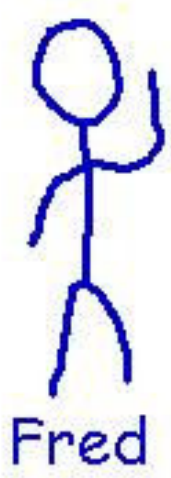
Visual Processing in CogSketch

Some Preliminaries

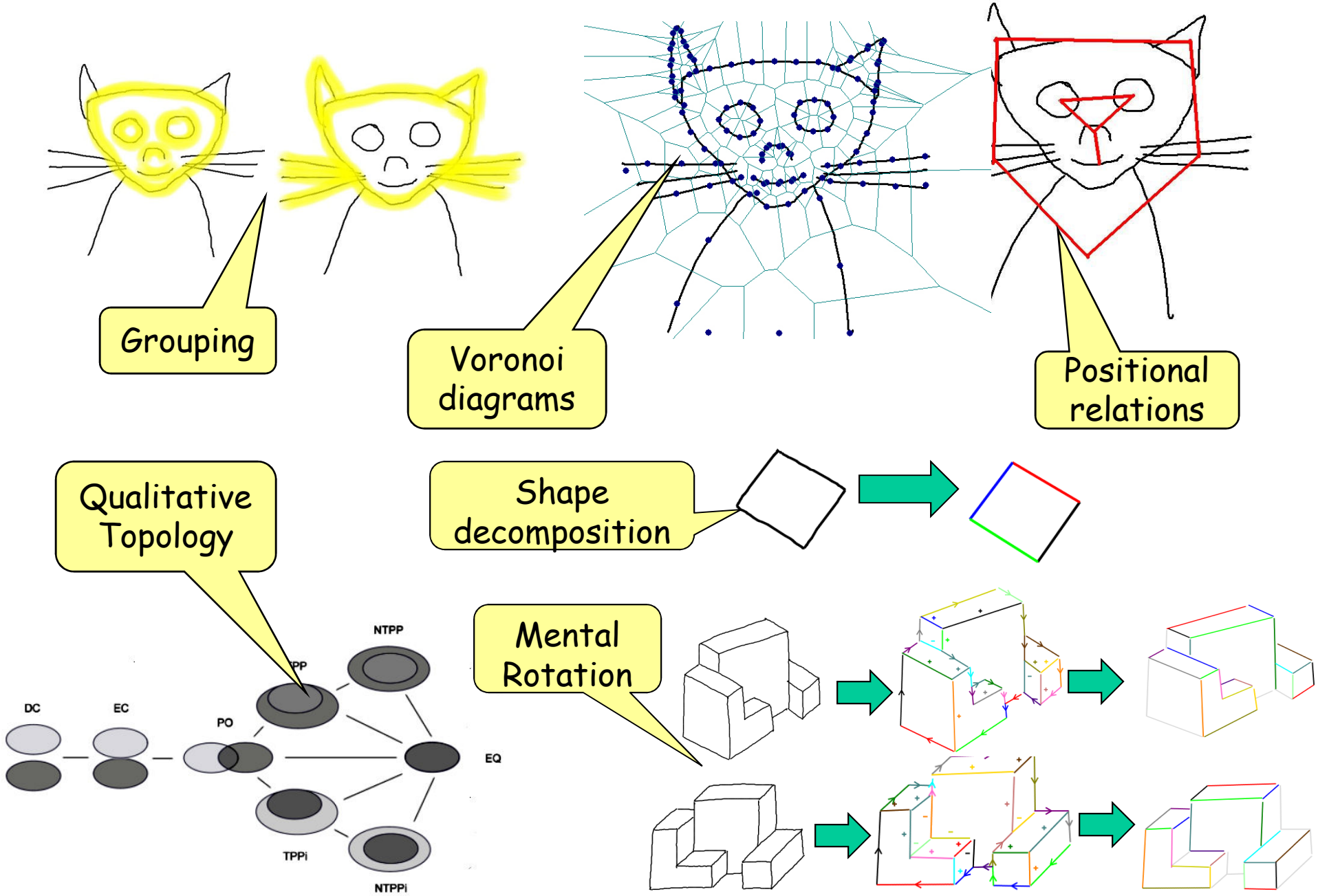
- Visual versus Spatial relationships:
  - Visual relationships: Computed over glyphs.
  - Spatial relationships: Hold between what is denoted by the glyphs
  - Visual relationships + genre + pose → Spatial relationships
- Our visual computations are inspired by psychological evidence when available
  - Best guesses otherwise
  - We expect it to continue to evolve

Glyphs



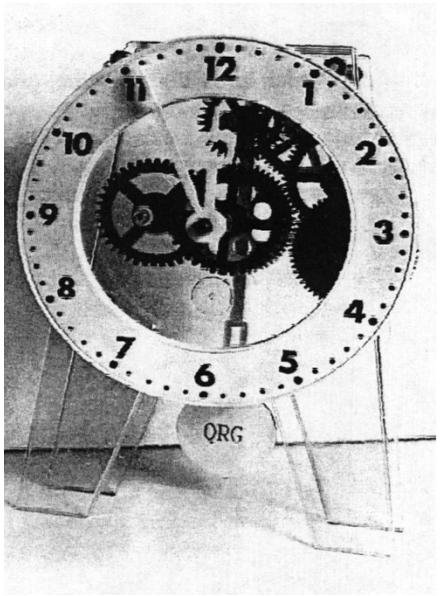
- Glyphs have two parts: *Ink* and *Content*
- Content = the entity represented by the glyph
  - Instance of some collection in the KB
- Ink = visual representation of the content
  - Consists of all of the ink drawn between button presses
- Visual properties are computed on the ink
  - Only coarse visual properties computed automatically
    - Bounding box
    - Closed contour (ink needn't be connected)
    - Major/minor axes
  - Small set of visual relationships between glyphs
  - Segmentation, other visual relationships computed on demand (e.g., perceptual sketchpad)

Some CogSketch spatial computations

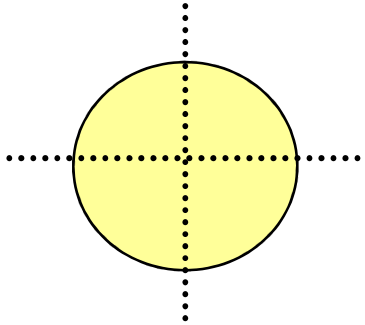


Qualitative Spatial Reasoning

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

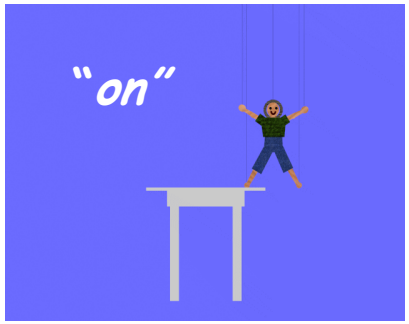


CLOCK project (Forbus, Nielsen, & Faltings 1991)



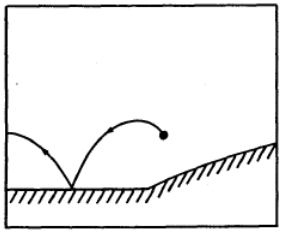
Spatial categories affect location judgments (Huttenlocher & Hedges)

Spatial language affects retrieval (Gentner & Feist, 2001)

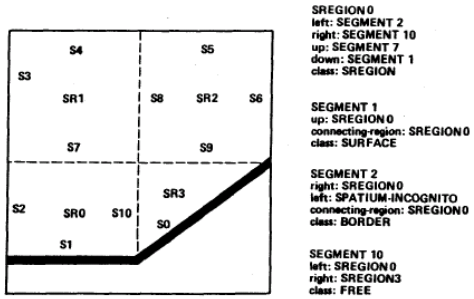


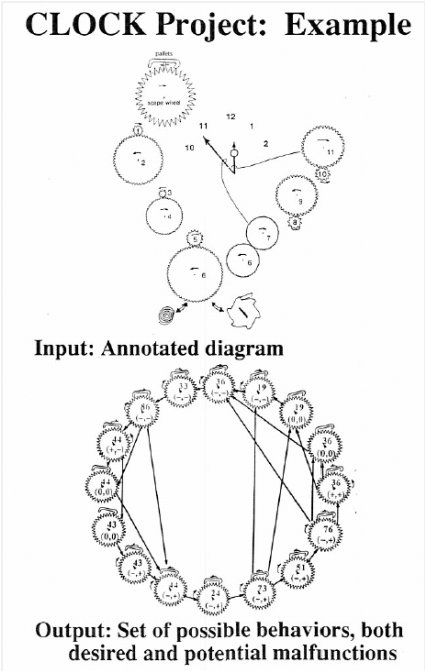
Metric Diagram/Place Vocabulary model

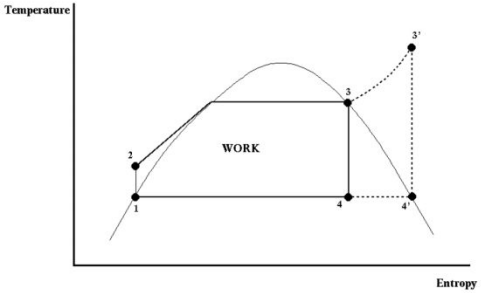
- Metric Diagram: Quantitative, visual representations and processing
- Place Vocabulary: Task-specific qualitative representations of shape and space, grounded in the metric diagram



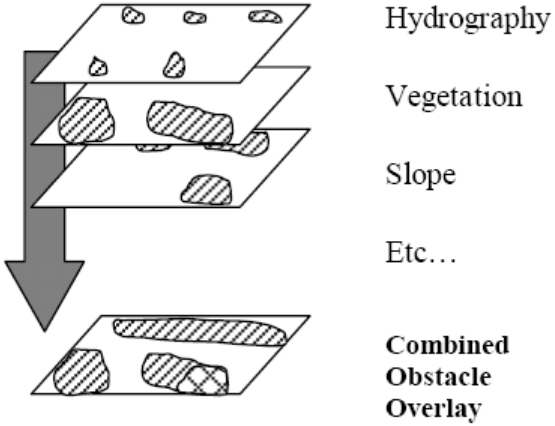
FROB (Forbus, 1980)





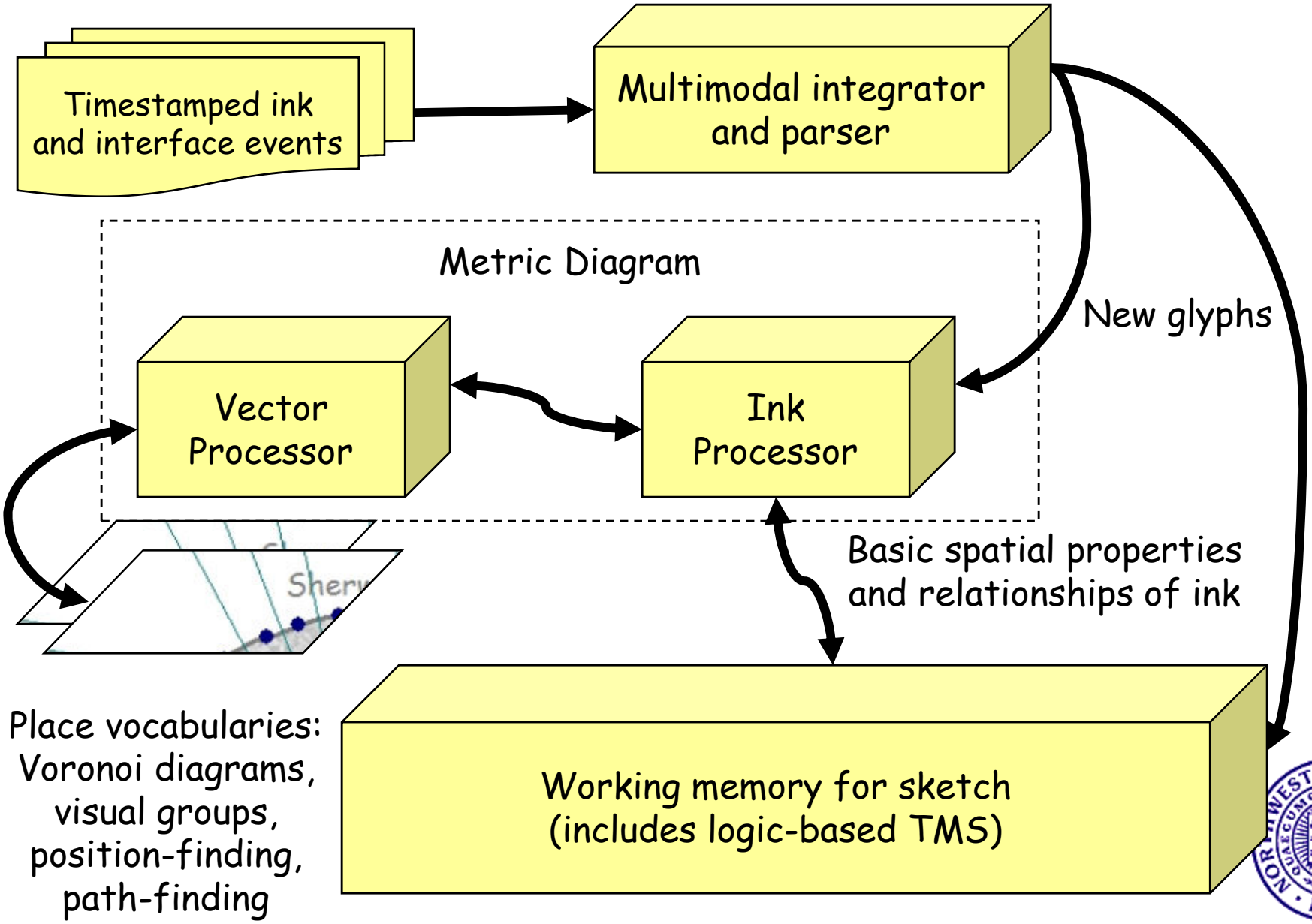


SKETCHY (Pisan, 1994)



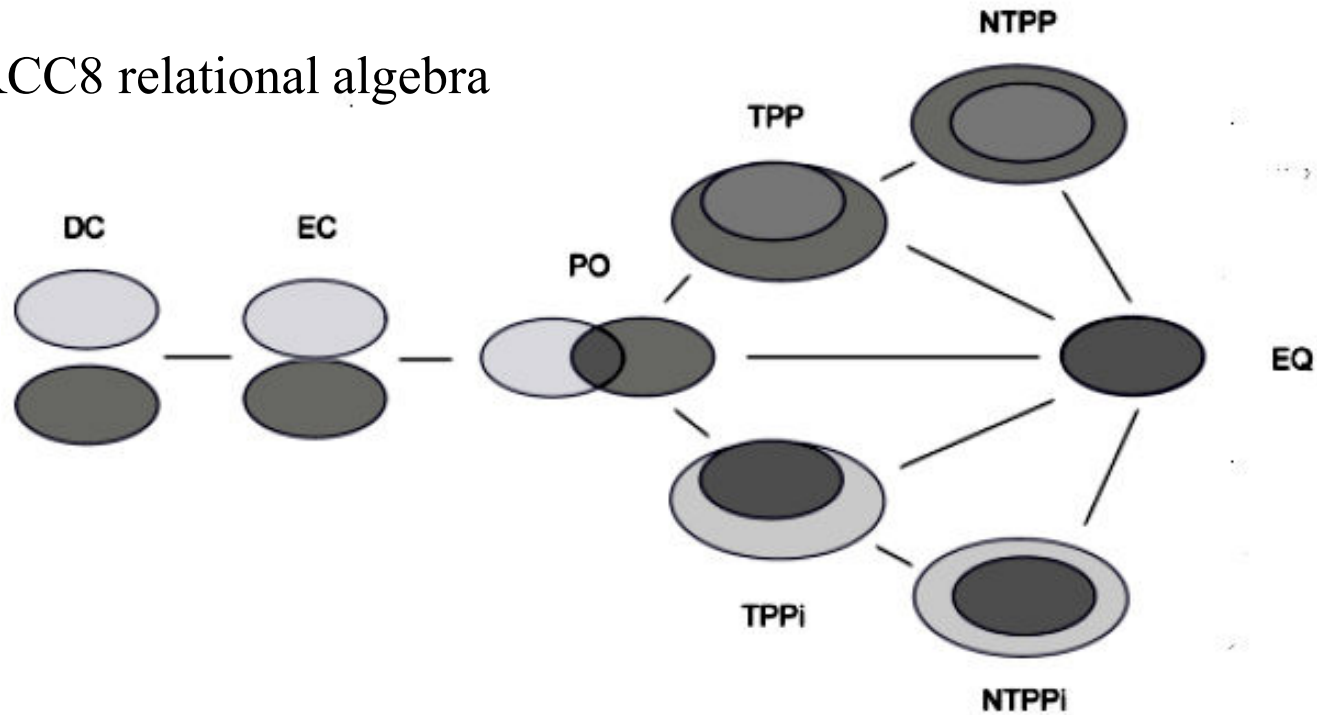
GIS-based Trafficability Reasoner (Donlon & Forbus, 1999)

Spatial Reasoning in CogSketch



Qualitative Topology

Cohn et al's RCC8 relational algebra



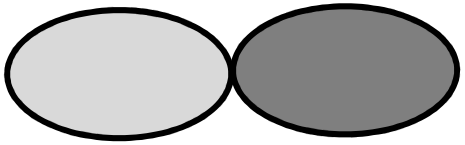
- Provides natural vocabulary for some visual concepts
  - Containment: NTPP, TPP
  - Touching: PO, EC

Using RCC8

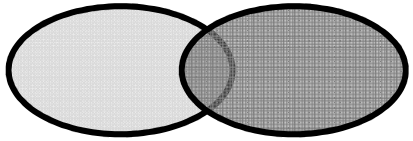
- Compute relationships directly from ink
  - Transitivity algebra unnecessary
  - Need to be clever about noise
- Computed between every pair of glyphs on a layer
  - Incrementally updated when a glyph is moved or resized
  - Only computed across layers on demand
- Internal uses
  - Controlling computation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

Higher-Level Topological Relations

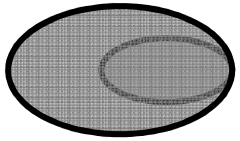
- objectsIntersect
  - The ink of the two glyphs intersects



- objectsOverlap
  - The interiors of the two glyphs overlap



- objectContains
  - One glyph lies within another glyph's area



- Not mutually exclusive
- Used in comparison

Contained Glyph Groups

- When more than one glyph is NTTPi, TPPi of some other glyph
  - Single-level, groups can be found recursively
-
```
(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

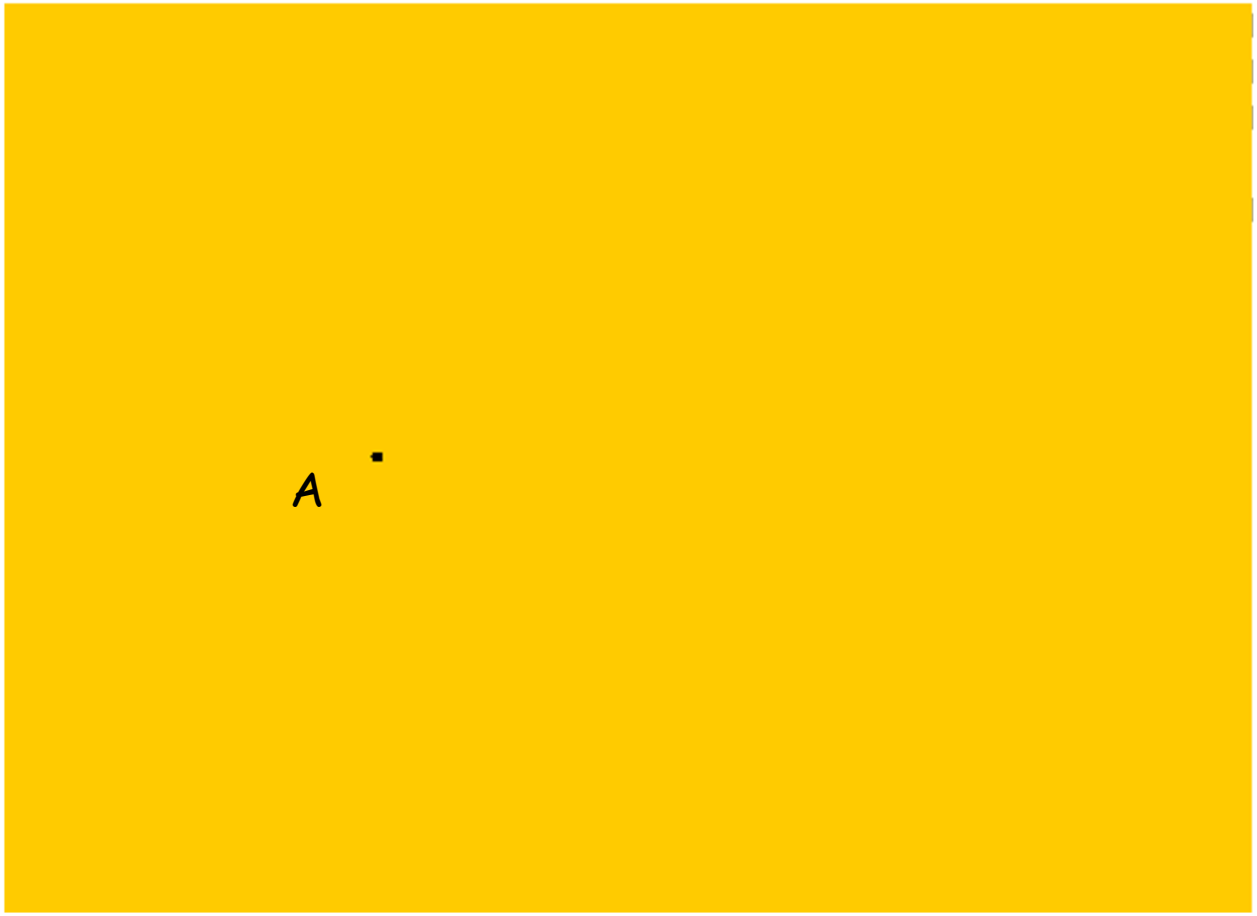
- Set of glyphs connected via EC or PO
-
```
(ConnectedGlyphGroupFn
  (TheList (GlyphFn Object-10 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-11 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-12 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-21 User-Drawn-Sketch-Layer-1)
   (GlyphFn Object-22 User-Drawn-Sketch-Layer-1)

   (GlyphFn Object-9 User-Drawn-Sketch-Layer-1)))
```

Computing Glyph Groups

- Connection graph: Nodes = glyphs, Edges between all pairs that are EC or PO
  - Connected Glyph Groups = connected subsets of connection graph
- Containment graph: Nodes = glyphs, Edges between all pairs that are TPPi or NTPPi.
  - Contained glyph groups = All glyphs with more than one glyph inside of them, only counting directly inside glyphs
- Incrementally maintained as sketch updated

Voronoi Diagrams: A tutorial



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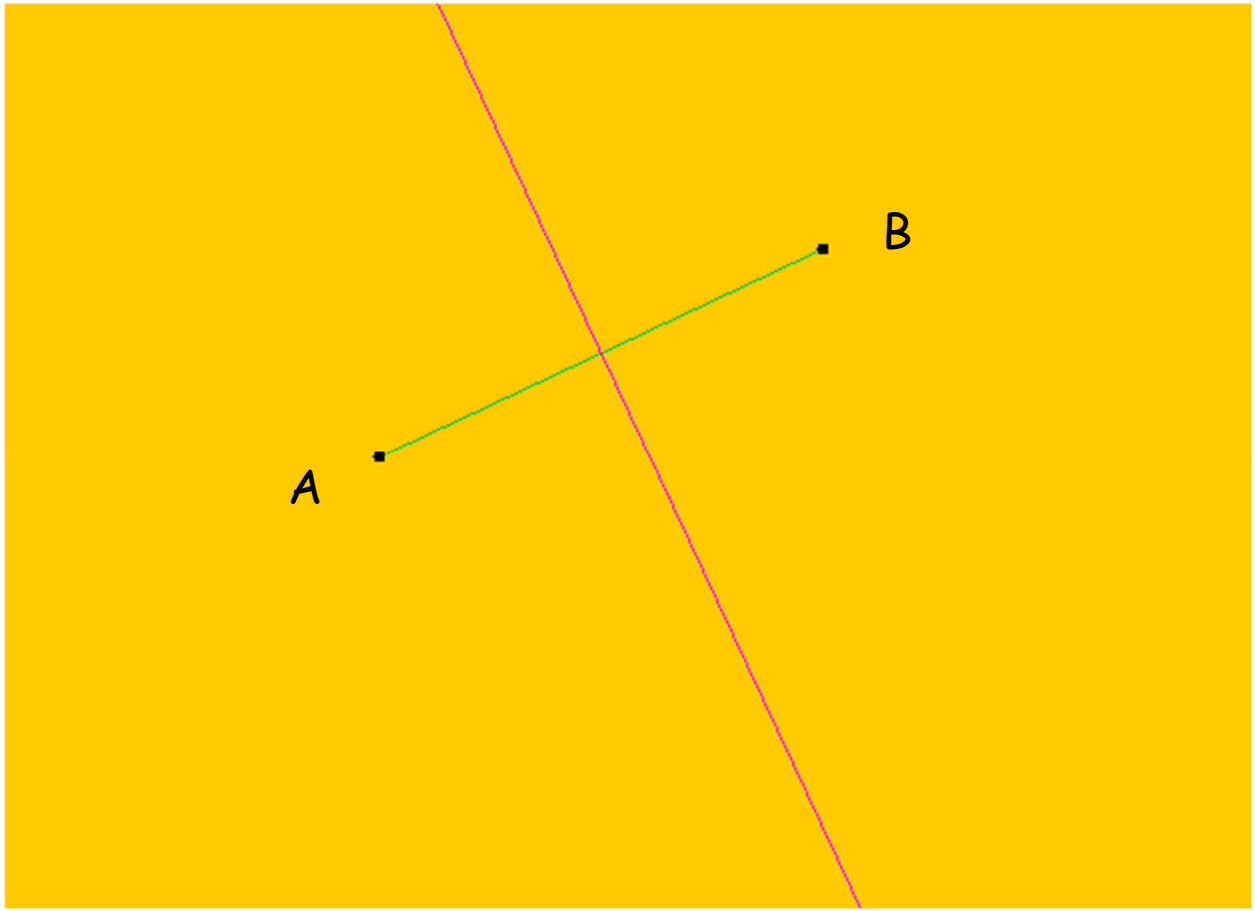
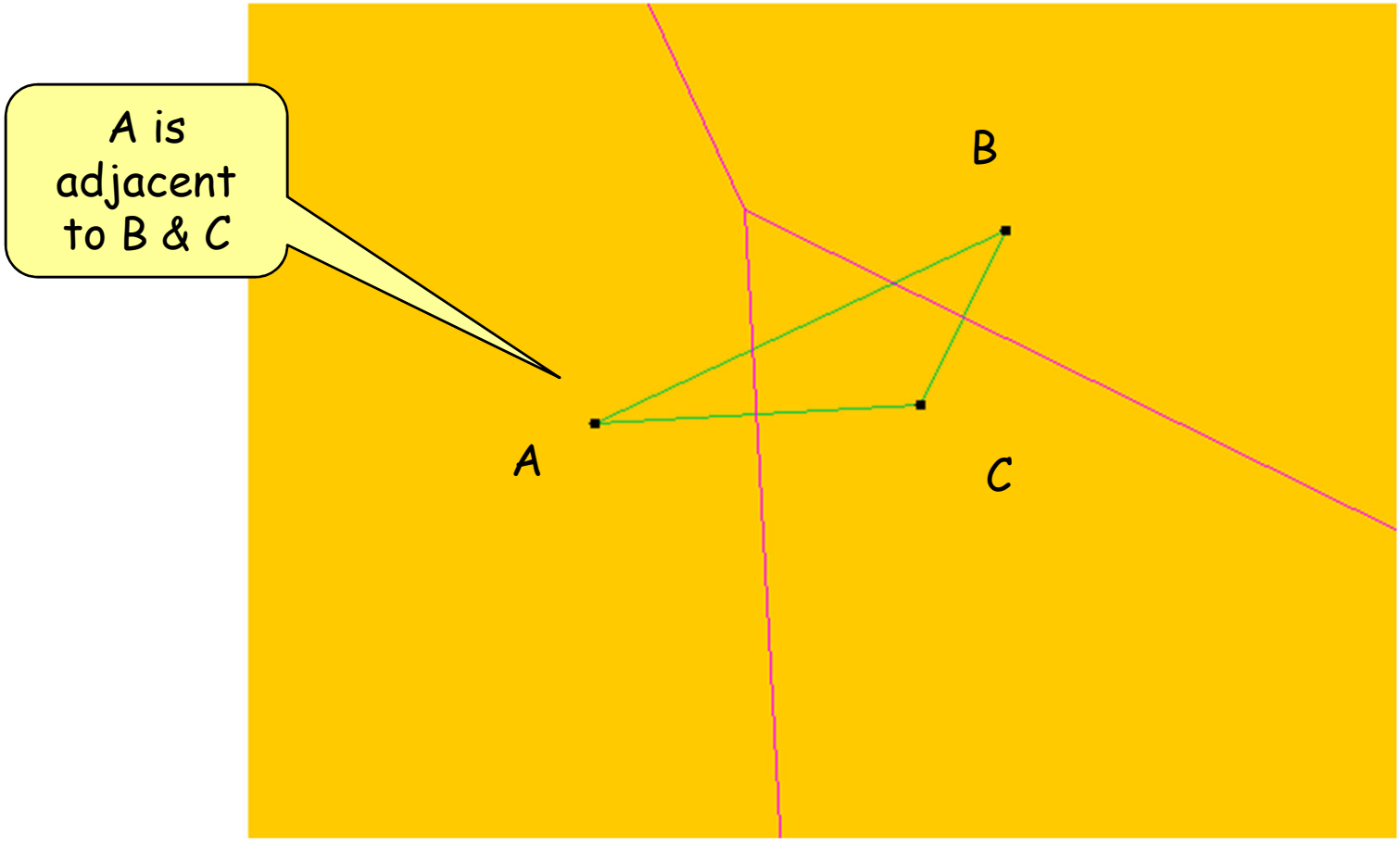


Red = cell boundary in Voronoi diagram
Green = arc in Delaunay triangulation
Voronoi diagrams and Delaunay triangulations are duals

Voronoi Diagrams: A tutorial



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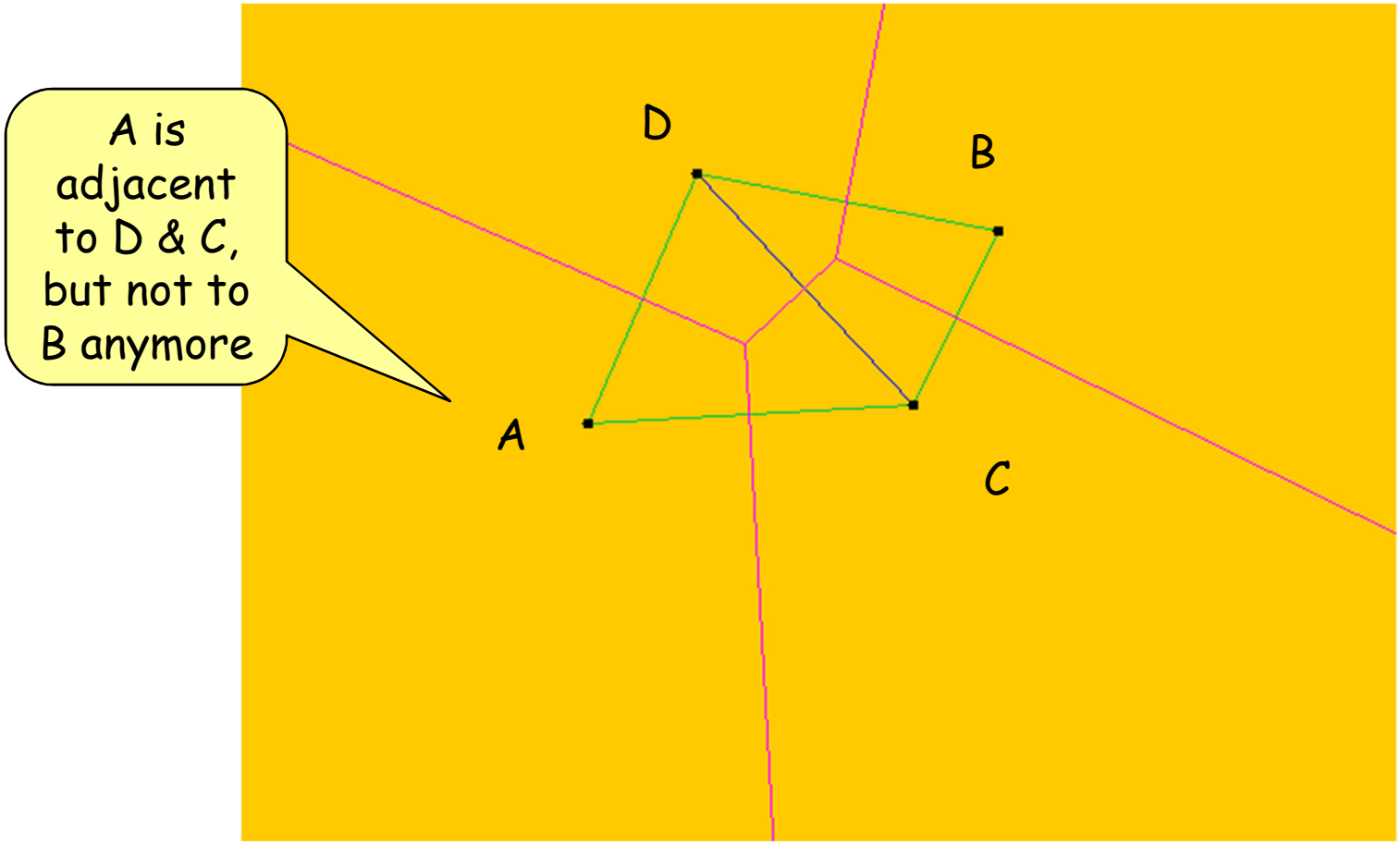
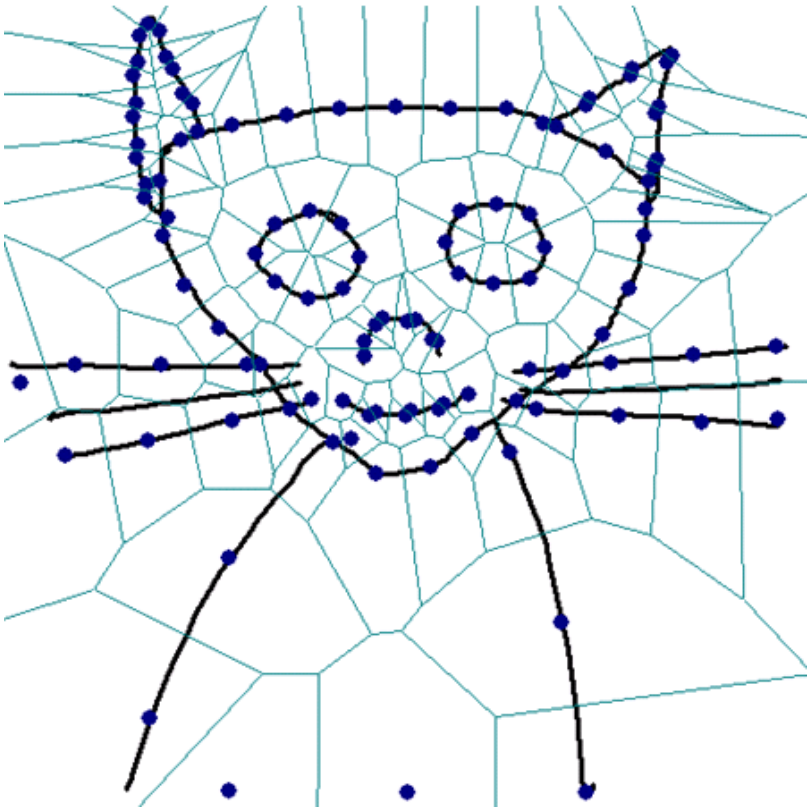


Edwards & Moulin (1998) argue that Voronoi diagrams are useful for capturing visual adjacency

Voronoi Relationships

- Provides a notion of adjacency

- Generalizing to glyphs:
  - Use sample points along contour of glyphs to define standard Voronoi (site-level Voronoi)
  - Label edges with glyph membership
  - Define glyph-level relations in terms of site relations
    - E.g., two glyphs are **`siteAdjacent`** $\Leftrightarrow \exists$ samples on glyphs | edge-connected in site-level Delauney triangulation



- One Voronoi diagram computed per subsketch in CogSketch

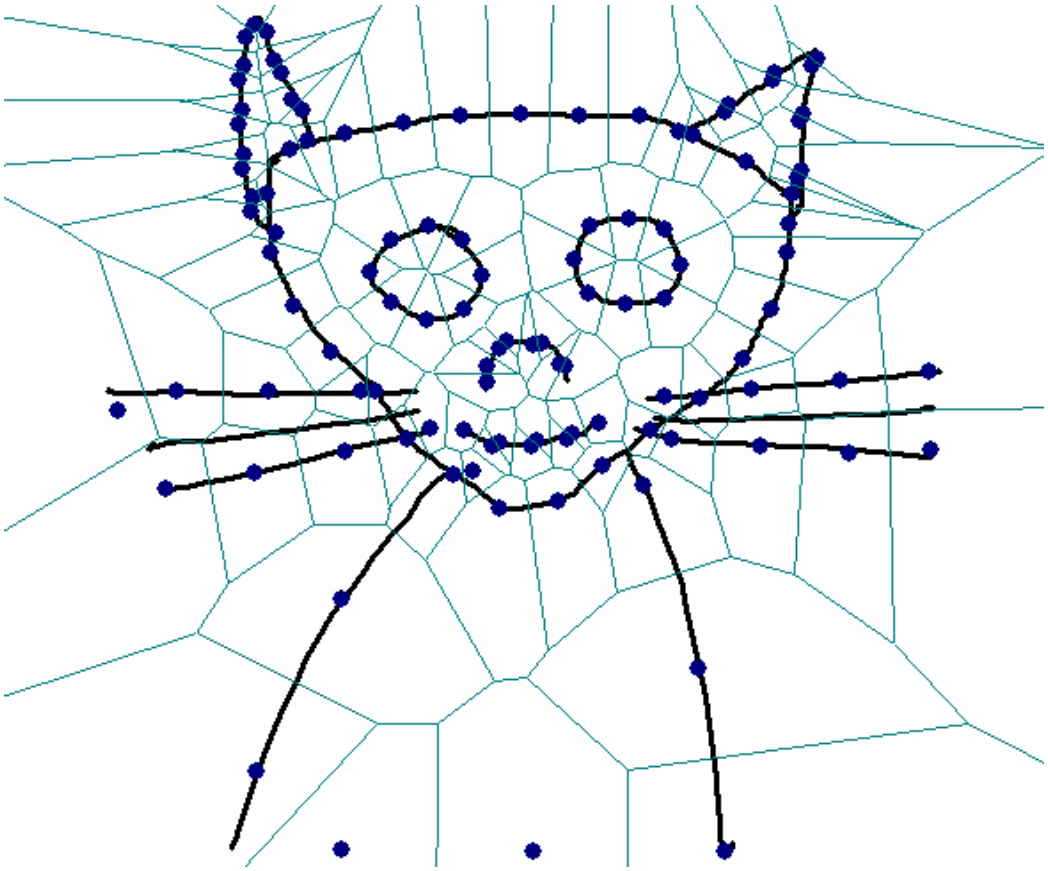
Positional Relations

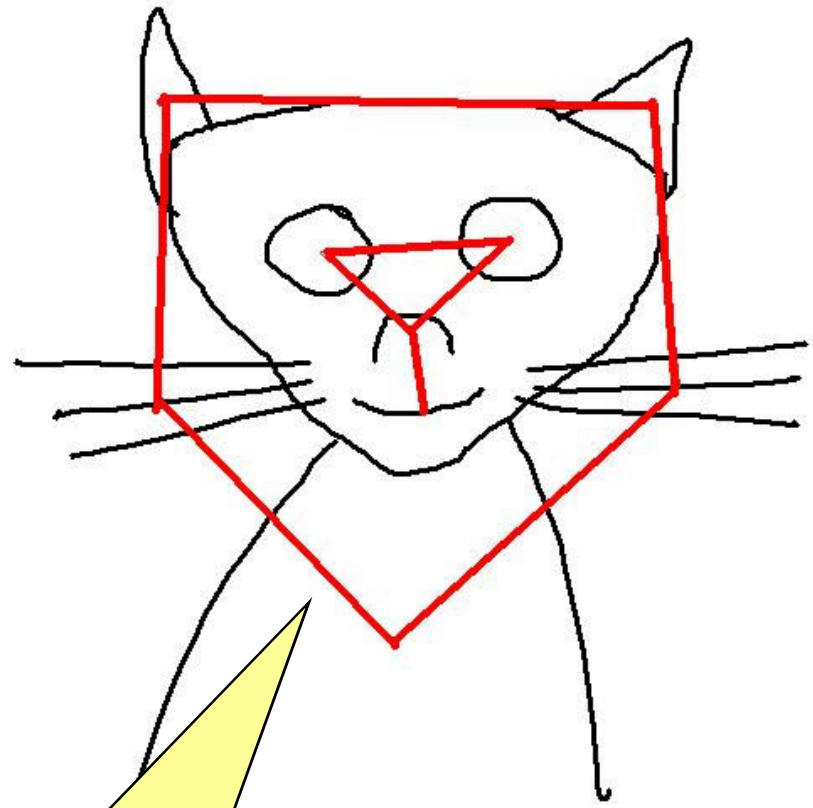
- Provide qualitative position, orientation information with respect to global frame of reference
  - For glyphs, `leftOf`, `rightOf`, `above`, `below`
  - For contents, depends on genre and viewpoint
    - Physical/side: Same as glyphs
    - Geospatial/TopDown: `northOf`, `southOf`, `eastOf`, `westOf`
    - 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 `siteAdjacent` on Voronoi diagram
  - Can also be computed on demand
- Hypothesis: This local neighborhood structure corresponds to default encoding method in human sketch perception

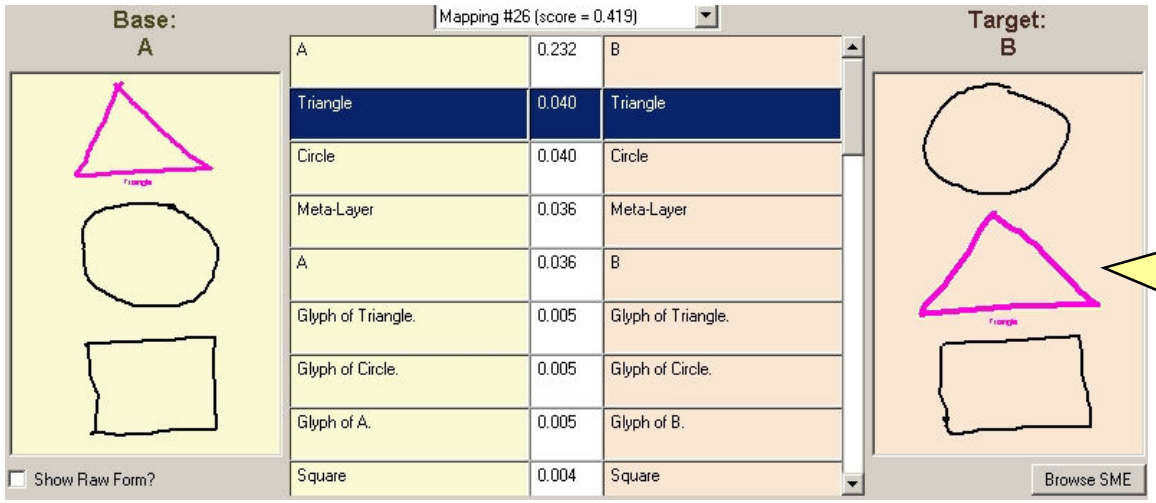
Voronoi adjacency guides positional relation finding



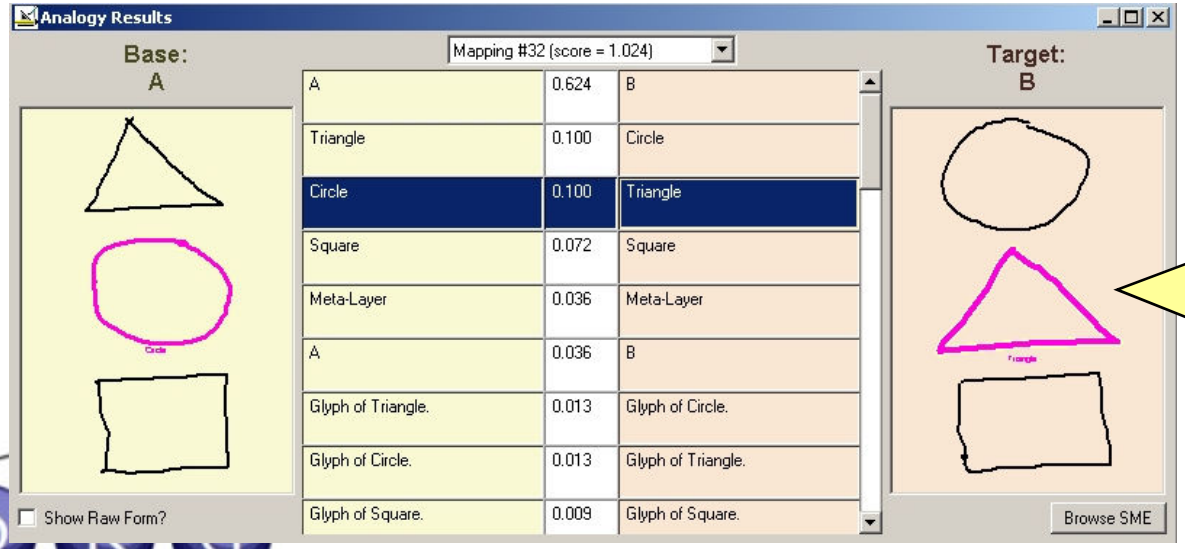


Positional relations only created between site-adjacent glyphs

Positional Relations help frame visual structure



Corresponds to what people choose in fast response-time task



Corresponds to what people choose when given more time

Perceptual Sketchpad

Perceptual Sketchpad Motivation

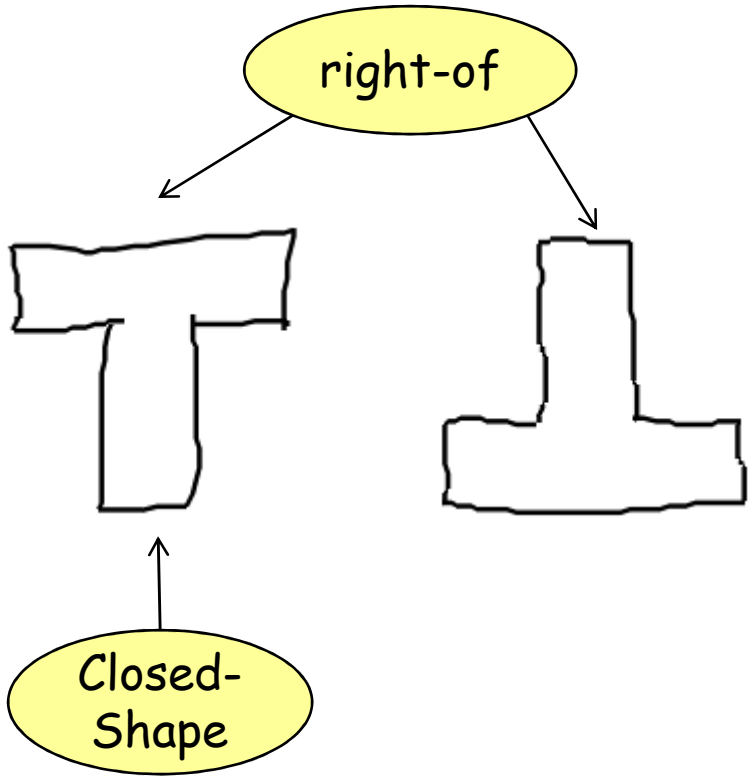
- Facility for experimenting with expressive representation of shapes
  - Decomposing glyphs
  - Within-glyph relationships also important
    - e.g., symmetry
  - Modeling mental rotation
- Still experimental, hence separate subsystem
  - Not all CogSketch users need it
  - Is now being integrated into educational worksheets

Understanding Form

- Focus is on understanding the form of glyphs
  - *Don't* recognize a glyph
  - *Do* recognize that two glyphs are the same shape
  - Identify transformations between two glyphs' shapes
    - Scaling
    - Rotation
    - Reflection

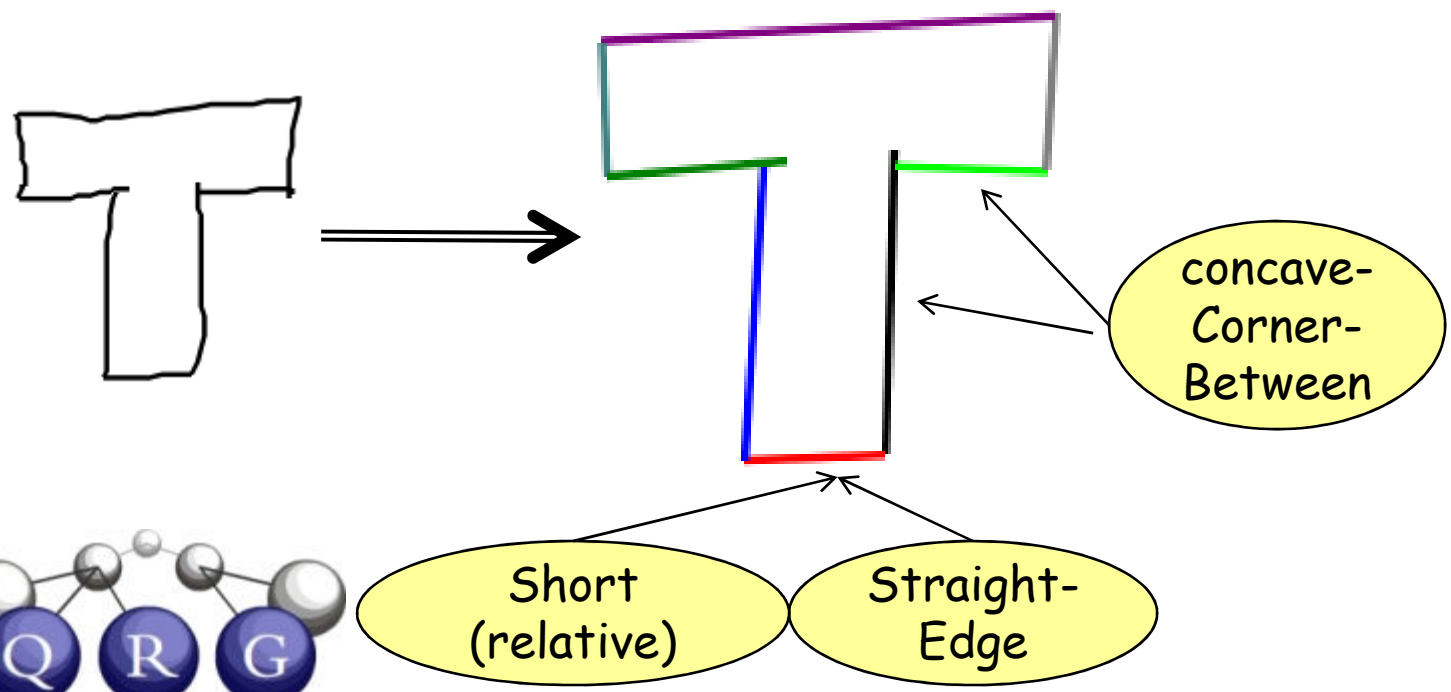
Three Levels of Representational Focus

1) Object-Level Representation
   - Default CogSketch representation level
   - Glyphs are the entities
   - Represent attributes of, relations between glyphs



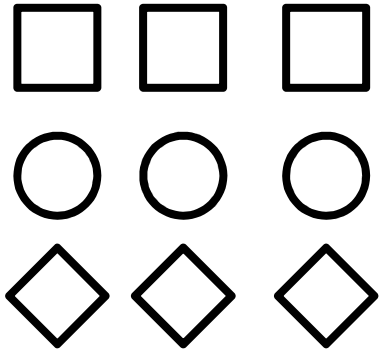
Three Levels of Representational Focus

2) Edge-Level Representation
   - Glyph is automatically segmented into edges
   - Edges are the entities
   - Represent attributes of, relations between edges within a glyph



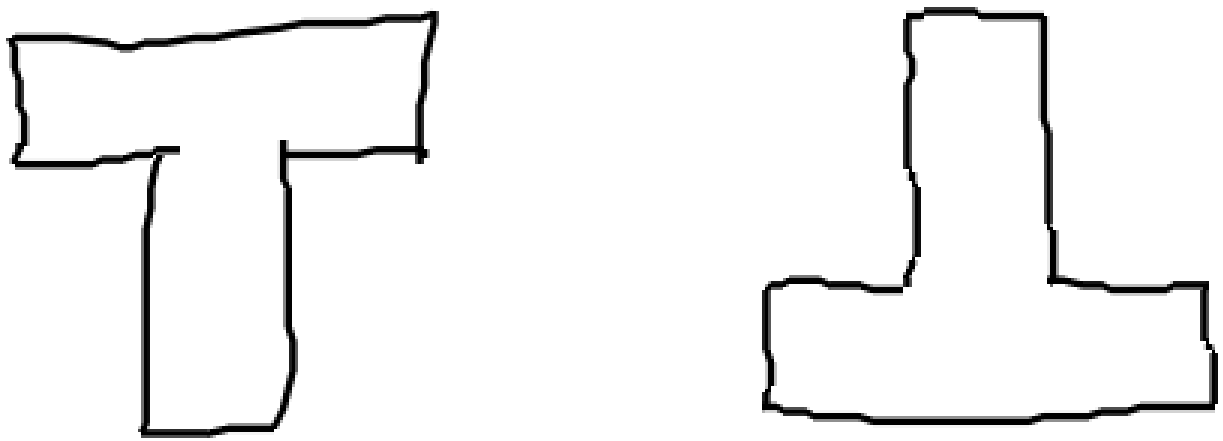
Three Levels of Representational Focus

3) Group-Level Representation
   - Glyphs grouped together based on similarity



Shape Relations

1) Compare two glyph's edge representations to find corresponding edges
2) Compare orientations of corresponding edges to identify rotations or reflections



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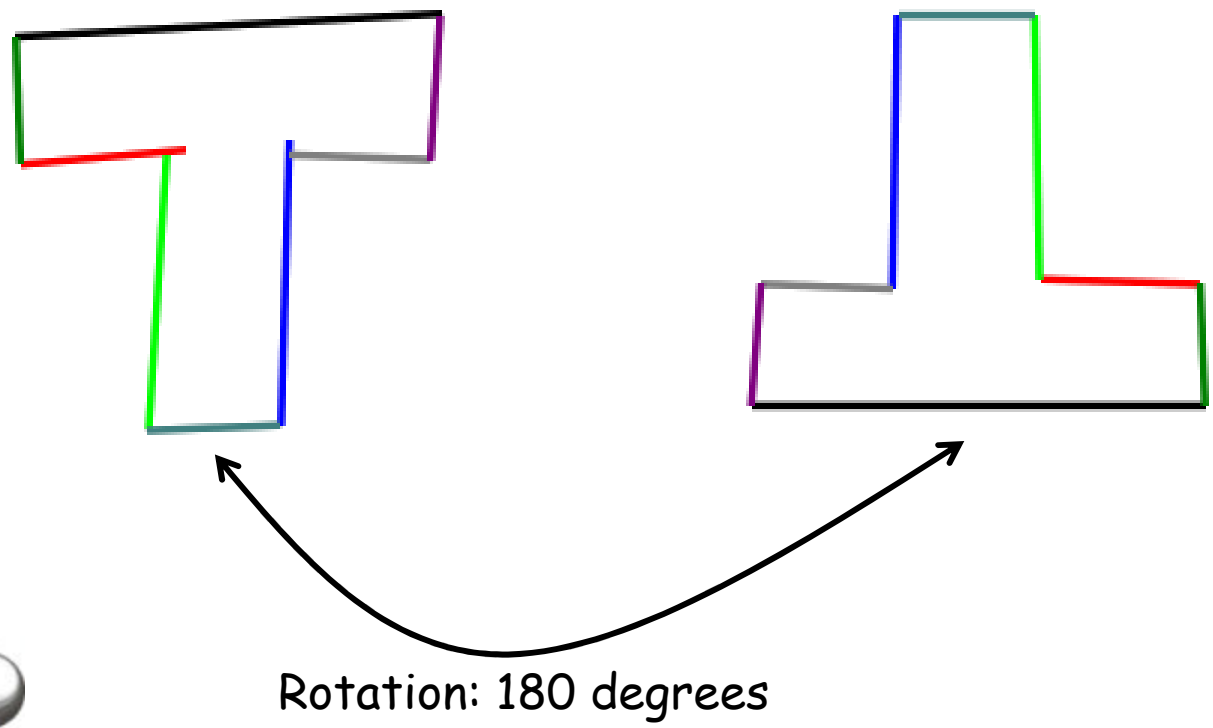

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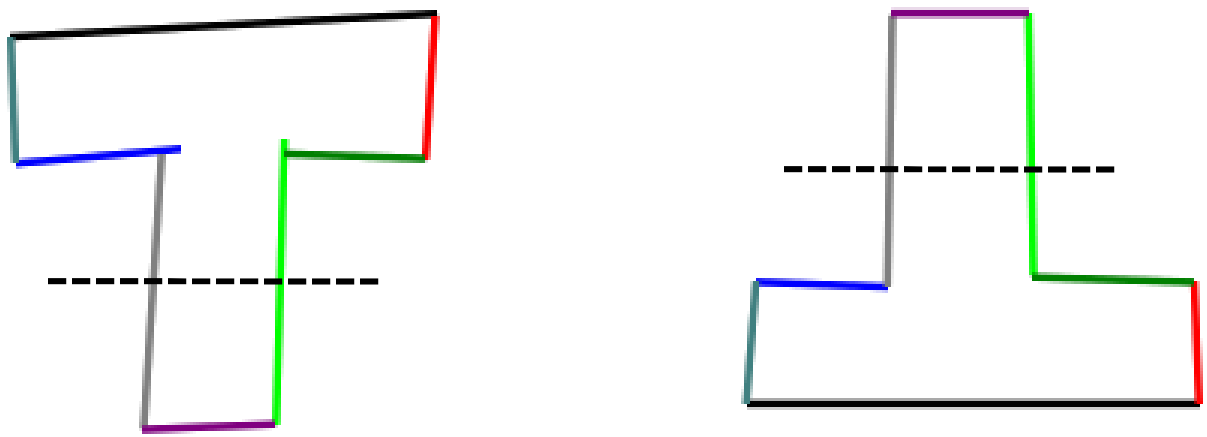


Reflection: X Axis

Sampling of Spatial Vocabulary

Objects

- Relations
  - Relative position
  - Topology
    - Intersect, Overlap, Contains
  - Alignment
    - Centered-On
  - Shape Relations
    - Rotation
    - Reflection
- Attributes
  - Fill/Edge color
  - Closed vs. Open
  - Relative size
  - Symmetry

Sampling of Spatial Vocabulary

Edges

- Relations
  - Corners
    - Concave/Convex
  - Relative orientation
    - Parallel/Perpendicular
- Attributes
  - Straight/Curved/ Elliptical
  - Relative length

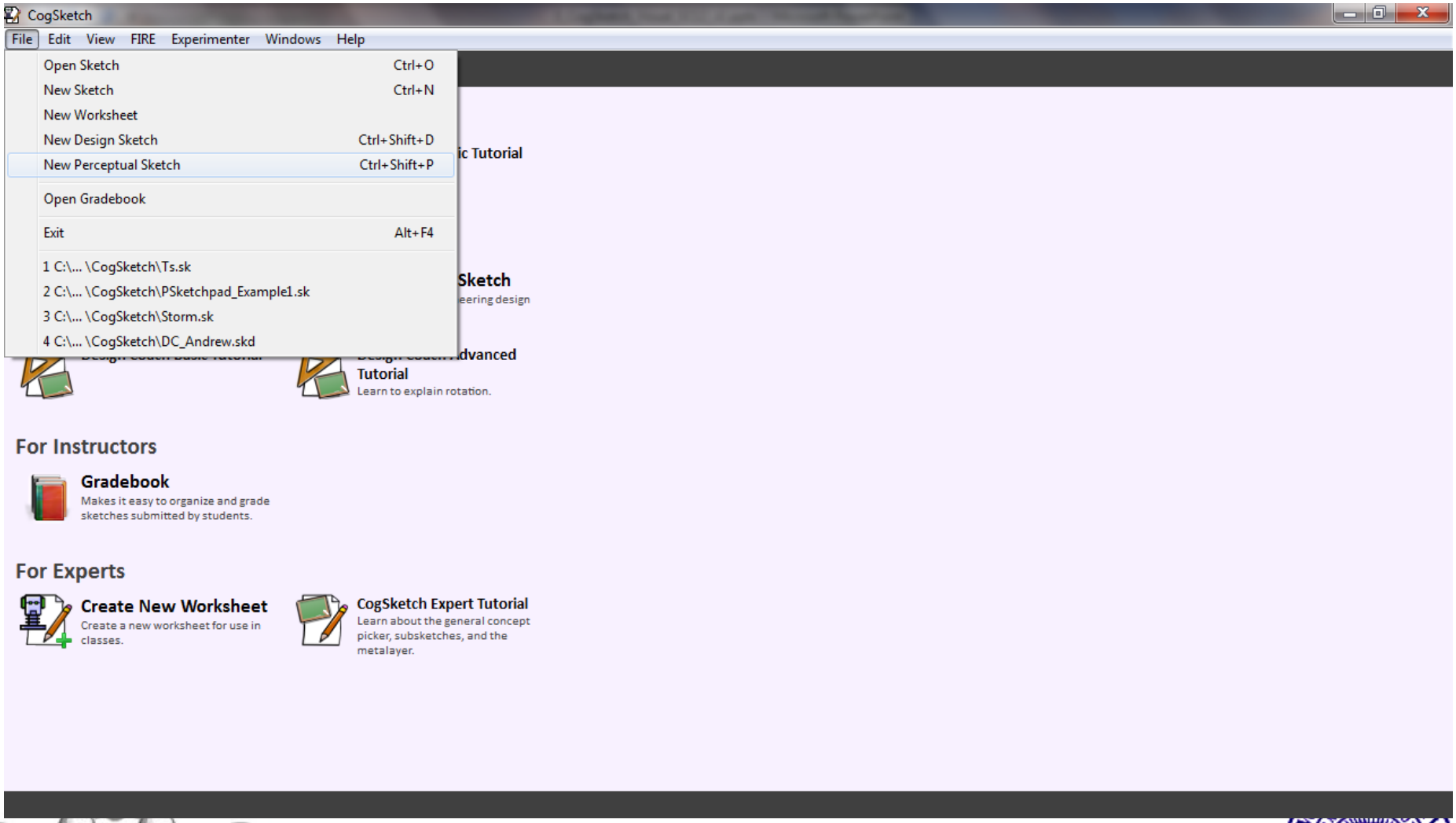
Using the Perceptual Sketchpad

- 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



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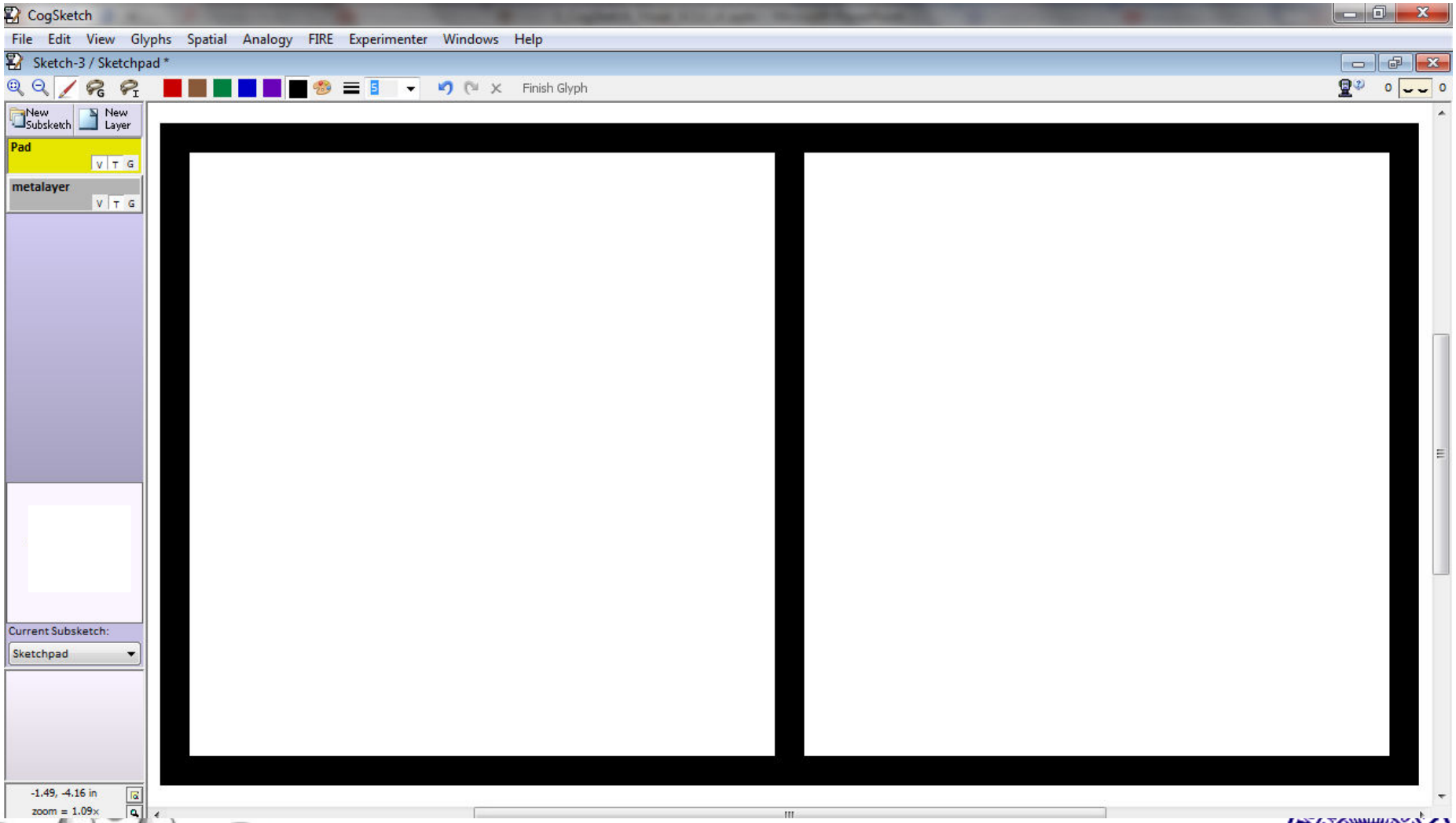

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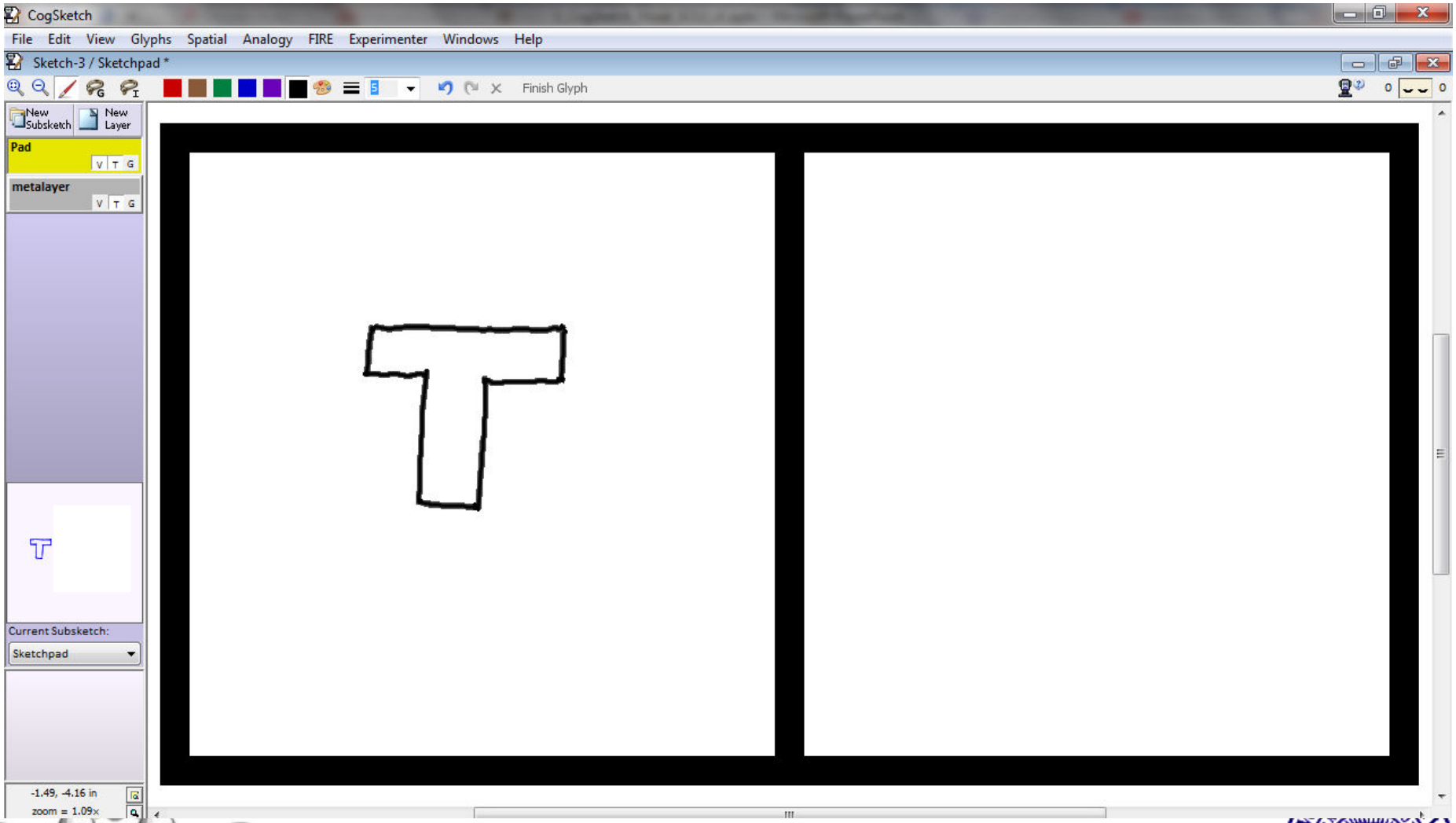

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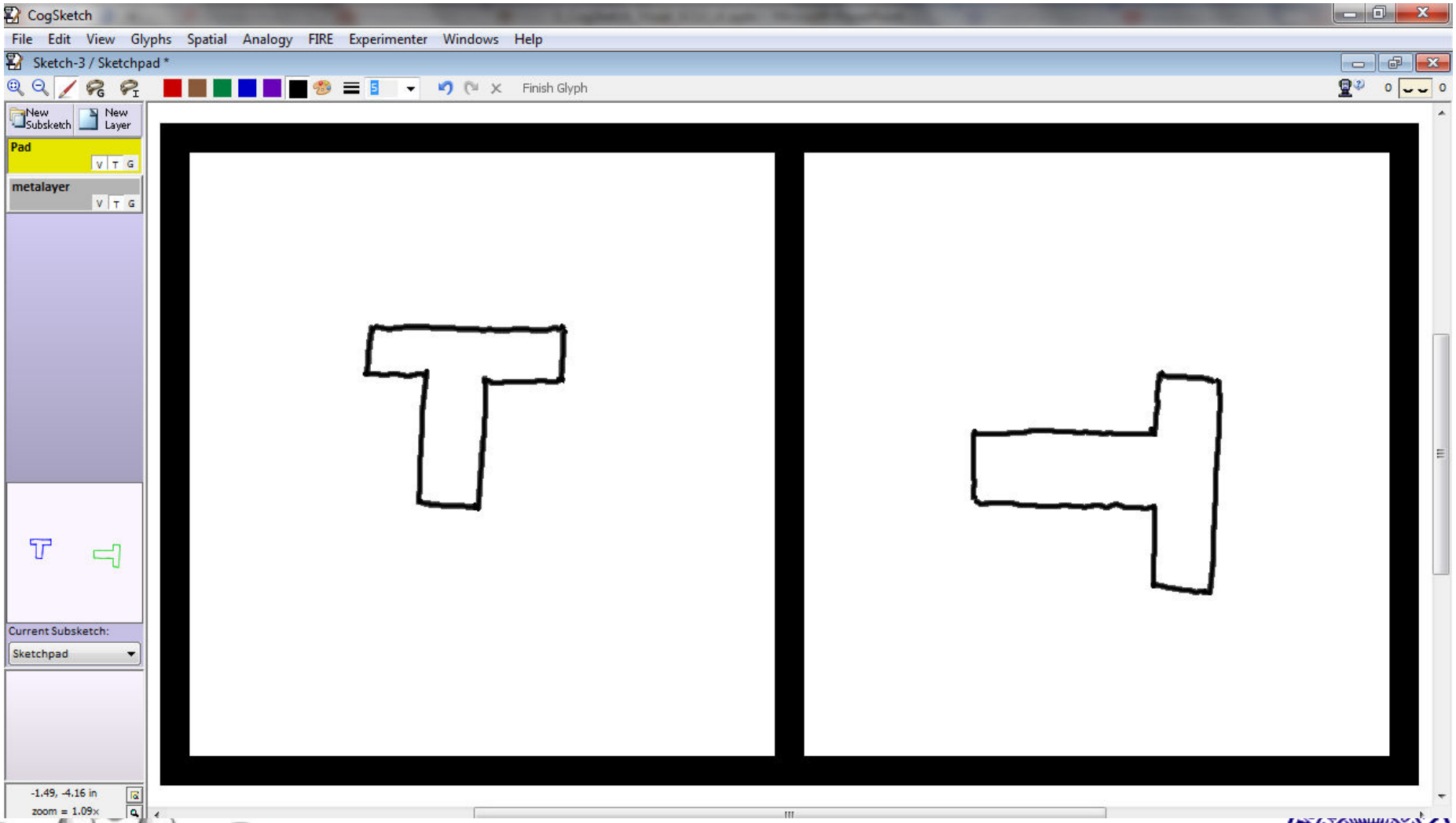

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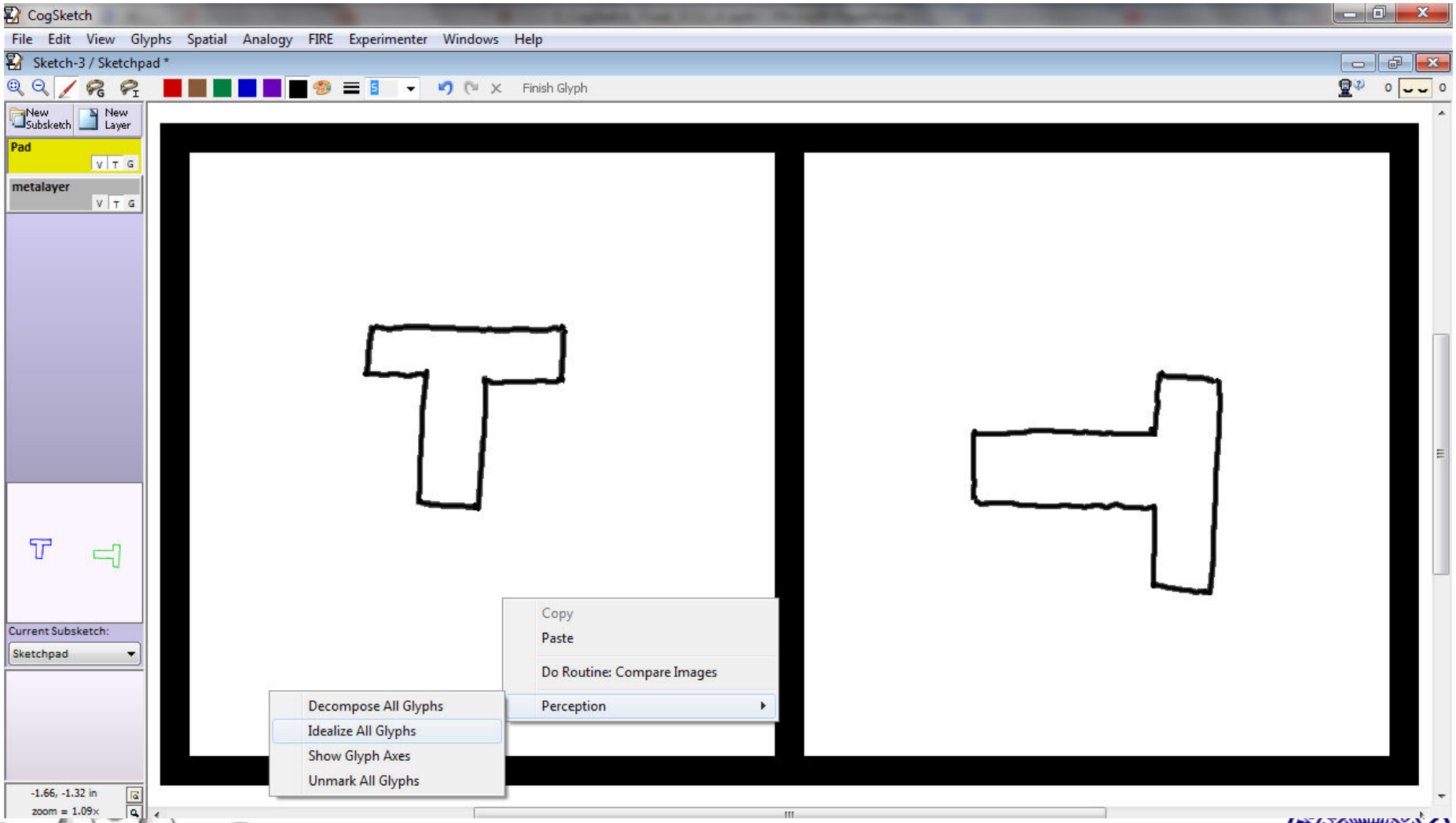

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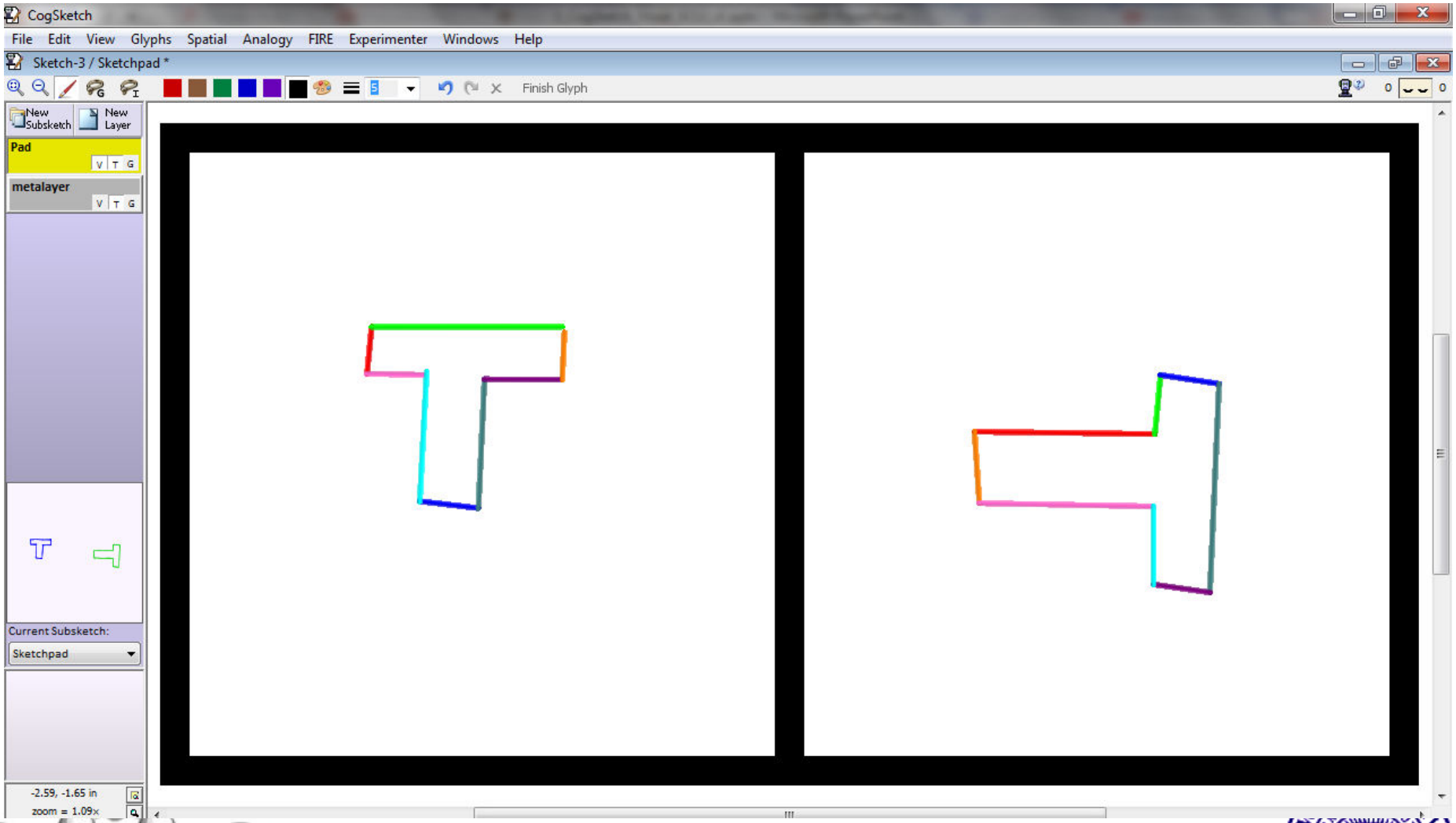

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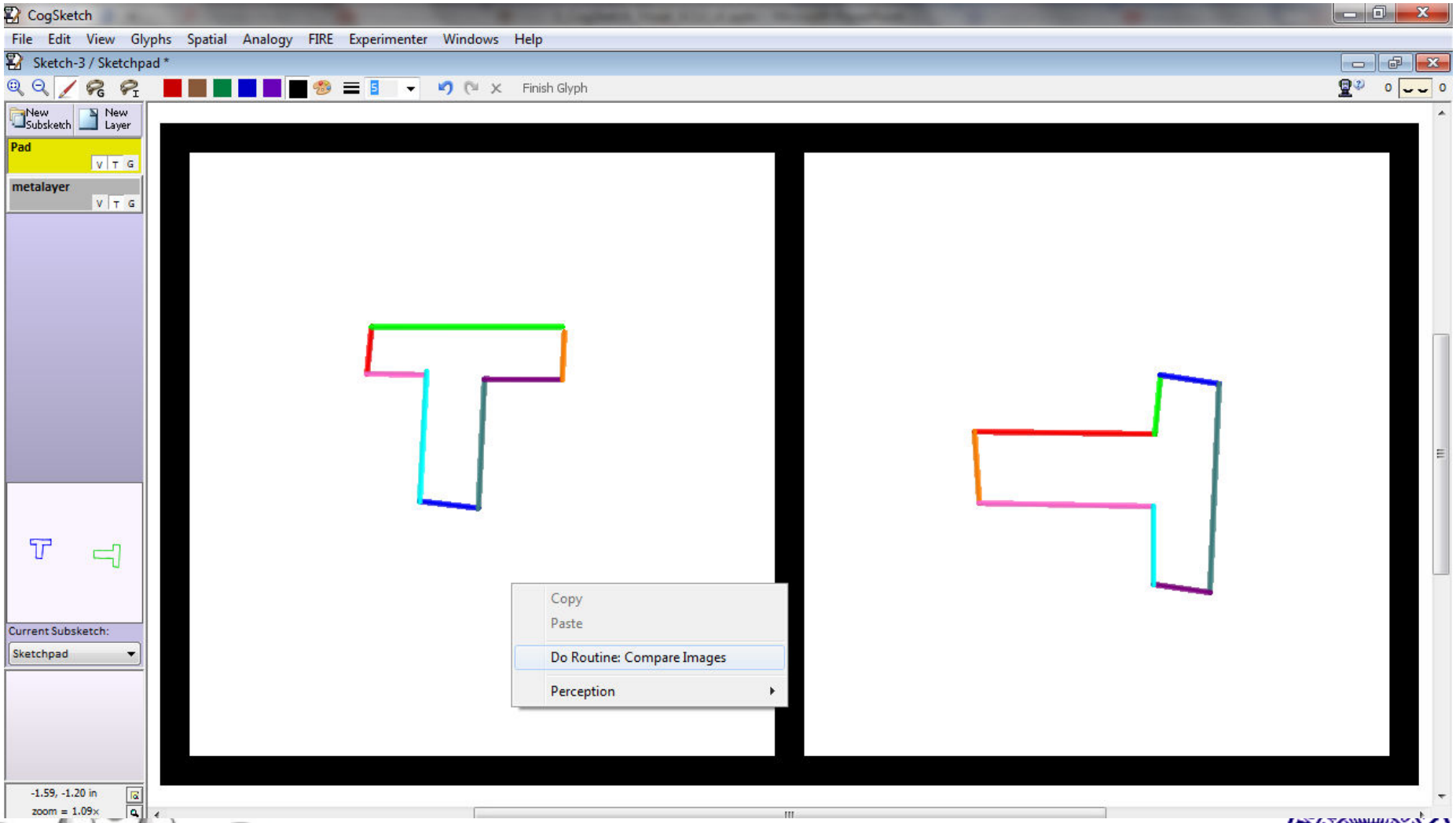

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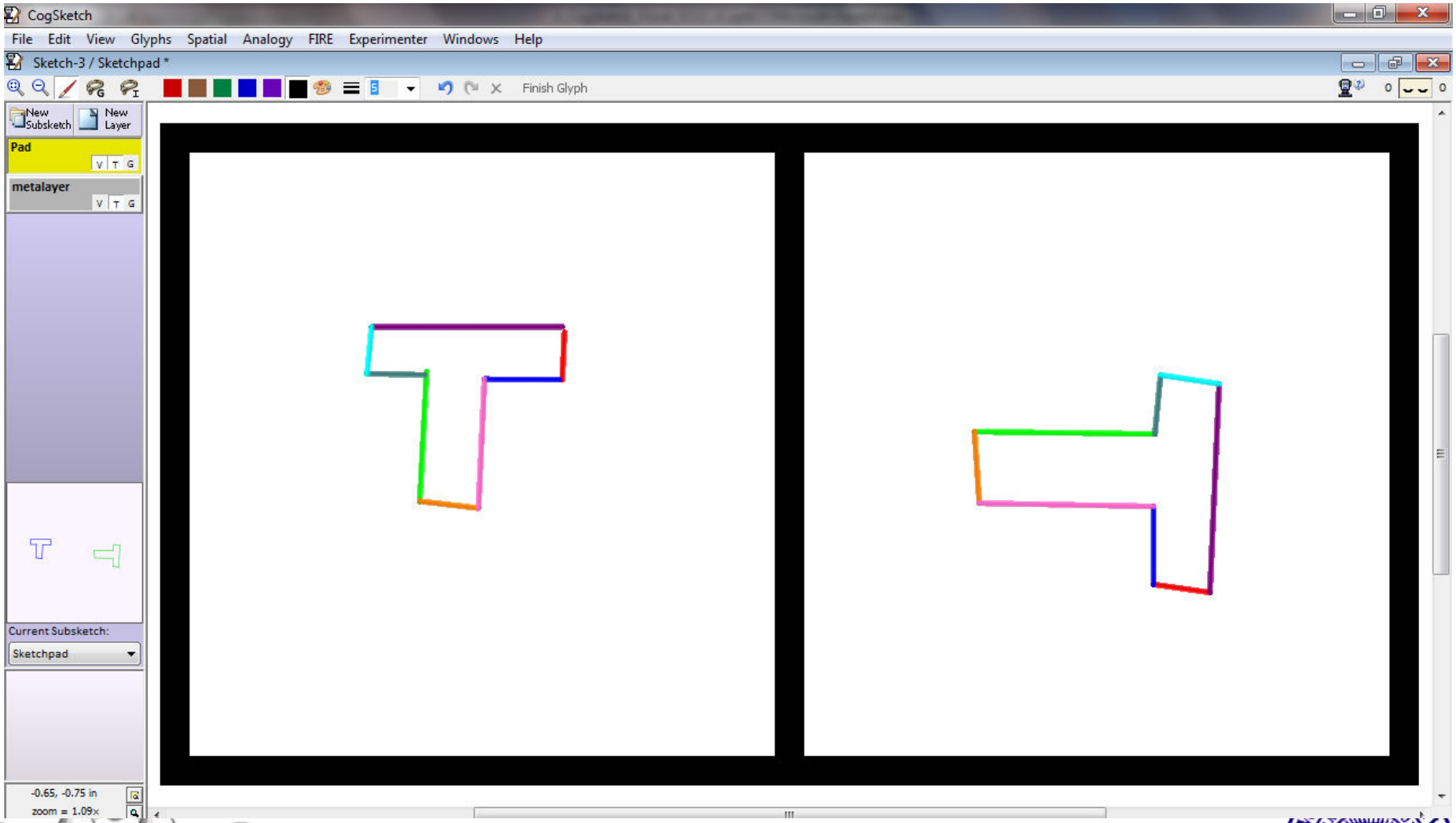

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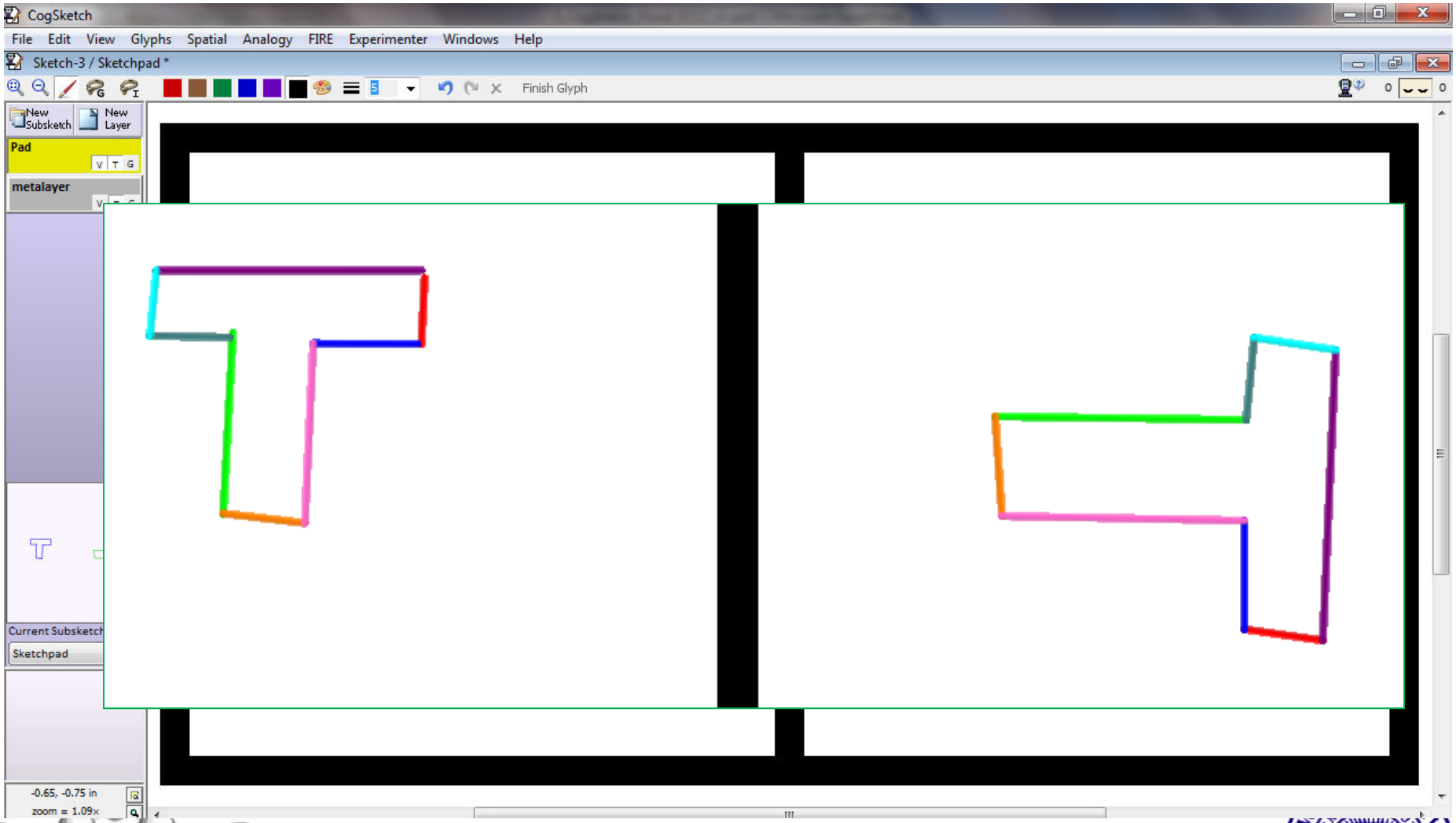

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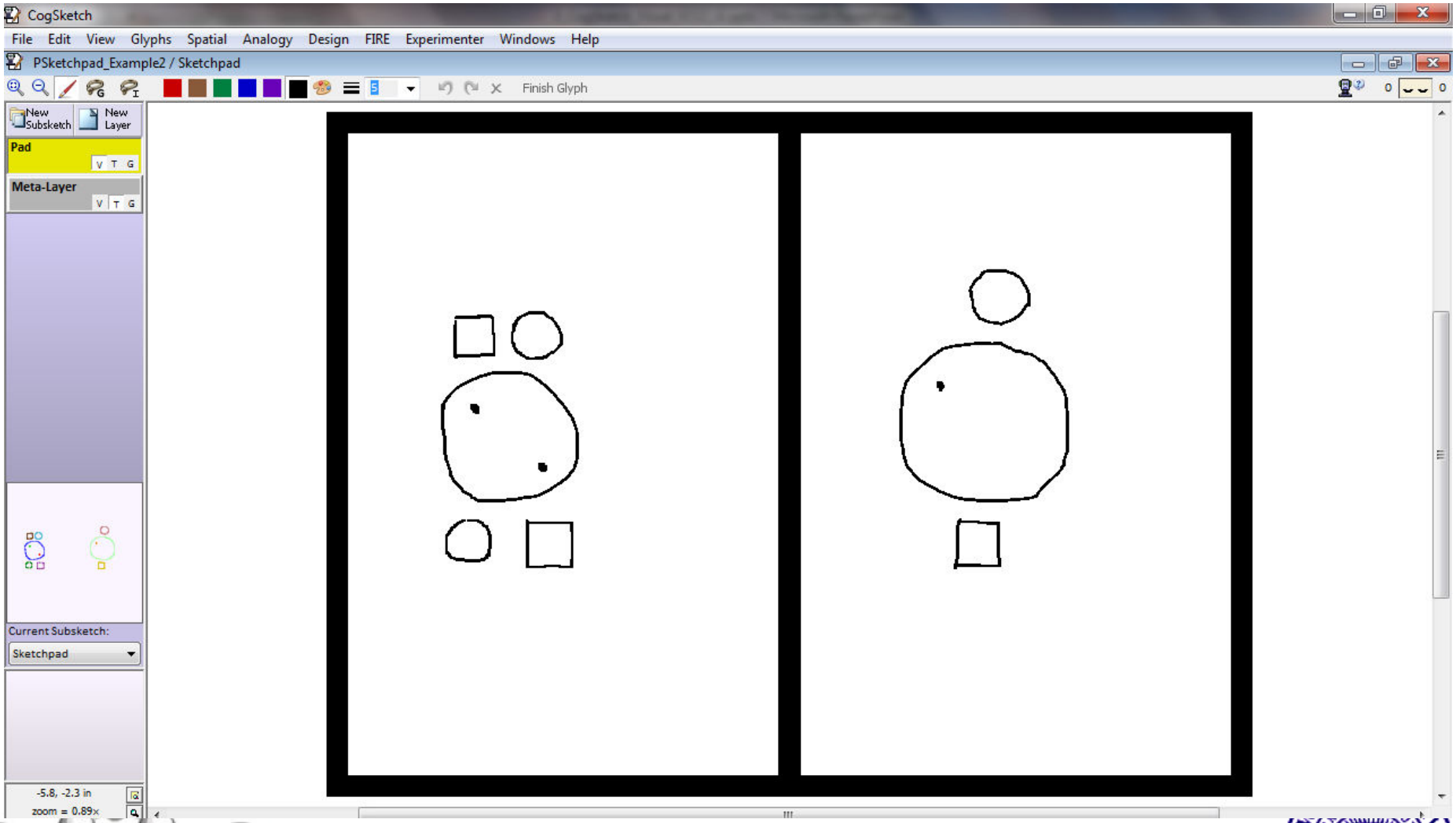
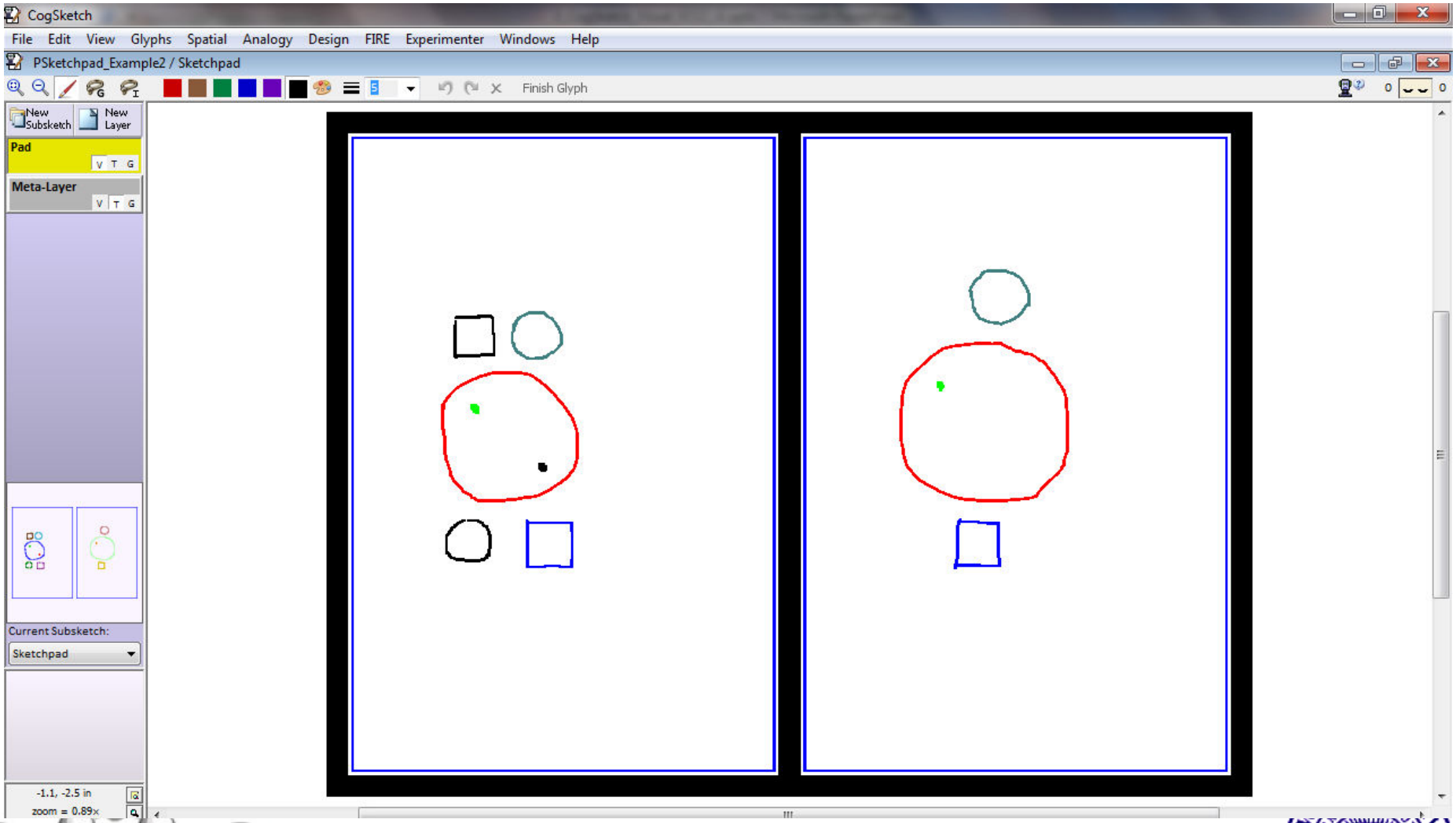


PSketchpad_Example2

Using the Perceptual Sketchpad



PSketchpad_Example2

Using the Perceptual Sketchpad

- If there is one glyph in each entry
  - Edge representations will be used
- If there are multiple glyphs
  - Object representations will be used
- Elements will be color-coded to indicate correspondences
  - Right-click and choose “Unmark all glyphs” to remove colors