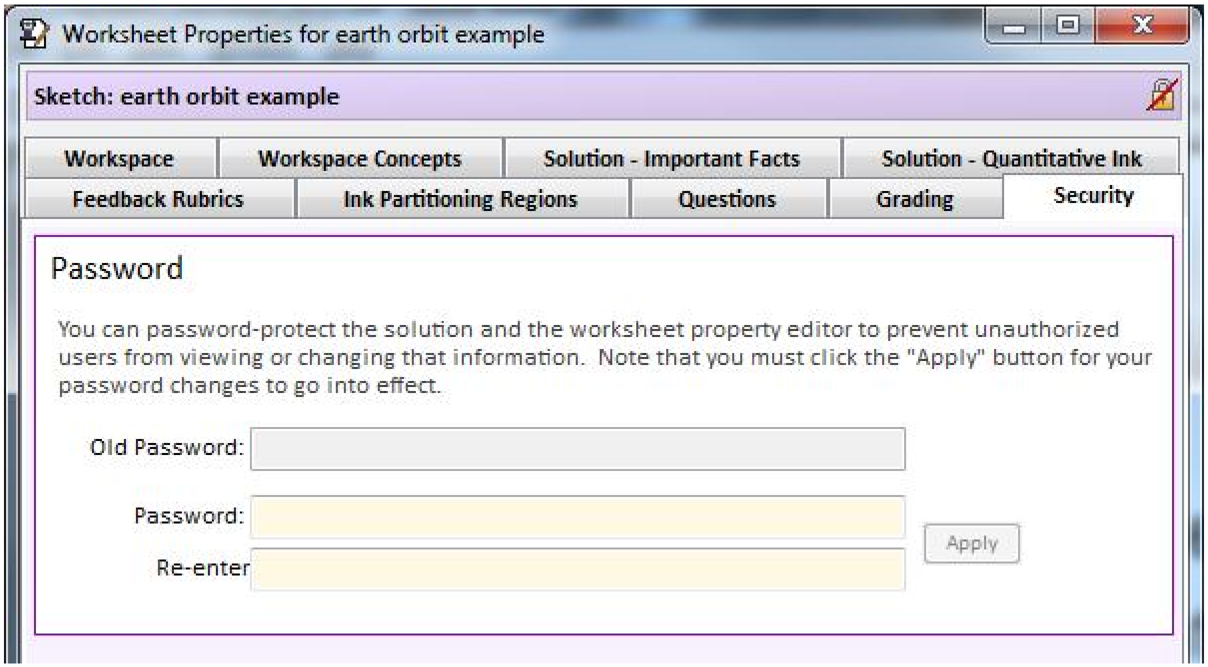
Points are normalized automatically

List of important items and facts are listed automatically

You assign point values for each item

5. Password

- Prevents students and/or research participants from viewing the solution

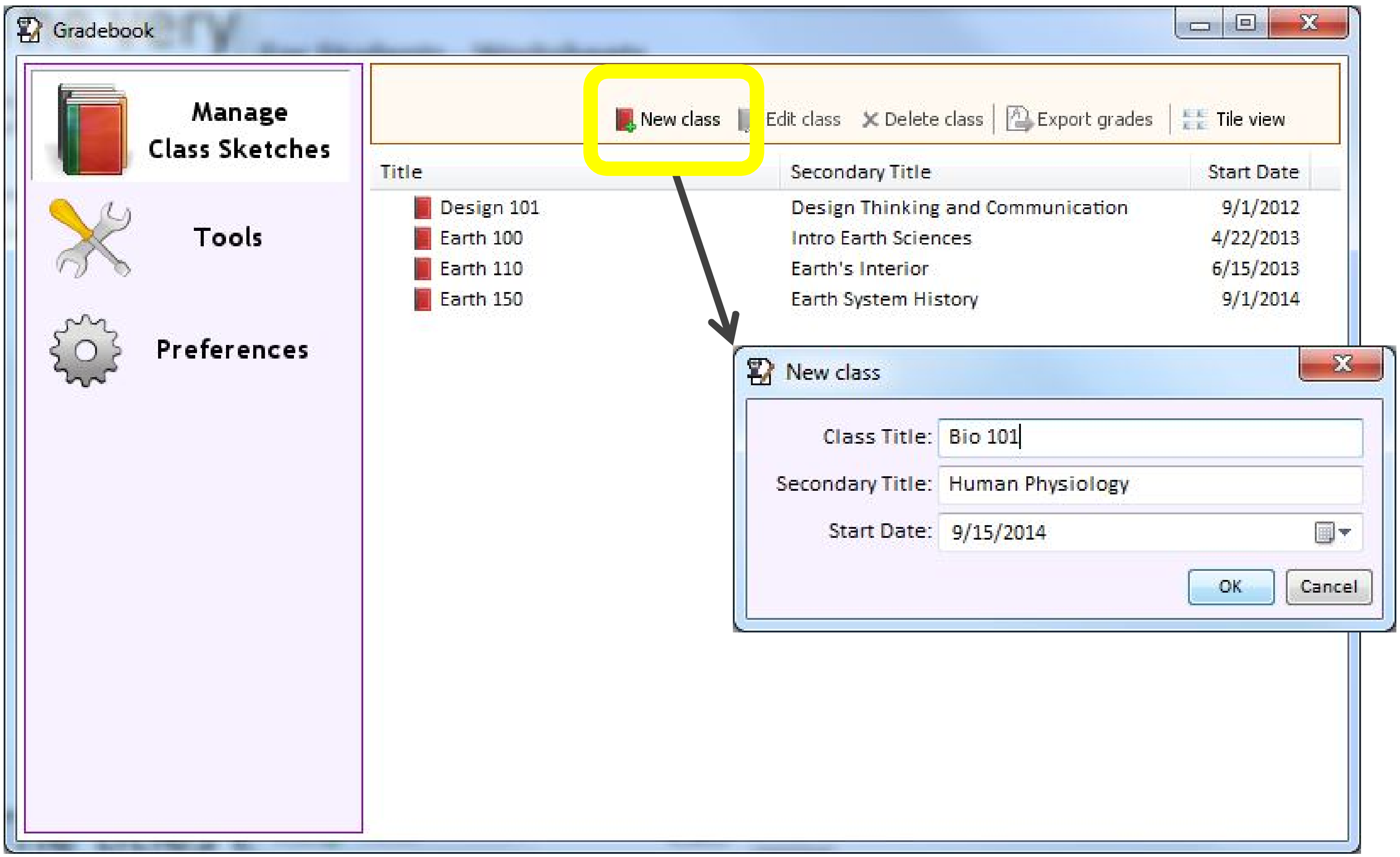


6. Testing

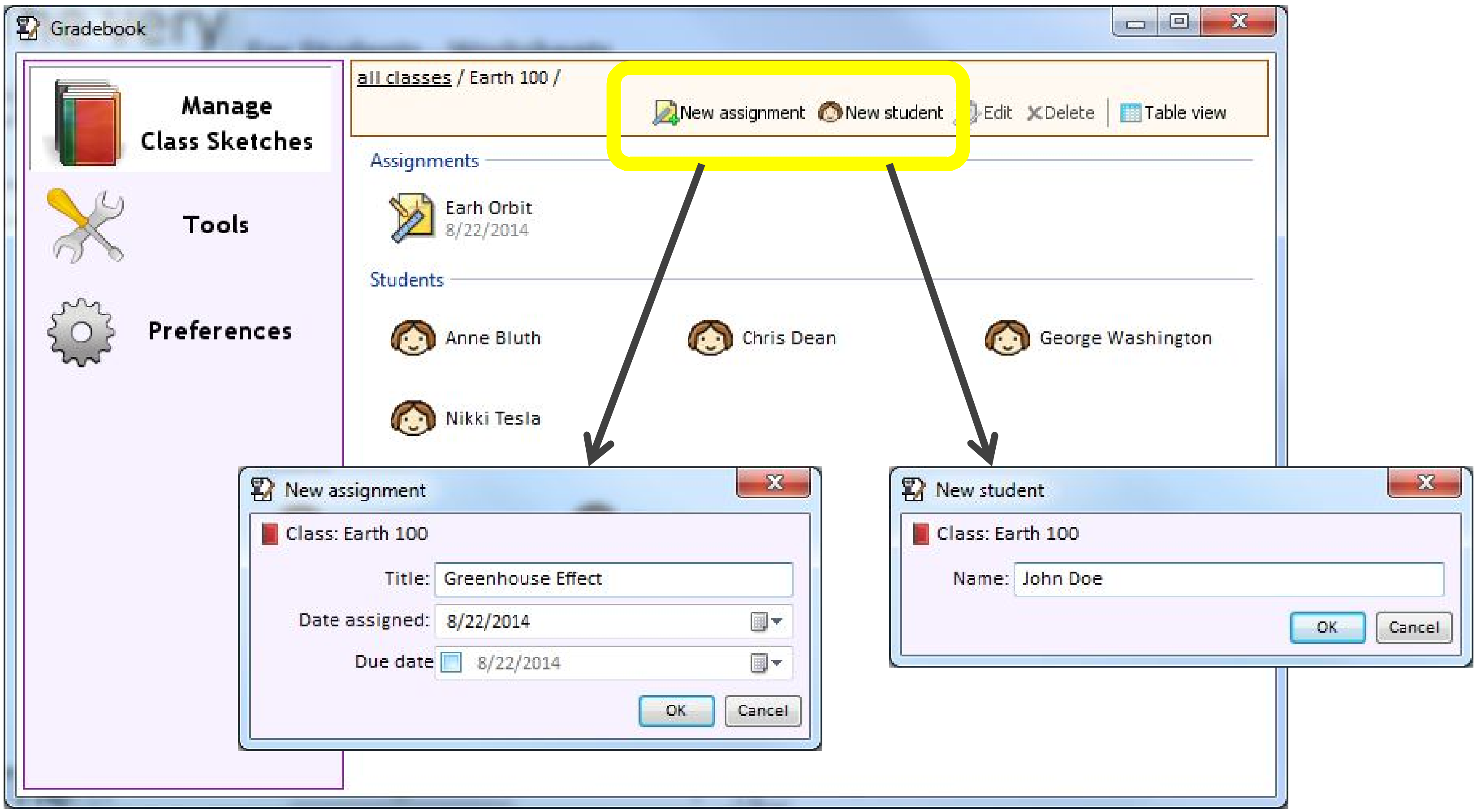
- Try different variations of correct answers
  - Does the tutor view them all as correct?
- Try different error types
  - Missing glyphs
  - Extra glyphs
  - Different spatial arrangements
  - Incorrect conceptual relationships
  - Any other variations you can think of
- Pilot test with friends or small groups of students
- Testing is crucial because students often do things we do not expect!

Gradebook: adding classes

- Gradebook will initially be empty
- Add classes that you want to keep track of



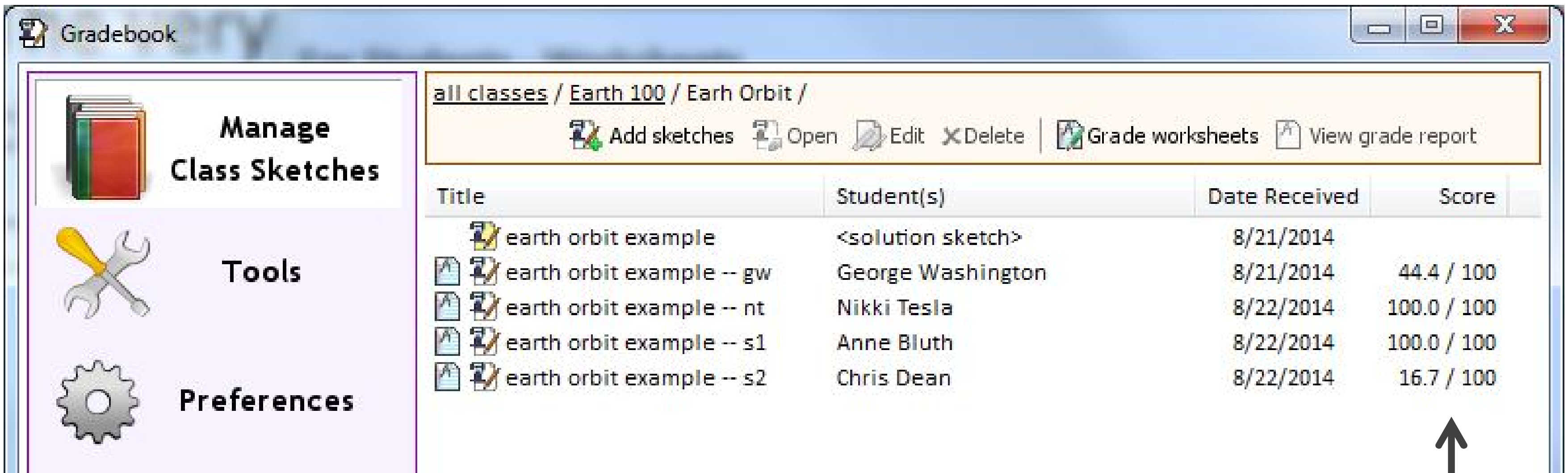
Gradebook: adding students and assignments



(fictitious students, for privacy)

Gradebook: managing student sketches

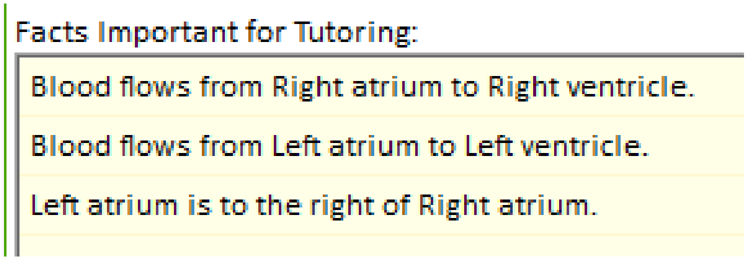
- Double click on assignment to view/add sketches
- Uploading a solution sketch enables **automatic grading**

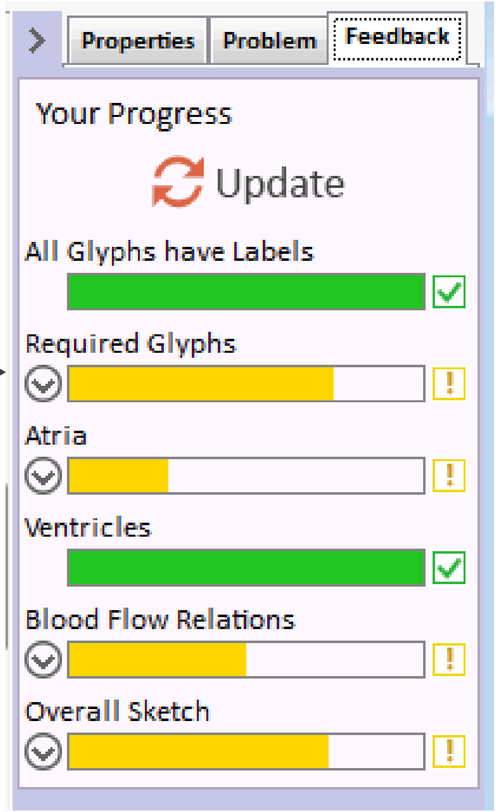


These scores are based on the grading rubrics defined in the worksheet

Worksheet Studies: Lessons Learned

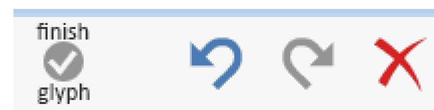
- New improvements to authoring environment
  - Important sketch facts now viewable as natural language
  - Ability to add domain-specific concepts on a per worksheet basis and query for additional facts on-demand
- New improvements to feedback
  - Feedback at a glance (filling meters) and detailed (text)
  - More detailed feedback options for location-specific items, e.g. "Your right atrium is incorrect." → "Your right atrium is too high."

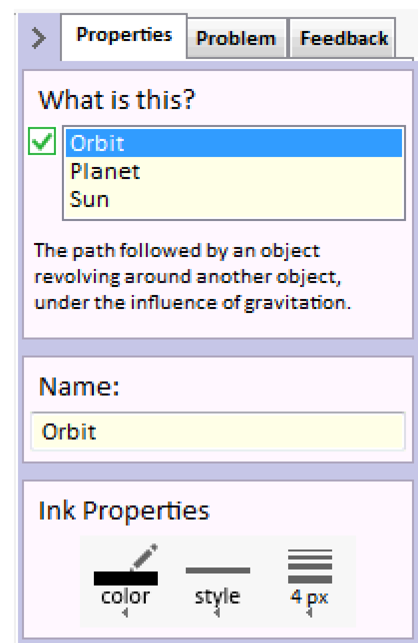




Worksheet Studies: Lessons Learned

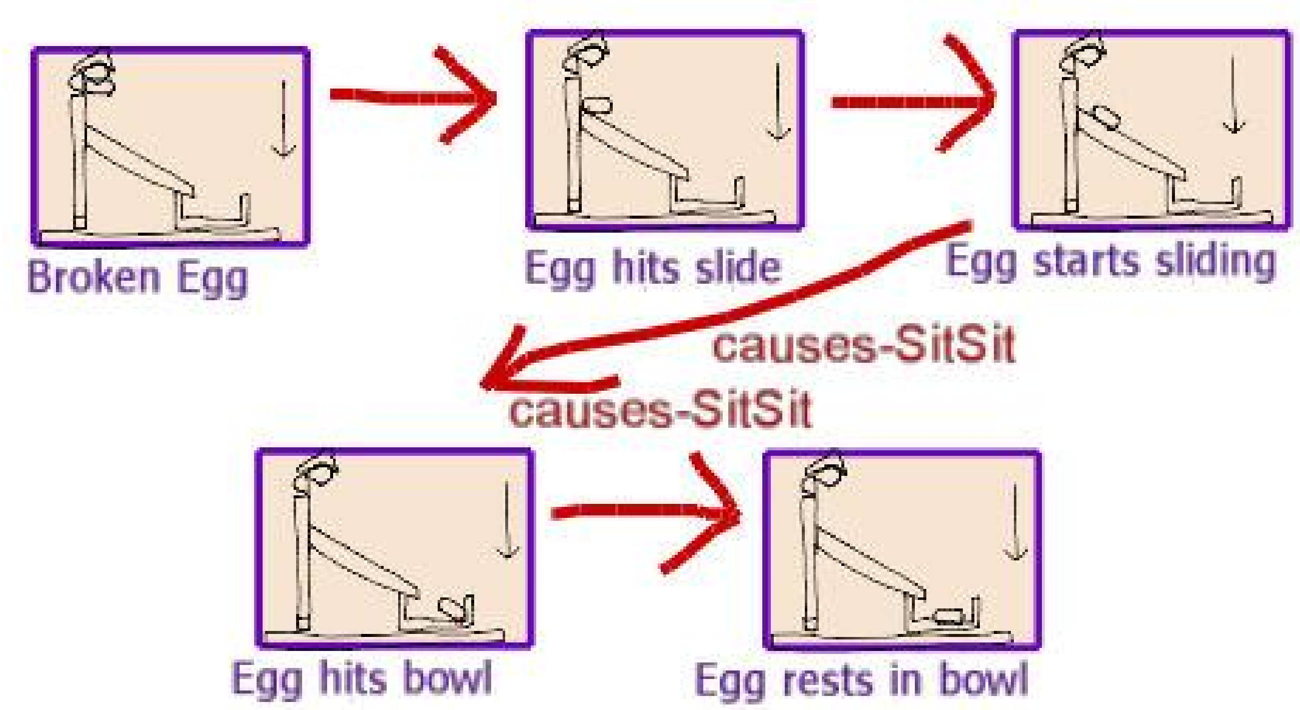
- New User experience improvements
  - Bigger icons, reduced clutter to improve touch friendliness
  - Sidebar instead of pop ups for labeling and feedback improves transparency
- Usage and Usability
  - May be used as homework assignments or in-class and group activities
  - Undergrads: learn software and complete ~2 worksheets in < 1 hour
  - 5th graders: positive user experience
    - Likert scale class average: 5.8/7 response to “I liked using CogSketch”





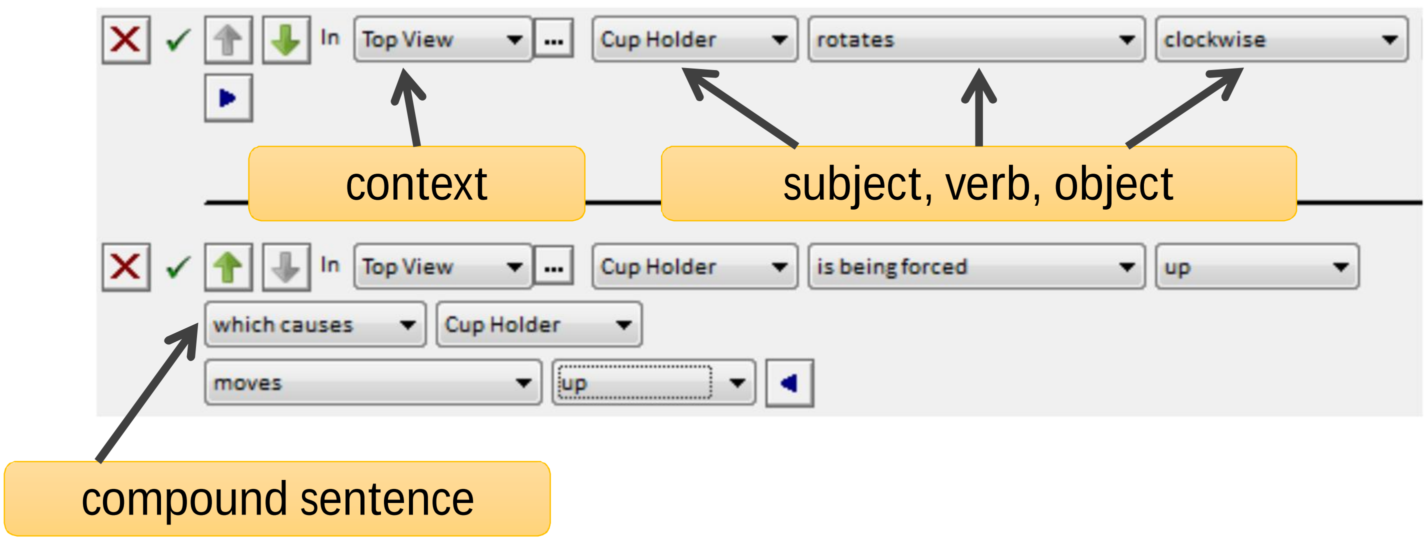
Supporting Designs with multiple states

- Multiple sketches can depict the design in different operating states
- Student draws arrows between states (e.g. causation), forming a comic graph



Supporting language-like explanations

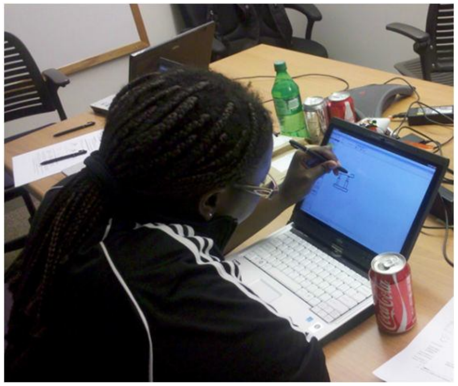
- Template-based entry of sentences
- Subject-verb-object form, may be compound

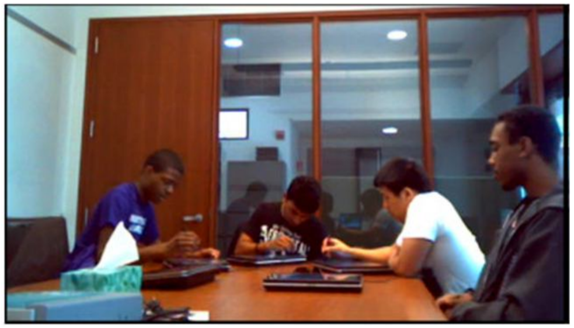


- Coach uses information from sketch *and* language to evaluate the student’s explanation

Design Coach in the Lab and Classroom

- Qualitative physical reasoning expanded to improve coverage of
  - Past design projects [Wetzel & Forbus, 2009]
  - Optional homework assignments from 2010-2011 academic year
  - Mandatory homework assignments from 2011-2012 academic year
- Capabilities now include understanding of
  - Mechanical properties: support forces, motion, springs, gears, pulleys, cords
  - Teleological vocabulary: increasing comfort, containing/holding, attaching/detaching





Supporting Designs with multiple states

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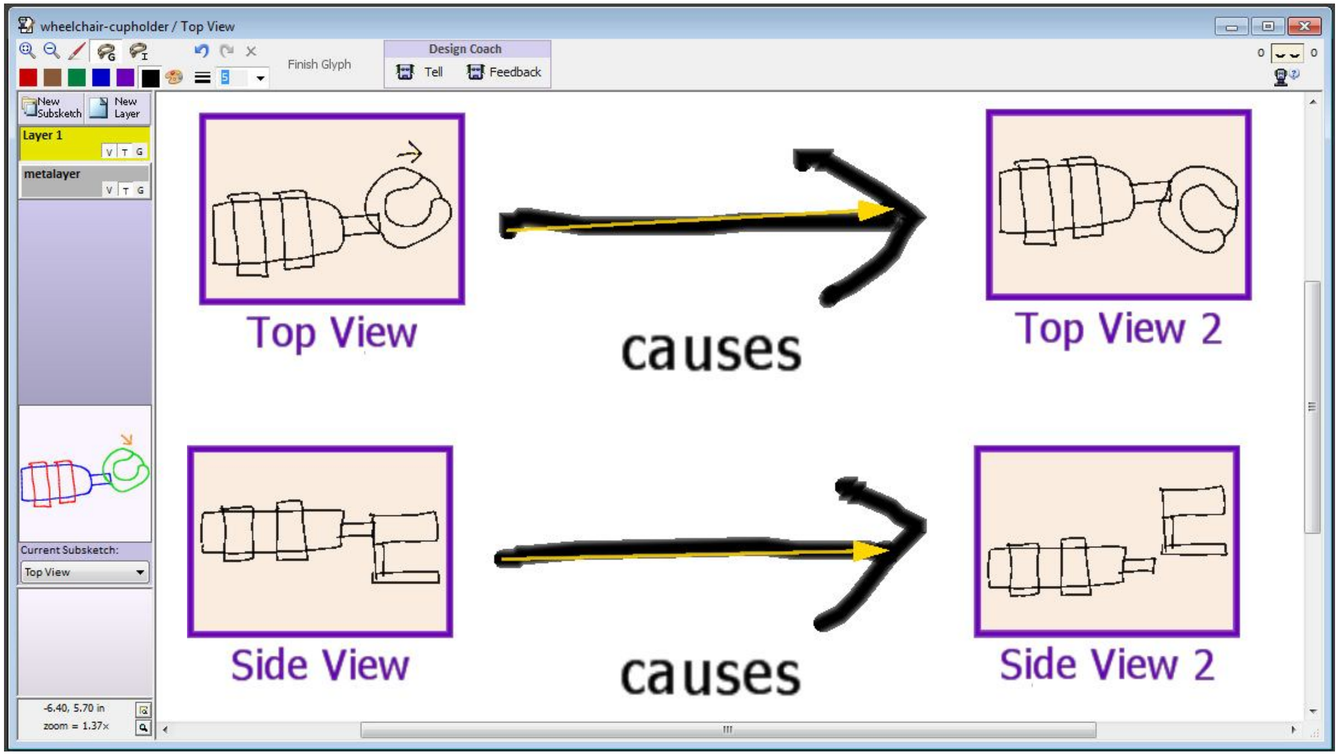

Analogical Comparison

- Mapping between student and solution sketch
- *Correspondences*: which items match
  - Match constraints: only entities of the same type can match
- *Candidate inferences* (i.e. important differences)
  - True in the base, hypothesized to be true in the target

Base: Solution Sketch	Target: Student Sketch
right-atrium	right-atrium
left-atrium	left-atrium
right-ventricle	right-ventricle
left-ventricle	left-ventricle

Analogical Comparison

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- *Correspondences*: which items match
  - Match constraints: only entities of the same type can match
- *Candidate inferences* (i.e. important differences)
  - True in the base, hypothesized to be true in the target

Base: Solution Sketch	Target: Student Sketch
(rightOf right-atrium left-atrium)	(rightOf right-atrium left-atrium)
(above right-atrium right-ventricle)	(above right-atrium right-ventricle)
(bloodFlows left-atrium left-ventricle)	(bloodFlows left-ventricle left-atrium)
(bloodFlows right-atrium right-ventricle)	(bloodFlows right-atrium right-ventricle)

Advanced Topics

A bluffer's guide to Cyc-style knowledge

Browsing/adding knowledge in CogSketch

Working memory and the knowledge base

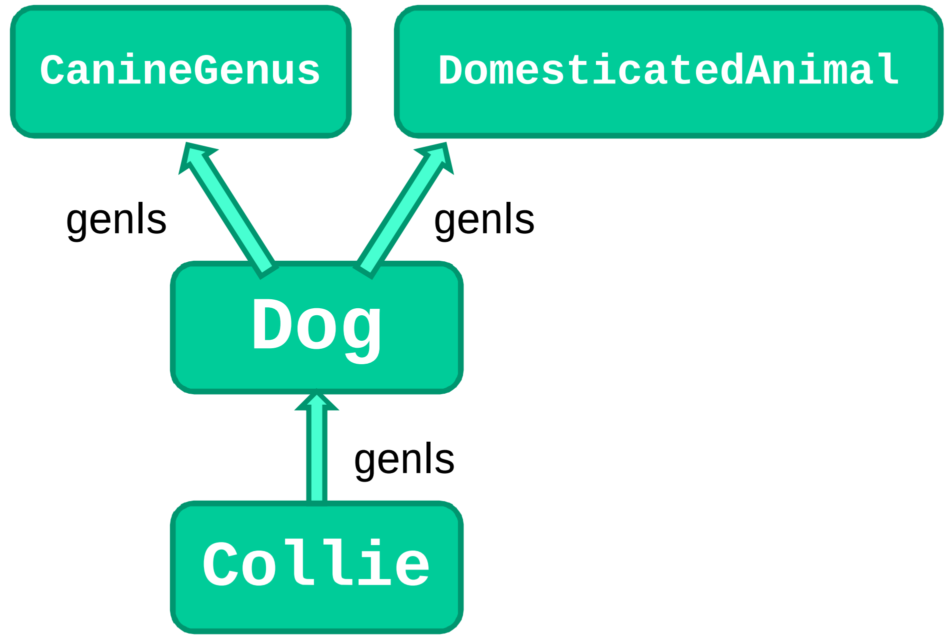
A KQML API for connecting CogSketch to other software

OpenCyc Knowledge Base

- Cyc = World's largest and most complete general knowledge base
  - Hundreds of thousands of terms
  - Many millions of assertions
  - Rich set of lexical and linguistic linkages to concepts
- OpenCyc = open-source subset of Cyc
  - Freely available
  - Much smaller
- CogSketch uses OpenCyc KB contents
  - Selected a subset relevant for our purposes
  - Added extensions to support new capabilities

Collections and Genls

- Concepts and categories in OpenCyc are modeled as *collections*
  - Collection names begin with capital letters
- Collections are related to each other through the *genls hierarchy*



`Collie` is the collection of all dogs of the breed Collie

Everything that is an instance of `Collie` is also an instance of `Dog` but not vice versa

Individuals

- An *individual* is a single thing, not a collection
- Individuals do not have instances—they *are* instances
- Use `isa` to relate an individual to a collection

`(isa Lassie1 Dog)`

`Lassie1` is an *instance* of the *collection* `Dog`.

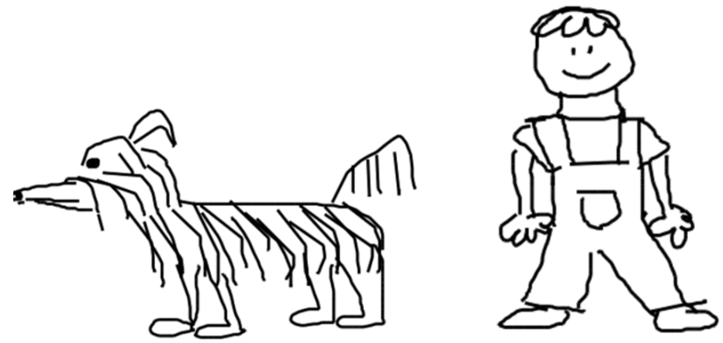
`Lassie1` is also an *individual.*

`(isa Timmy1 MaleChild)`

Predicates and genlPreds

- *Predicates* are used to build *sentences*
  - Predicate names begin with lower-case letters
- A sentence built with a predicate is either true or false
- *genlPreds* indicates a hierarchical relationship between predicates

```
(genlPreds mother
           biologicalRelative)
```



```
(owns Timmy1 Lassie1)
```

True

False

```
(biologicalRelatives Timmy1
           Lassie1)
```

Predicates can also relate Collections

```
(animalTypeMakesSoundType
       Dog
       BarkingSound)

(disjointWith Cat Dog)
```

Arity and Argument Types

- Every predicate has two central features:
  - *Arity*: How many arguments does it require?
  - *Argument types:* What types of arguments does it require?
    - arg*N*isa
    - arg*N*Genl
- Every sentence must be both *semantically* and *syntactically* well-formed

Predicate: owns
arity: 2
arg1Isa: SocialBeing
arg2Isa: SomethingExisting

`(owns Timmy1 Lassie1)`

OK!

`(owns Timmy1 Lassie1 Rover2)`

Syntactically poorly-formed

`(owns Timmy1 Dog)`

Semantically poorly-formed

Microtheories

- The knowledge in OpenCyc is organized into *Microtheories*
- Microtheories can be based on time, source, perspective, …
- Facts **within** a microtheory must be must be mutually consistent
- Facts in **different** microtheories may be inconsistent

TimmyInWellMT

```
(objectFoundInLocation Timmy1
OldWell1)
(isa Lassie1 Dog)
…
```

Inconsistent but in different Microtheories

TimmyEatsDinnerMT

```
(objectFoundInLocation Timmy1
Home1)
(isa Lassie1 Dog)
…
```

Using Microtheories

- To make a new microtheory
  - `(isa TimmyInWellMT Microtheory)`
- To relate one microtheory to another
  - `(`*`genlMt`*` TimmyInWellMT LassieMT)`

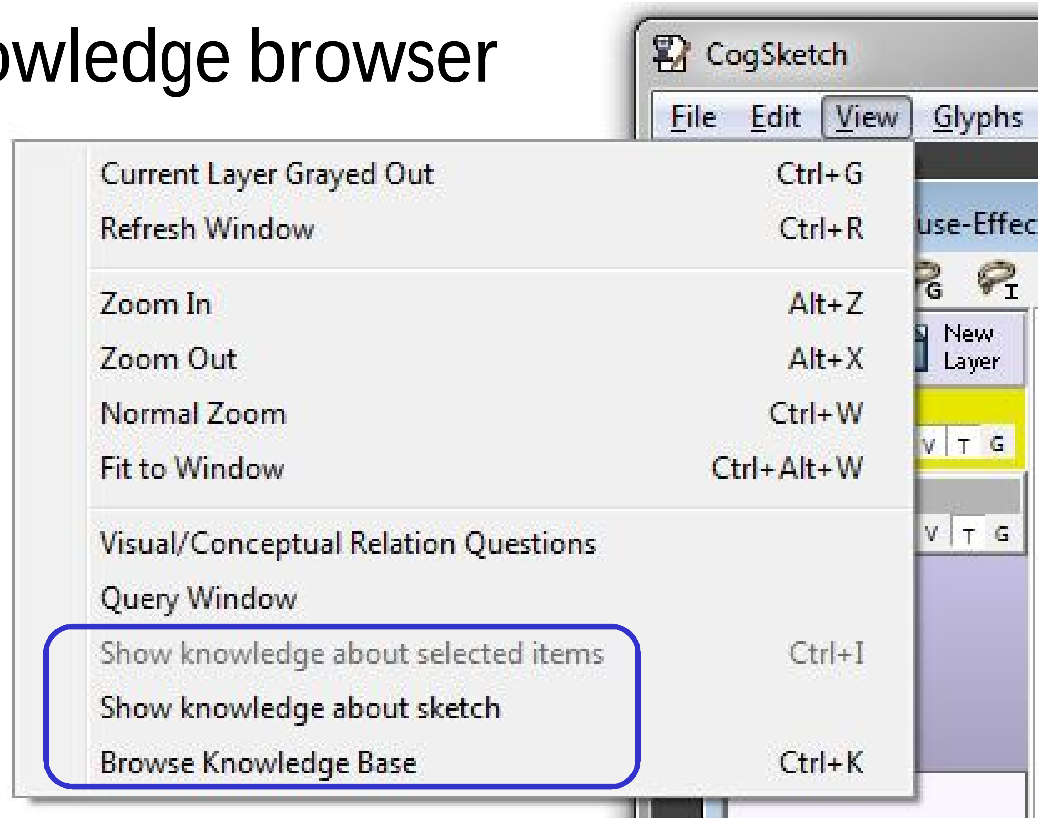
Every assertion that is true in `LassieMT` is also true in `TimmyInWellMT`

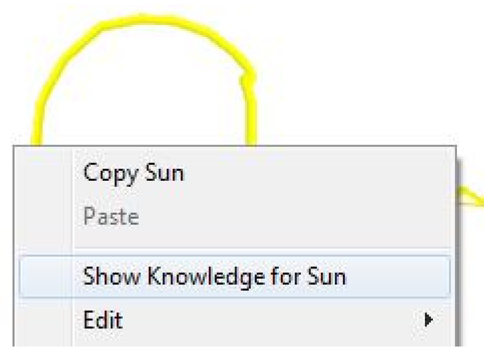
- To make a statement in a microtheory
  - `(`*`ist-Information`*` LassieMT`
    `(isa Lassie1 Dog))`

The assertion `(isa Lassie Dog)` **is true** in the microtheory `LassieMT`

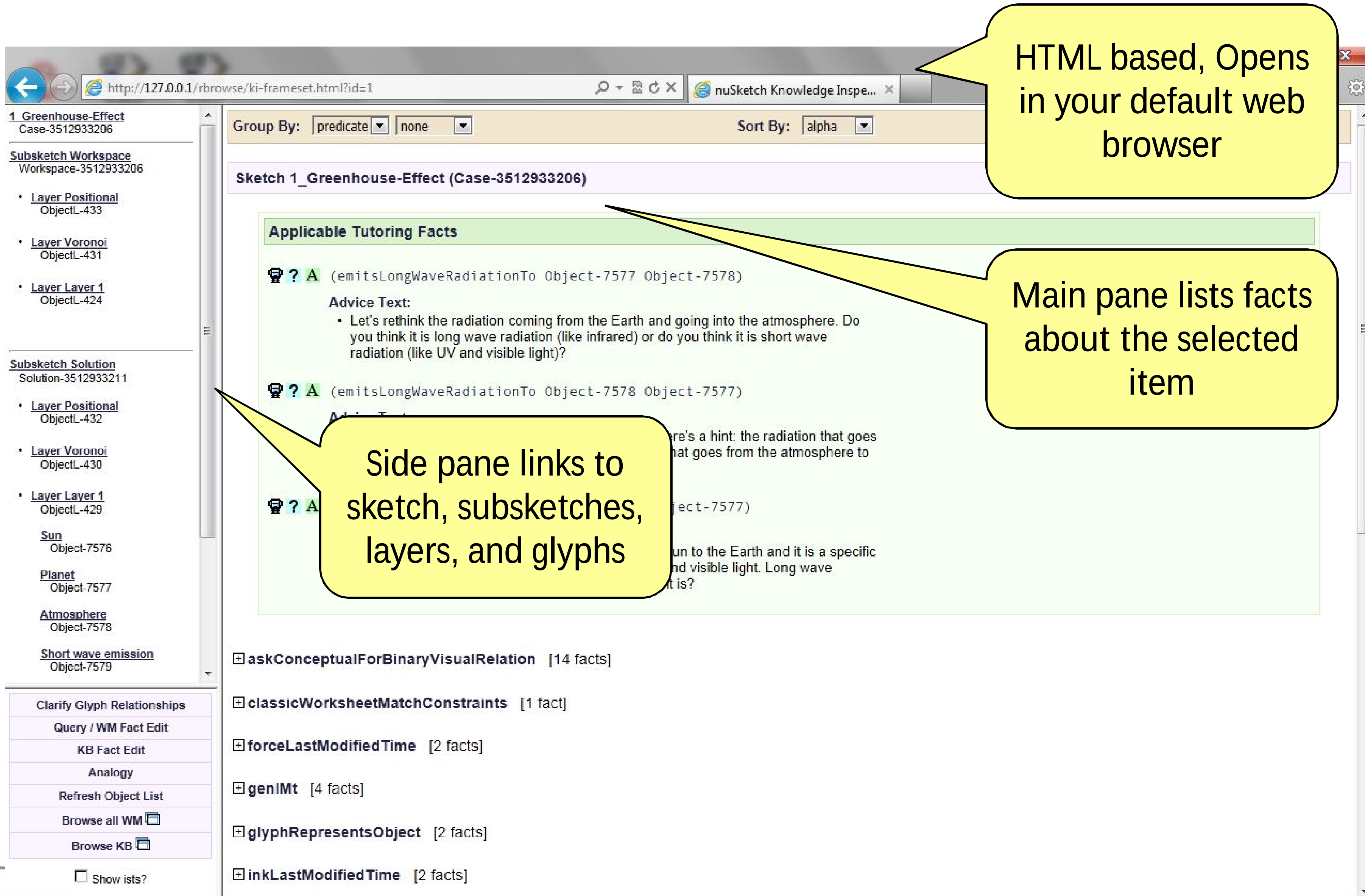
Browsing Knowledge in CogSketch

- You can open the knowledge browser from the View menu
- You can see browse knowledge about the whole sketch, selected items, or the whole KB
- You can also right-click on a glyph to see its knowledge



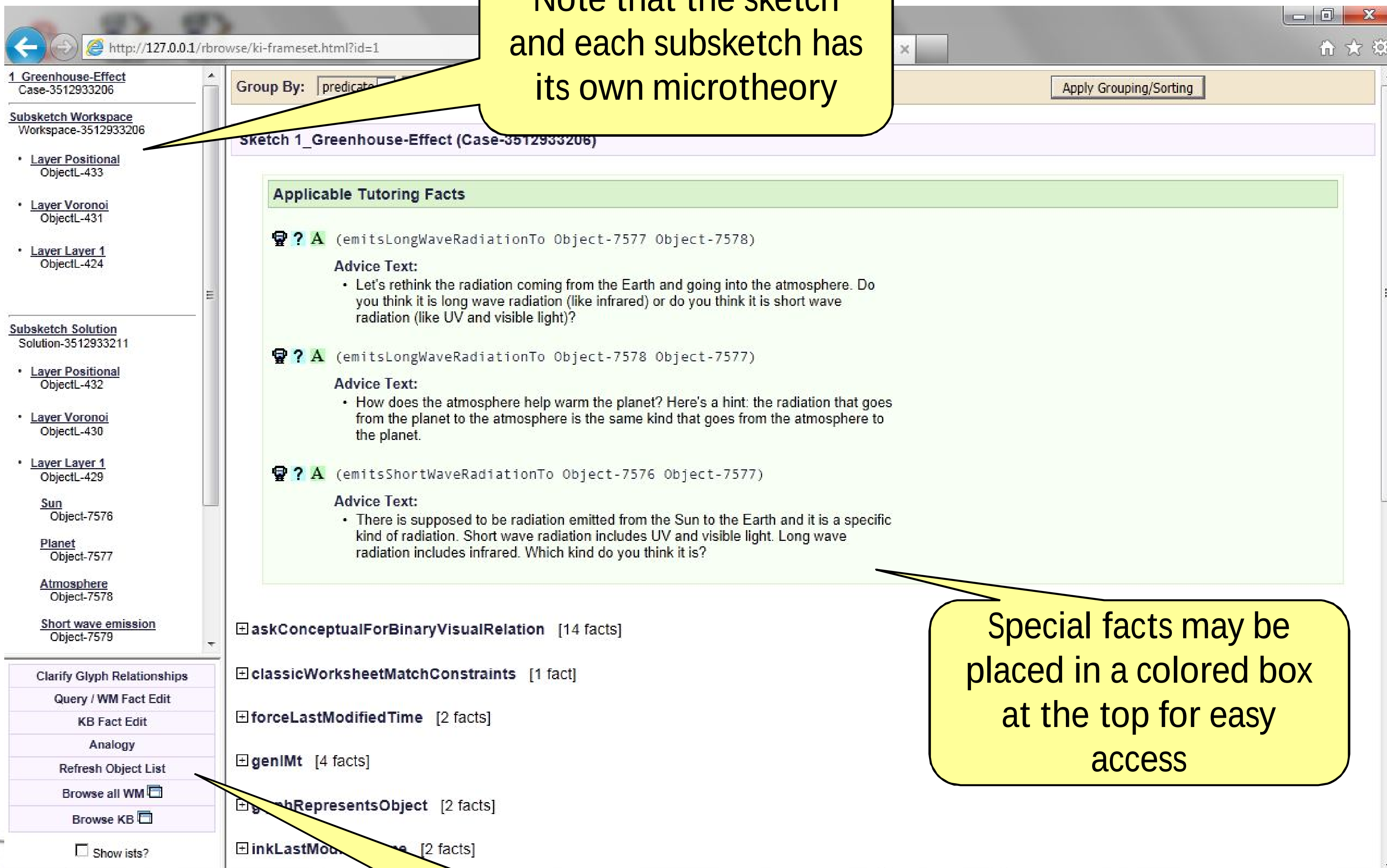


Knowledge Browser Interface



Knowledge Browser Interface

Note that the sketch and each subsketch has its own microtheory



Special facts may be placed in a colored box at the top for easy access

Useful utilities!

Working Memory (WM) vs Knowledge Base (KB)

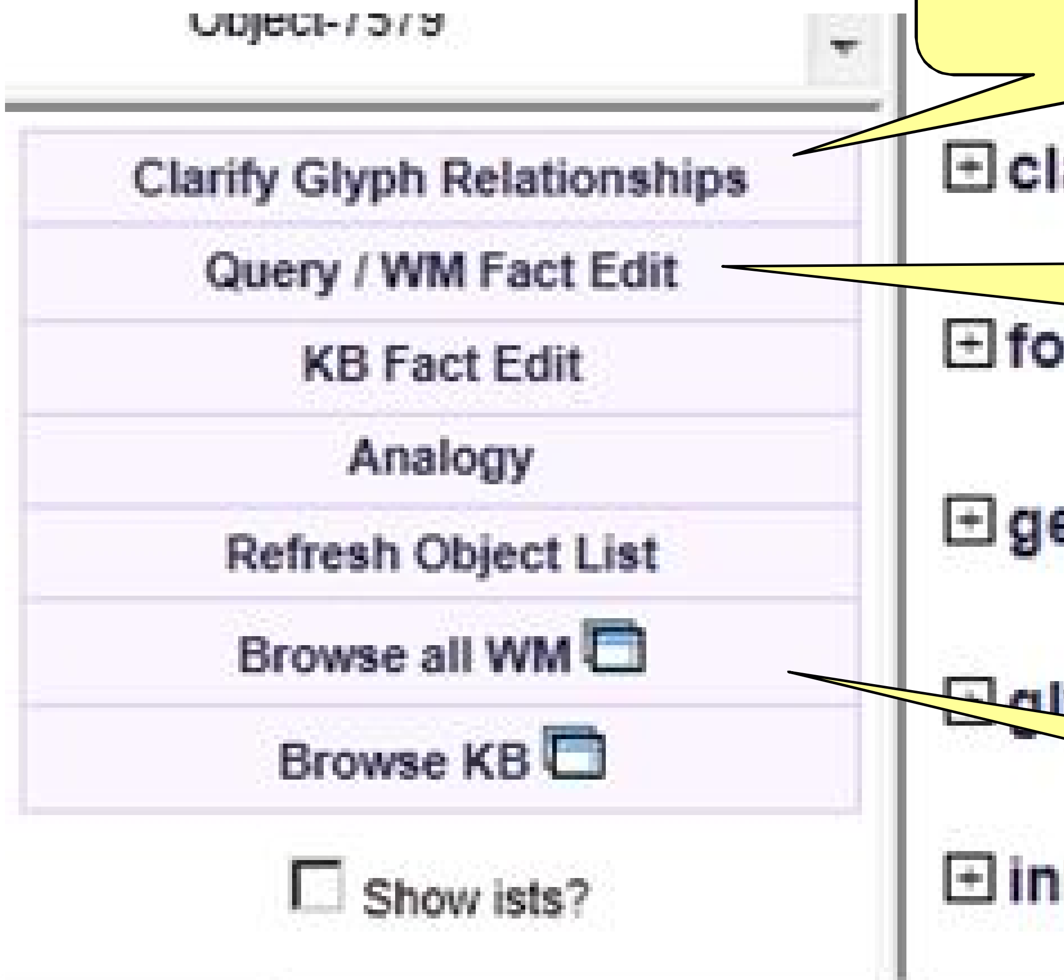
Working Memory

- Each sketch has one
- Changes as user works with the sketch
- Reflects content of individual sketch

Knowledge Base

- Each CogSketch installation has one
- Generally not affected by the sketch
- Source of concepts and relations for all sketches

Knowledge Browser and Working Memory



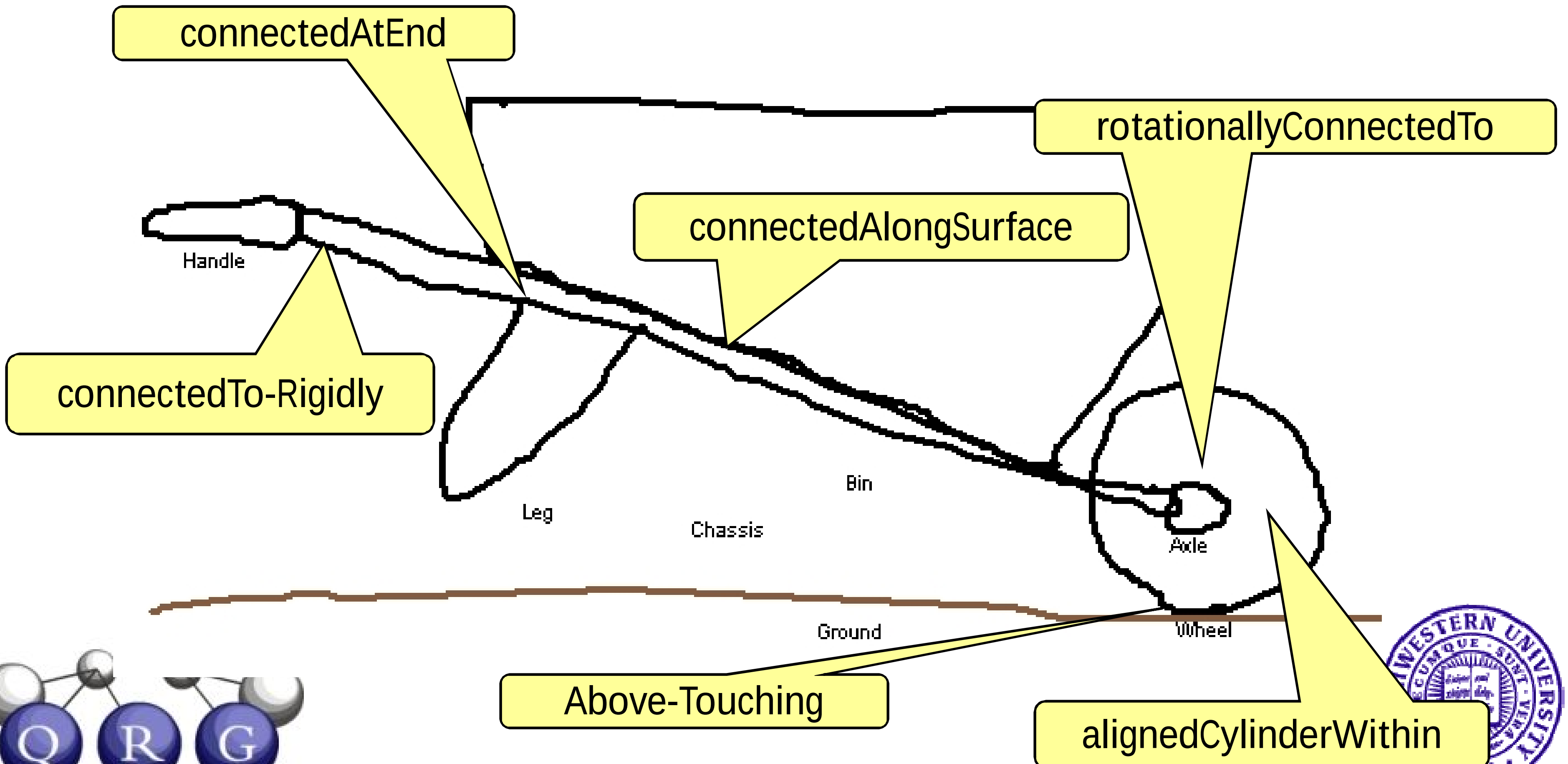
Allows you to add additional visual/conceptual relations to the sketch's WM

Search for facts/ask if a fact is true, and edit facts in WM

Browse the entire WM in one window

Visual/Conceptual Relationships

- People use conventions for depicting physical relationships in sketches
- You can tell CogSketch about your assumptions



Example: Shopping Cart

(GlyphFn Object-147 User-Drawn-Sketch-Layer-225)

human-readable namestring: **front wheel**
glyph represents: **Object-147**

⊟ **isa** [6 facts]

? A `(isa Object-147 Entity)`

? A `(isa Object-147 Wheel)`

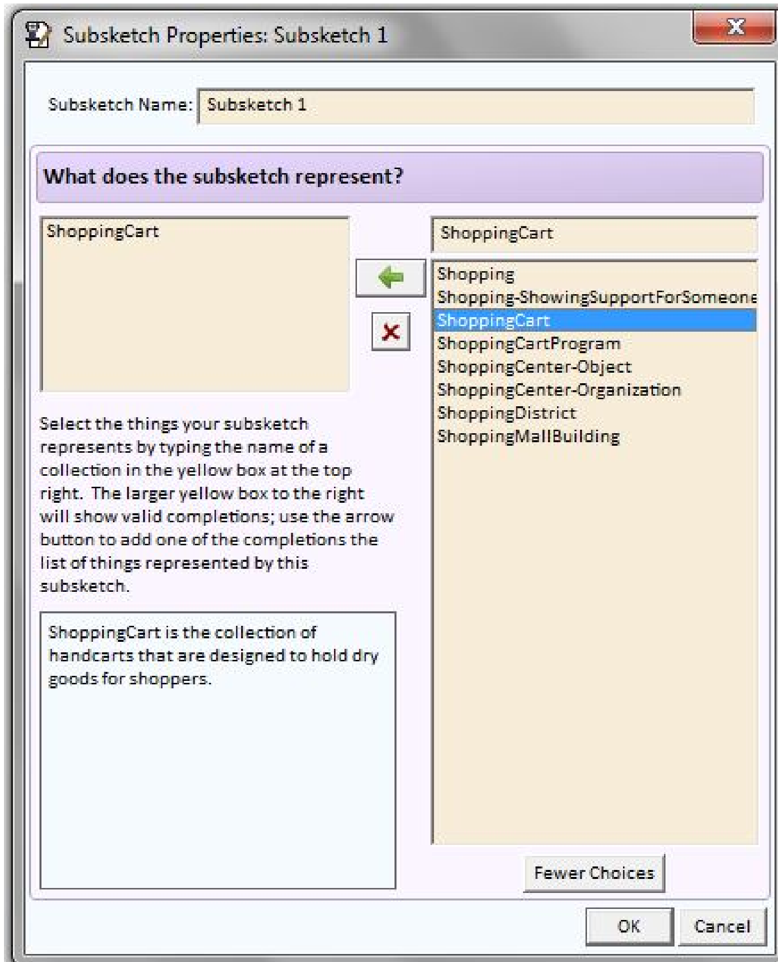
⊟ **spatiallyIntersects** [4 facts]

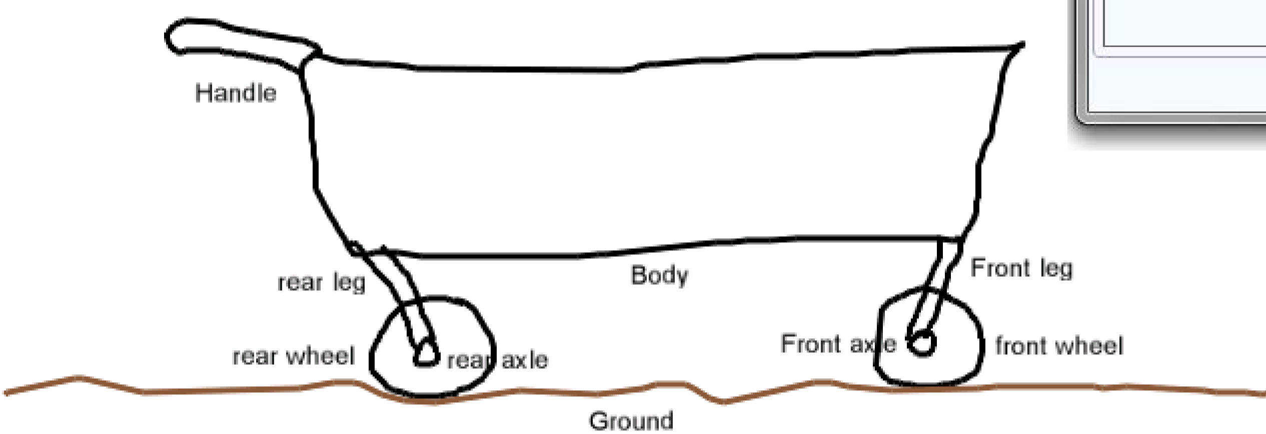
? A
```
(spatiallyIntersects
  (GlyphFn Object-147 User-Drawn-Sketch-Layer-225)
  (GlyphFn Object-150 User-Drawn-Sketch-Layer-225))
```

? A
```
(spatiallyIntersects
  (GlyphFn Object-147 User-Drawn-Sketch-Layer-225)
  (GlyphFn Object-153 User-Drawn-Sketch-Layer-225))
```

? A
```
(spatiallyIntersects
  (GlyphFn Object-150 User-Drawn-Sketch-Layer-225)
  (GlyphFn Object-147 User-Drawn-Sketch-Layer-225))
```

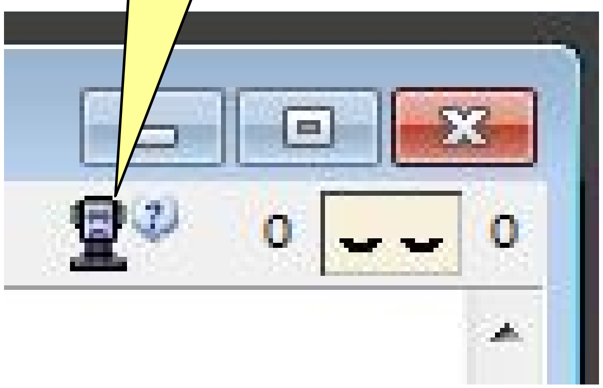
? A
```
(spatiallyIntersects
  (GlyphFn Object-153 User-Drawn-Sketch-Layer-225)
  (GlyphFn Object-147 User-Drawn-Sketch-Layer-225))
```





Providing Visual/Conceptual Relations

Use this button to bring up web interface on selected bundle



Bundle Shopping Cart Anatomy:

Conceptual relationships between Body and Front leg:

User supplied relationship
Which of the following best describes the relationship between Body and Front leg?
(connectedAtEnd Front leg Body)

Conceptual relationships between Body and Handle:

User supplied relationship
Which of the following best describes the relationship between Body and Handle?
(connectedAtEnd Handle Body)

Conceptual relationships between Ground and front wheel:

User supplied relationship
Which of the following best describes the relationship between Ground and front wheel?
(above-Touching front wheel Ground)

Conceptual relationships between Front axle and front wheel:

User supplied relationship
Which of the following best describes the relationship between Front axle and front wheel?
(alignedCylinderWithin Front axle front wheel)

How Visual/Conceptual Relations are Hypothesized

- Qualitative topology used to suggest initial candidates
  - **`(insideInSketch o1 o2)`** if **`(glyph o1)`** is inside **`(glyph o2)`**
  - **`(atOrOverlapsInSketch o1 o2)`** if **`(glyph o1)`** touches or overlaps **`(glyph o2)`**
- Possible specializations filtered by argument type relationships
- You can choose more specialized relationship if desired
- Not an easy problem
  - Worst case: 150 possibilities for **`insideInSketch`**, 204 for **`atOrOverlapsInSketch`**, with ResearchCyc KB
  - For one corpus of 34 sketches:
    - Mean # questions/sketch = 4
    - Mean # candidates to consider per question = 122

Example: Front Wheel/Axle

Conceptual relationships between Front axle and front wheel:

User supplied relationship

Which of the following best describes the relationship between Front axle and front wheel?

--

- --
- (alignedCylinderWithin Front axle front wheel)
- (artifactFoundInLocation Front axle front wheel)
- (commerciallyUsefulParts Front axle front wheel)
- (connectedToInside Front axle front wheel)
- (constituents Front axle front wheel)
- (cospatial Front axle front wheel)
- (covers-Baglike Front axle front wheel)
- (embeddedCylinderInSheet Front axle front wheel)
- (entirePortion Front axle front wheel)
- (externalParts Front axle front wheel)
- (hasStoredInside Front axle front wheel)
- (in-Among Front axle front wheel)
- (in-ContClosed Front axle front wheel)
- (in-ContCompletely Front axle front wheel)
- (in-ContFullOf Front axle front wheel)
- (in-ContGeneric Front axle front wheel)
- (in-ContOpen Front axle front wheel)
- (in-Rooted Front axle front wheel)
- (in-Snugly Front axle front wheel)
- (inRegion Front axle front wheel)
- (inertIngredients Front axle front wheel)
- (ingredients-Constituent Front axle front wheel)
- (ingredients-Separable Front axle front wheel)
- (internalParts Front axle front wheel)
- (internalSubRegions Front axle front wheel)
- (localityOfObject Front axle front wheel)
- (mainConstituent Front axle front wheel)

and front wheel?

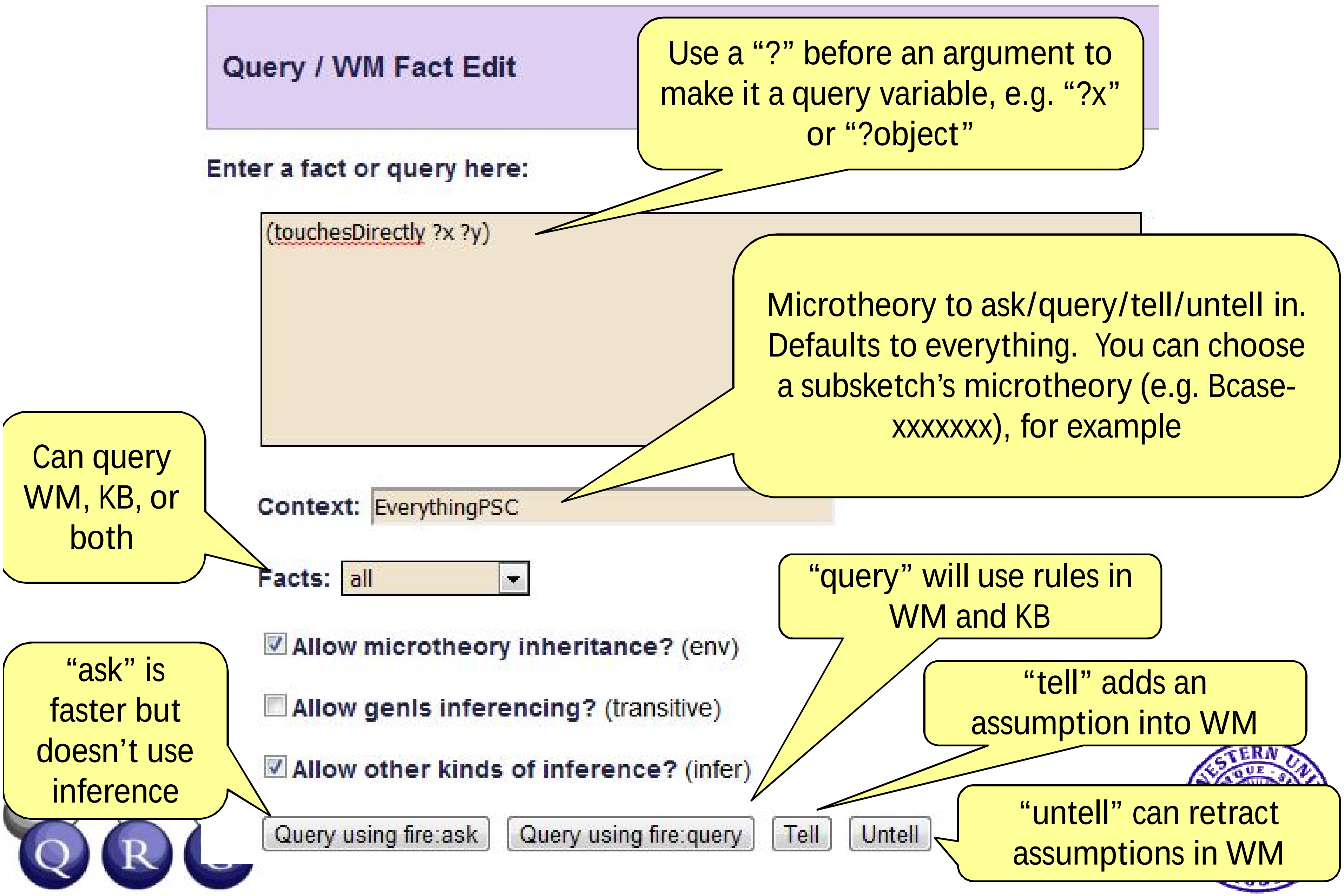
nd front wheel?

nd rear wheel?

- (localityOfObject Front axle front wheel)
- (mainConstituent Front axle front wheel)

- (objectFoundInLocation Front axle front wheel)
- (objectSides Front axle front wheel)
- (physicalDecompositions Front axle front wheel)
- (physicalParts Front axle front wheel)
- (physicalParts-Separated Front axle front wheel)
- (physicalPortions Front axle front wheel)
- (physicallyContains Front axle front wheel)
- (pigments Front axle front wheel)
- (pluggedInto Front axle front wheel)
- (properPhysicalDecompositions Front axle front wheel)
- (properPhysicalParts Front axle front wheel)
- (properlySpatiallySubsumes Front axle front wheel)
- (properlySpatiallySubsumes-Nontangential Front axle front wheel)
- (properlySpatiallySubsumes-Tangential Front axle front wheel)
- (protectiveContains Front axle front wheel)
- (protrudesInto Front axle front wheel)
- (screwedIn Front axle front wheel)
- (spans-Bridgelike Front axle front wheel)
- (spatiallyContains Front axle front wheel)
- (spatiallyIncludes Front axle front wheel)
- (spatiallySubsumes Front axle front wheel)
- (sticksInto Front axle front wheel)
- (sticksInto-2D Front axle front wheel)
- (subRegions Front axle front wheel)
- (surfaceParts Front axle front wheel)
- (surrounds-3D Front axle front wheel)
- (surroundsCompletely Front axle front wheel)

Querying from Working Memory



Can Get Answers

Query / WM Fact Edit

```
(touchesDirectly ?x ?y)
```
action = ask
context = EverythingPSC; facts = all, env, infer

Answers:

in EverythingPSC:

? A (touchesDirectly Object-43 Object-44)
? A (touchesDirectly Object-43 Object-46)
? A (touchesDirectly Object-43 Object-51)
? A (touchesDirectly Object-44 Object-43)
? A (touchesDirectly Object-44 Object-51)
? A (touchesDirectly Object-44 Object-68)
? A (touchesDirectly Object-46 Object-43)

Click “?” to see why fact is believed

Click “A” to see the list of underlying assumptions

Can Drill Down for Reasons

Drill down using the “?” icon

Touches is believed because of this rcc8 relation and this rule in the KB

Justifications

```
(touchesDirectly Object-43 Object-44)
```

The above expression is true because of the following:

?	A	(hasRCC8Relation (GlyphFn Object-43 User-Drawn-Sketch-Layer-13) (GlyphFn Object-44 User-Drawn-Sketch-Layer-13) rcc8-PO)	[true]
?		(inKB (ist-Information NuSketchQMRulesMt (<== (touchesDirectly ?obj1 ?obj2) (wmOnly (hasRCC8Relation (GlyphFn ?obj1 ?sketch-layer) (GlyphFn ?obj2 ?sketch-layer) rcc8-PO)))))	[true]

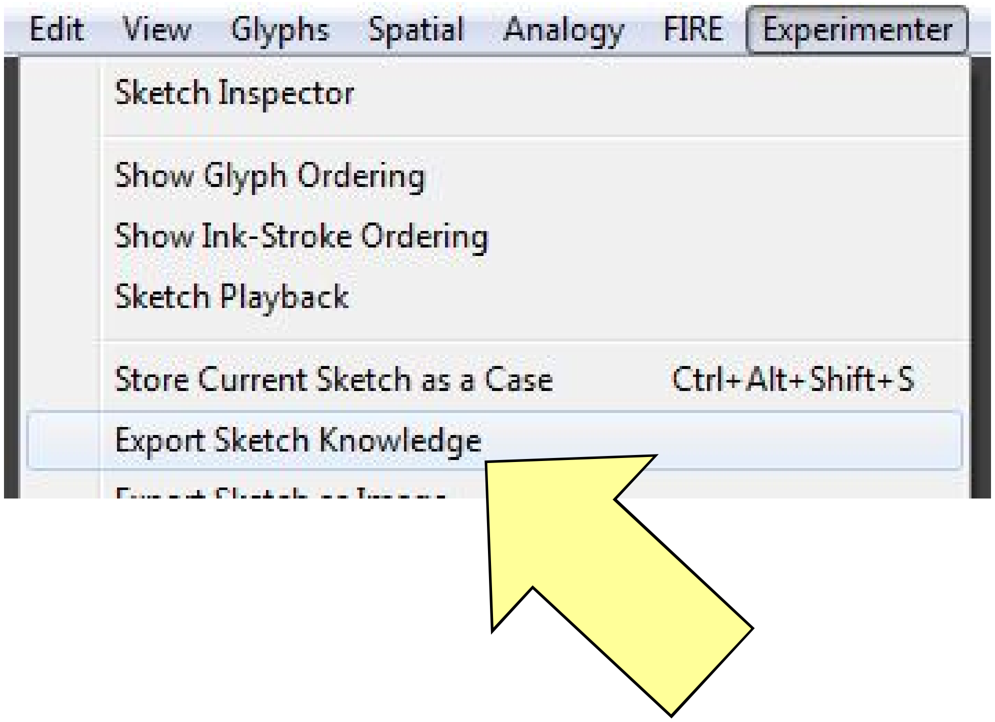
It is true via:

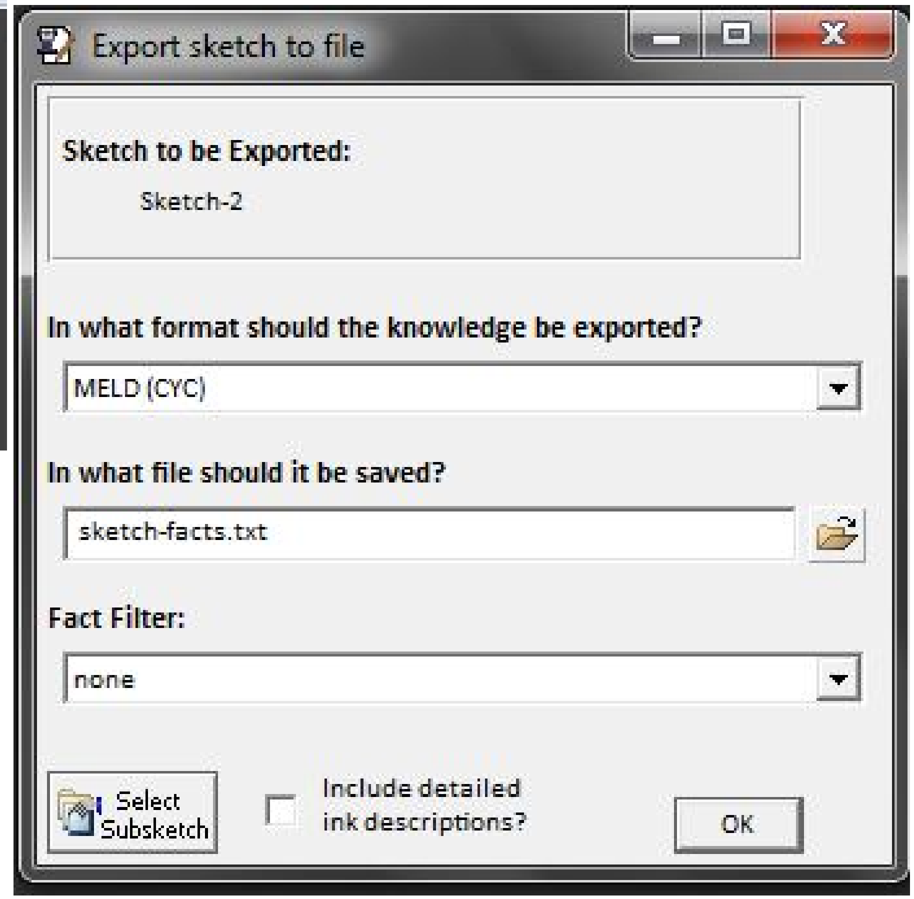
```
(:implied-by
  (:implies
    (:and (inKB (ist-Information NuSketchQMRulesMt
                 (<== (touchesDirectly ?obj1 ?obj2)
                      (wmOnly
                        (hasRCC8Relation
                          (GlyphFn ?obj1 ?sketch-layer)
                          (GlyphFn ?obj2 ?sketch-layer)
                          rcc8-PO)))))
          (ist-Information BCase-3487440799
            (hasRCC8Relation
              (GlyphFn Object-43 User-Drawn-Sketch-Layer-13)
              (GlyphFn Object-44 User-Drawn-Sketch-Layer-13)
              rcc8-PO)))
    (ist-Information BCase-3487440799
      (touchesDirectly Object-43 Object-44)))
  :bc-justify-clause-bc-result)
```

Direct Consequences:

?	A	(touchesDirectly Object-43 Object-44)	[true]

Exporting Knowledge to Files





MELD format files

- Similar to Cyc KE format

```
;; constant: Case-3429195339.
;; in Mt: BaseKB.
(isa Case-3429195339 Microtheory)
(isa Case-3429195339 COASpecificationMicrotheory)
(genlMt Case-3429195339 BaseKB)

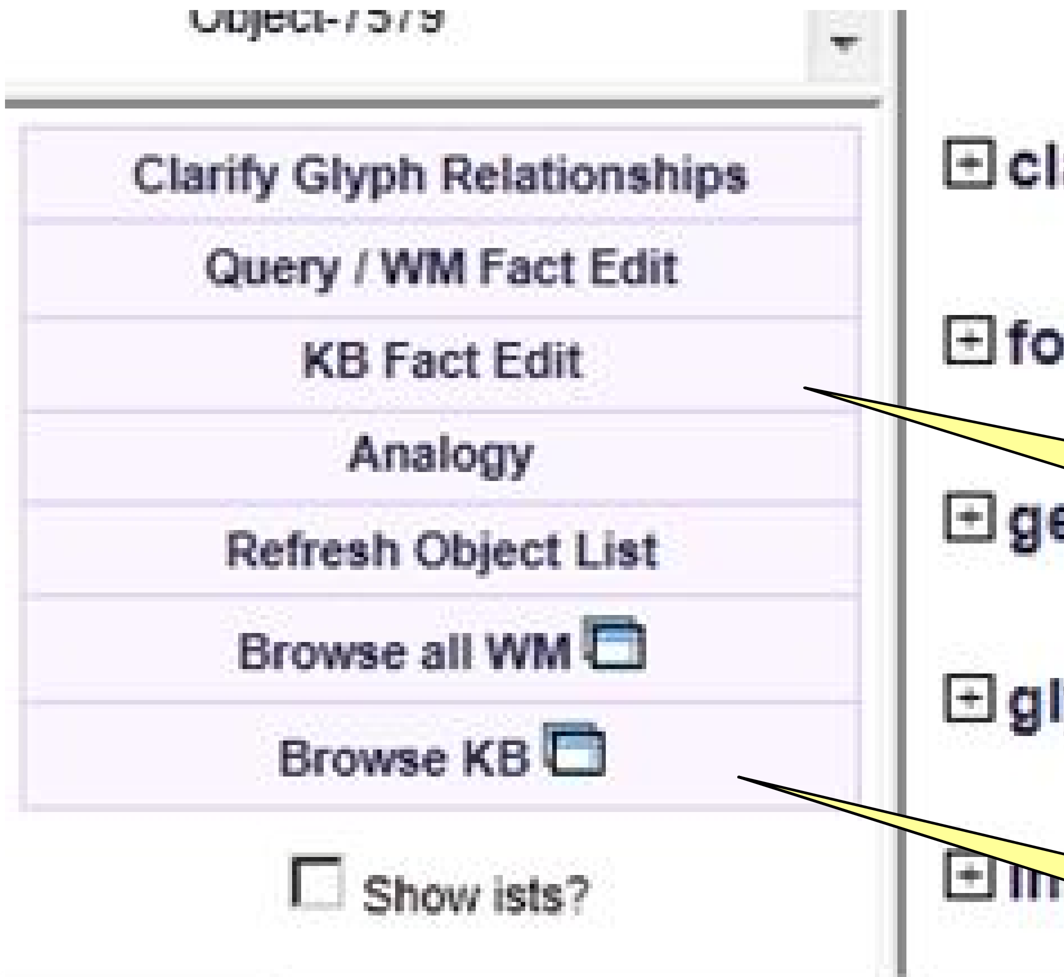
;; constant: BCase-3429195452.
;; in Mt: BaseKB.
(isa BCase-3429195452 Microtheory)
(isa BCase-3429195452 COASpecificationMicrotheory)
(genlMt BCase-3429195452 Case-3429195339)


;; Default Mt: Case-3429195339.
```

Working Memory - Summary

- You can add visual-conceptual relations to a sketch's knowledge
  - Useful for reasoning about what the sketch depicts
- You can view the facts about a sketch and all its parts with the knowledge browser
  - Drill down and see why those facts are believed
  - Useful for debugging
- You can make queries to infer new facts or look up old ones
- You can tell/untell some facts into WM
- You can export facts from your sketches to files

Working with the Knowledge Base



Retrieve/store facts in the KB

Browse the entire KB

Example: Browsing

- Let's look for other relationships involving rotation with the KB browser

rotat | search

Possible matches for "rotat":

- Rotataion-None (Collection)
- RotatedShape-180 (Collection)
- RotatedShape-45 (Collection)
- RotatedShape-90 (Collection)
- RotatedShape-None (Collection)
- Rotation-135 (Collection)
- Rotation-180 (Collection)
- Rotation-45 (Collection)
- Rotation-90 (Collection)
- Rotation-Clockwise135 (Collection)
- Rotation-Clockwise45 (Collection)
- Rotation-Clockwise90 (Collection)
- Rotation-CounterClockwise135 (Collection)

rotationallyConnectedT

- all genlPreds
- all specPreds
- all references

rotationallyConnectedTo [type = Relation]:

comment: A ConnectionPredicate (q.v.) and thus a specialization of connectedTo (q.v.). `(rotationallyConnectedTo OBJ1 OBJ2)` means that `OBJ1` and `OBJ2` are connected in such a way that rotational motion, and only rotational motion, can happen between them. The range of rotational motion possible might be full or partial. Non-rotational movement between two rotationally connected objects can occur only if the connection is broken, deformed, or disassembled. If `OBJ1` and `OBJ2` do rotate relative to one another, then this may be due to sliding of their surfaces, articulation of some joint part, or deformation of `OBJ1` or `OBJ2` (so long as that deformation only allows rotation between `OBJ1` and `OBJ2`). Positive examples: Femurs are rotationally connected to hips, doors are rotationally connected to door frames, doorknobs are rotationally connected to doors, and propellers are rotationally connected to airplanes; in computer trackballs the ball is rotationally connected to the housing. Also a book cover is rotationally connected to its binding (but flapHingedTo is even more appropriate for describing such a connection because it is more specific). Negative examples: a planet orbiting a star (they are not connected; cf. MovingInACircle) and a toothpick stuck in a person's leg (although elastic deformation of flesh allows there to be rotational motion between toothpick and leg, it also may allow a small amount of translational motion to occur between them; in-Lodged is more appropriate for describing this case).

isa:
- **in UniversalVocabularyMt:** ConnectionPredicate , IrreflexiveBinaryPredicate , SymmetricBinaryPredicate
- **in TopicMt:** Connections-Spatial-Topic

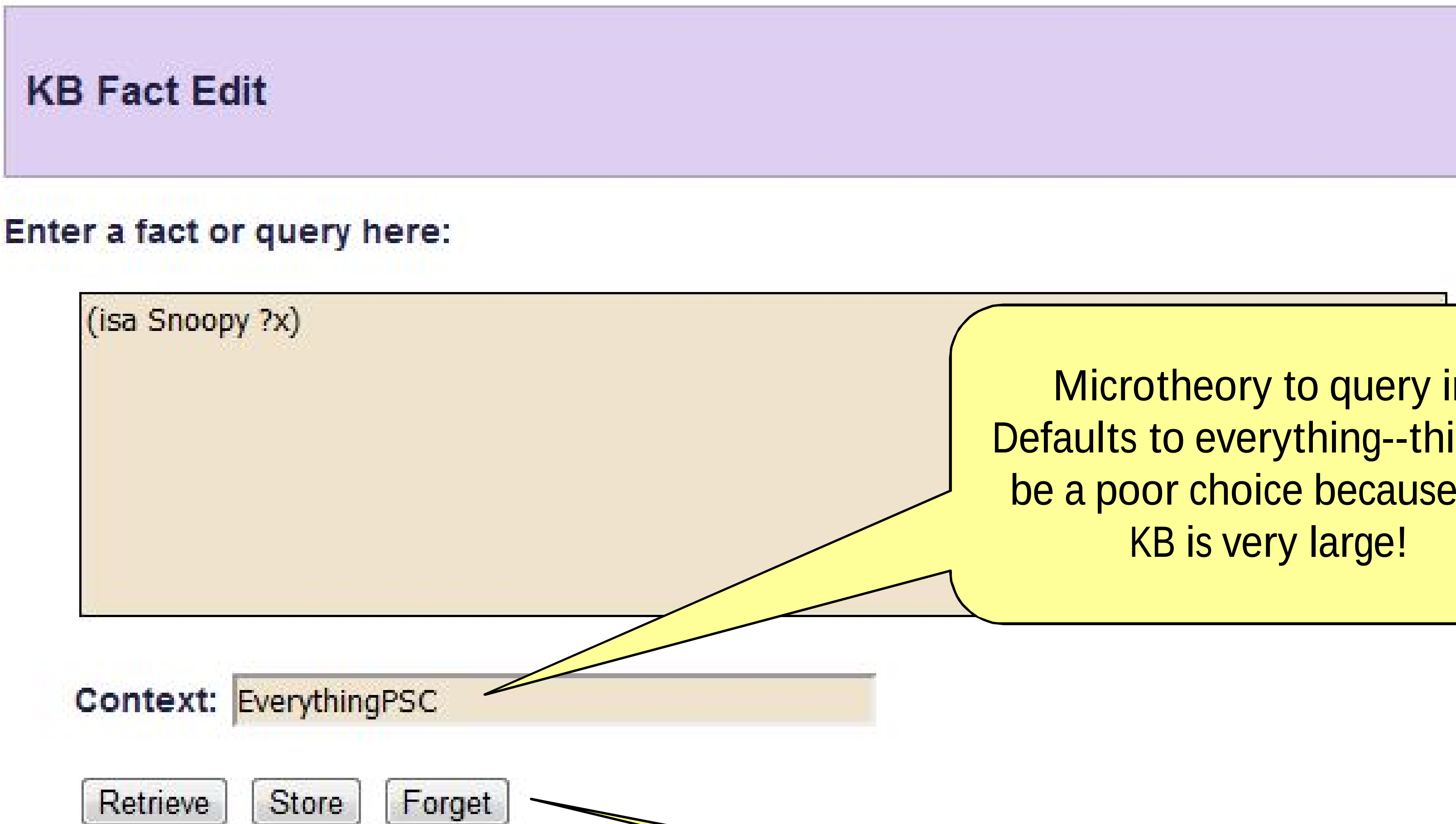
arity: 2
arg1Isa: SolidTangibleThing
arg2Isa: SolidTangibleThing

genlPreds:
- **in BaseKB:** rotationallyConnectedTo
- **in UniversalVocabularyMt:** connectedTo

specPreds:
- **in UniversalVocabularyMt:** connectedByBeltTo , hingedTo , screwedIn

---

Editing the KB through the Knowledge Browser



Microtheory to query in. Defaults to everything--this can be a poor choice because the KB is very large!

“Retrieve” looks up facts

“Store” adds fact

“Forget” removes fact

Knowledge Base Query Result

KB Fact Edit

(isa Snoopy ?x)
context = EverythingPSC
action = retrieve

Results:

in UniversalVocabularyMt:
(isa Snoopy Individual)

in FictionalWorksMt:
(isa Snoopy FictionalCharacter)

in MassMediaDataMt:
(isa Snoopy CartoonCharacter)

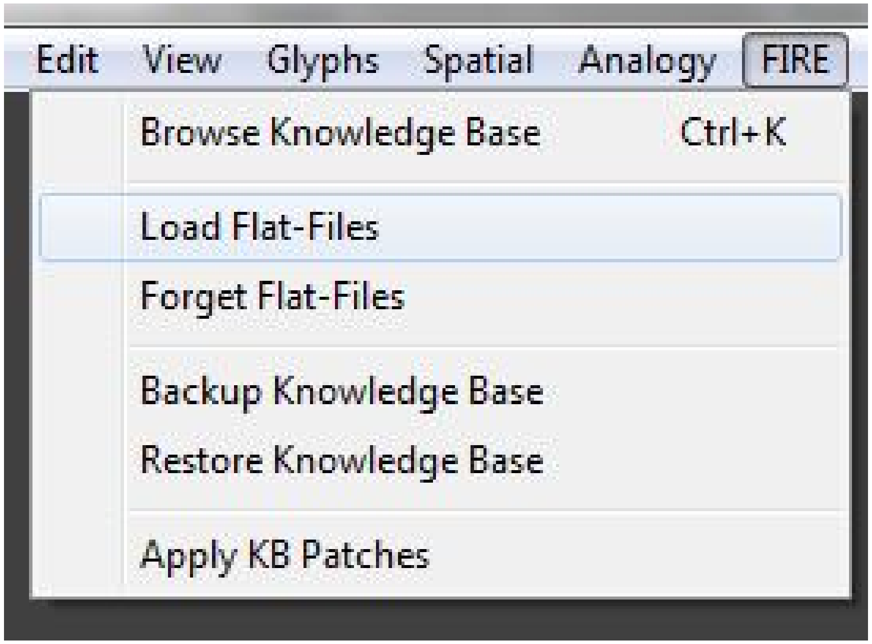
in ThePeanutsCartoonMt:
(isa Snoopy Beagle) (isa Snoopy MaleAnimal)

Return to Fact Edit Page

Note there is no option to drill down for justifications; these are simply facts retrieved from the KB

Extending the Knowledge Base

- OpenCyc has a lot of knowledge ... but it might not have everything you need
- You add knowledge using a .meld file
- Create using your favorite text editor



Hint: Use an editor that matches parentheses, such as emacs!

Example: A Simple Flat-File

```
(in-microtheory TimmyInWellMT) ;; Tells file
;; loader what microtheory to use.  All forms after
;; this command are facts for that microtheory.
(isa Lassie1 Dog)
(isa Timmy1 MaleChild)
(isa OldWell1 Well)
(owns Timmy1 Lassie1)
(objectInLocation Timmy1 OldWell1)
(isa LassieGetHelp RescuingSomeone)
(performedBy LassieGetHelp Lassie1)
(beneficiary LassieGetHelp Timmy1)
```

Adding a Collection

To add a collection you need at least three things:

1. A statement that it is a Collection
2. A genls statement
3. A comment describing the collection

```
(isa Firefly Collection)
(genls Firefly Insect)
(comment Firefly
 “the collection of all
insects that having
glowing   posteriors”)
```

Adding a Relation

To add a relation you need at least four things:

1. A statement that it isa Relation
2. An arity statement
3. ArgIsa statements
4. A comment describing the relation

```
(isa aboveGrazingLine
     Relation)
(arity aboveGrazingLine 2)
(arg1Isa aboveGrazingLine
         NuSketchGlyph)
(arg2Isa aboveGrazingLine
         NuSketchGlyph)
(comment aboveGrazingLine
  “the figure object
represented by the glyph in
arg1 is above the grazing
line created by the ground
object represented by the
glyph in arg2”)
```

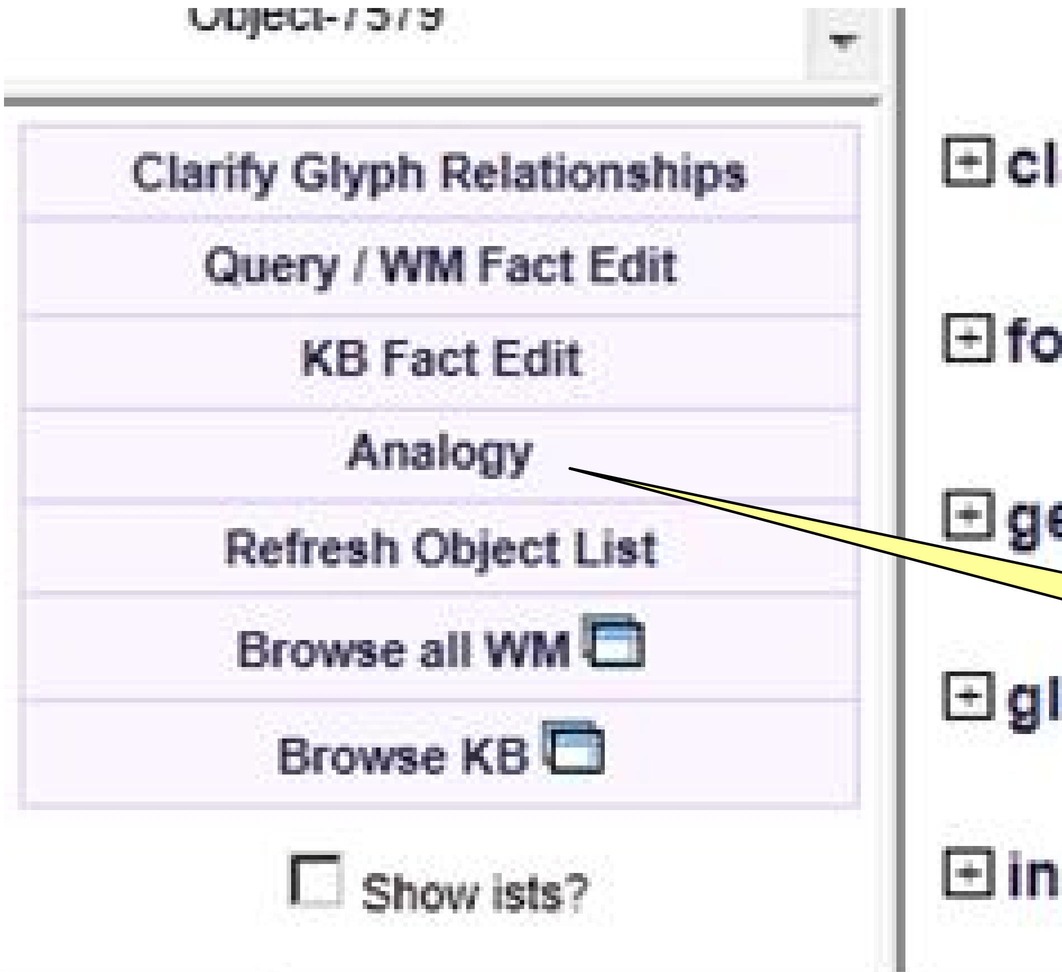
Using Your New KB entries in CogSketch

- Your new collections
  - Can be used in conceptual labeling
  - Can be used to constrain arguments to relations
- Your new relations
  - Can be used in worksheets
  - Can show up as hypothesized visual/conceptual relationship questions, if you weave them into the `genlPreds` hierarchy correctly
  - Can be used for your own reasoning, if you add Horn clause axioms involving them also
    - Via browser query window, or API calls
    - Documentation on doing this is in progress

Knowledge Base - Summary

- You can browse for existing collections and relations
- You can retrieve facts from the KB with the knowledge browser
- You can add your own collections and relations
  - You can store individual facts using the knowledge browser
  - You can add a large amount of facts at one time by making a flat file and importing it
  - New collections and relations can be used in worksheets, cognitive simulations, and other experiments

Browsing Analogies



Displays recent analogies

Analogy Browser

Clicking an SME opens it so you can view the list of mappings

Reasoner Analogy Source

Recorded SMEs:

- SME #1, version 0

Cached DGroups:

- (CogSketchTutorBundleCaseFn Workspace-3512933206 Subsketch-8)
  context = Workspace-3512933206
- (CogSketchTutorBundleCaseFn Solution-3512933211 Subsketch-9)
  context = Workspace-3512933206

Clear Analogy Source

SME #1

Base: (CogSketchTutorBundleCaseFn Solution-3512933211 Subsketch-9)

Target: (CogSketchTutorBundleCaseFn Workspace-3512933206 Subsketch-8)

Match Constraints

- (requireWithinPartitionCorrespondences Atmosphere)
- (requireWithinPartitionCorrespondences Planet)
- (requireWithinPartitionCorrespondences Relation)
- (requireWithinPartitionCorrespondences Sun)

Generally the mapping with the highest score is used for things like tutoring advice.

Mapping	Score	# MHs	# CIs
Mapping 249	0.6245	86	6
Mapping 330	0.5800	73	13
Mapping 316	0.5320	63	21

- 49 entity correspondences
- 212 expression correspondences
- 27 functor correspondences

Analogy Browser

Mapping 249

SME #1

Score: 0.6245

Base: `(CogSketchTutorBundleCaseFn Solution-3512933211 Subsketch-9)`

Target: `(CogSketchTutorBundleCaseFn Workspace-3512933206 Subsketch-8)`

Support	Base Item	Target Item	MH Score
(13)	Object-7578	Object-7652	0.1640
(12)	Object-7591	Object-7654	0.0720
(10)	Object-7592	Object-7655	0.0560
(9)	Object-7577	Object-7651	0.1520
(7)	Object-7579	Object-7653	0.0400
(6)	(ContainedGlyphGroupFn Object-7578 (TheList Object-7577 Object-7591 Object-7592))	(ContainedGlyphGroupFn Object-7652 (TheList Object-7651 Object-7654 Object-7655))	0.0520
(4)	Object-7576	Object-7650	0.0200
(4)	User-Drawn-Sketch-Layer-429	User-Drawn-Sketch-Layer-424	0.0160
(1)	(ConnectedGlyphGroupFn (TheList Object-7577 Object-7578 Object-7579 Object-7591 Object-7592))	(ConnectedGlyphGroupFn (TheList Object-7651 Object-7654 Object-7655))	0.0040
(1)	LookingFromSide-SubSketch	LookingFromSide-SubSketch	0.0080
(1)	PhysicalView-SubSketch	PhysicalView-SubSketch	0.0080

- 6 candidate inferences
- No reverse candidate inferences
- 49 expression correspondences
- 26 functor correspondences

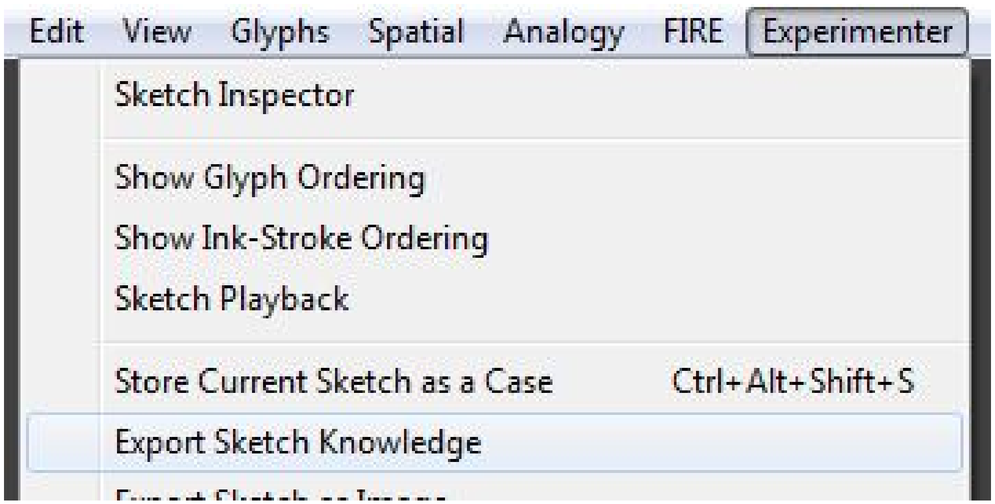
Legend:

= Match Hypothesis Details = Expression Details = Candidate Inference Explanation

Mapping view shows what was matched with what between subsketches

CogSketch as a Module

Reminder – you can export knowledge for use in other systems



Or access CogSketch directly using the KQML API

CogSketch API

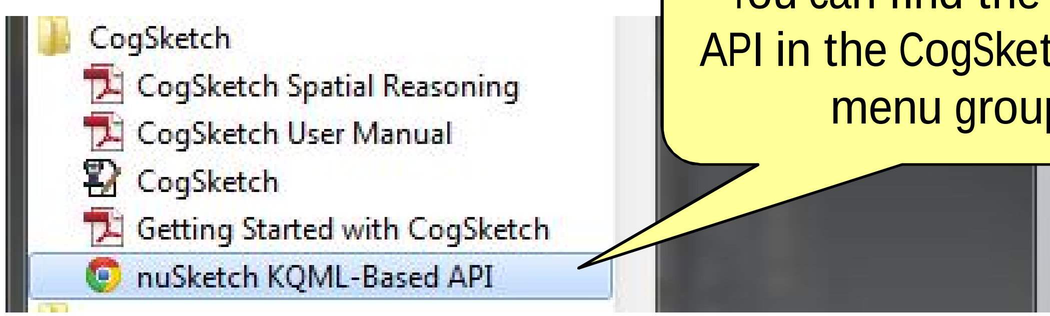
- Allows you to access CogSketch from code
- Socket-based, using KQML messages
- Documentation and sample client provided with CogSketch executable
- Suggestions for how we should extend the API to make it more useful for you are very welcome!

What Can I do with the API?

- Manipulate Sketches
- **(list-open-sketches)**
- **(get-active-sketch)**
- **(set-active-sketch :sketch-id <sketch id>)**
- **(save-sketch-to-file :sketch-id <sketch id>)**
- **(close-sketch :sketch-id <sketch id>)**
- **(open-sketch-from-file :filepath <full path to file (string)>)**
- **(create-new-sketch)**
- **(name-of-sketch :sketch-id <sketch id>)**
- **(user-namestring-of-sketch :sketch-id <sketch id>)**

What Can I do with the API?

- You can also manipulate subsketches, Layers and Glyphs
- **(list-bundles :sketch-id <sketch id>)**
- **(list-layers :sketch-id <sketch id> :bundle-id <bundle id>)**
- **(name-of-layer :sketch-id <sketch id> :layer-id <layer id>)**
- **(list-glyphs :sketch-id <sketch id> :layer-id <layer id>)**
- **(delete-glyph :sketch-id <sketch id> :glyph-id <glyph id>)**
- **(ask :sketch-id <sketch id> :query <query pattern> :num-responses <positive integer or :all>)**
- These are just examples of some of the available commands



You can find the whole API in the CogSketch start menu group