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ADVANCING THE STATE OF THE ART

QuickDraw: Improving Drawing for Geometric Diagrams

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Diagrams Can Be Tricky

Important in several disciplines

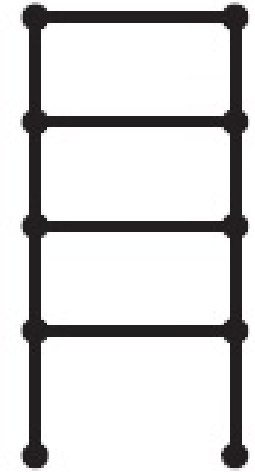
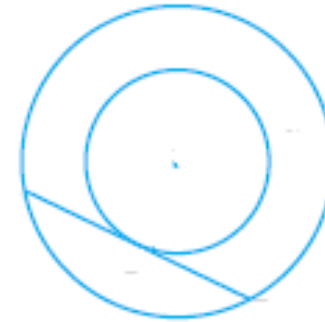
Mathematics

Physics

Often requires precision

Time consuming

Tricky to draw





Drawing Geometry Diagrams With Precision

Do it by hand

Using compass and set square

Use a software tool

Cabri II Plus, Geometry Expressions, etc

Our Solution: Enable natural sketching of diagrams, followed by constraint-based precise beautification



Outline

Motivation (done)

Related Work

QuickDraw overview

Technical Details

Findings of our Usability Study

Conclusions



Related Work

Sketch Recognition & Beautification

CogSketch (2011)

LADDER (2005)

MathPad² (2004)

PaleoSketch (2008)

Lineogrammar (2008)

Wais, Wolin, Alvarado (2007)

Igarashi et al (1997)

PenProof (2010)

IIPW (2007)

Constraint Solving

Gulwani et al (2011)

Aldefeld (1988)

Bouma et al (1995)

Kondo (1992)

Nelson (1985)



Underlying Problem

Sketch-based interaction

Natural and ingrained method of making diagrams

Sketches are Imprecise ☹️

Problem: Given a rough sketch, generate a mathematically precise diagram!

Observation: geometric constraints will probably be the same in both the rough sketch and the precise diagram

Heuristics to infer geometric constraints

Use inferred constraints to beautify sketch



QuickDraw's User-Interface

Sketch diagrams using stylus on a tablet PC

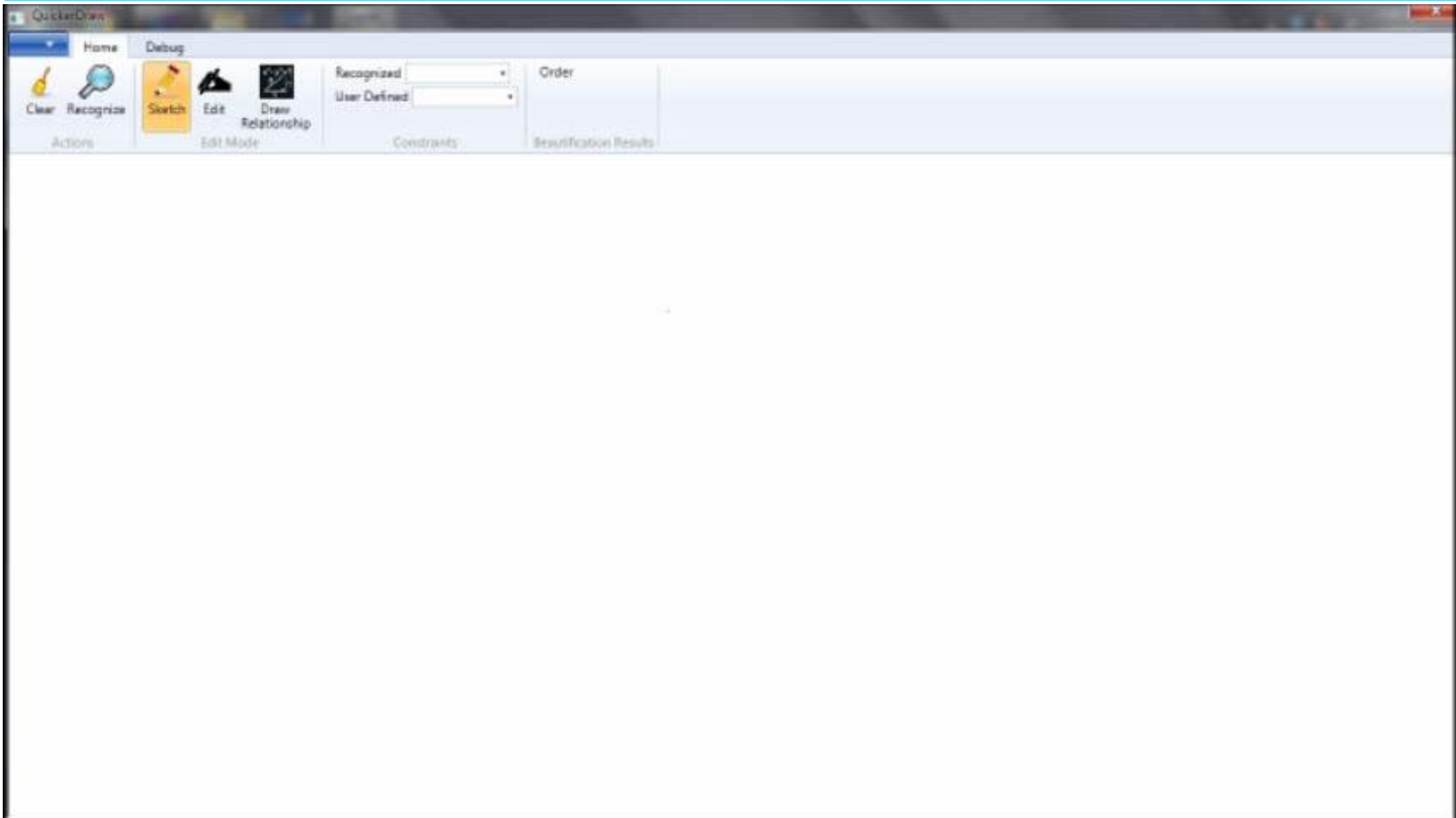
In one go
Incrementally

Editing Capabilities

Clear the canvas
Erase ink or recognized diagram components
Reposition components by manipulating control points

Recognition is triggered explicitly

QuickDraw Video 1



Input and Recognition

Sketch: Set of ink strokes

Ink Stroke: Collection of 2D points

Cusp: Region of high curvature in ink stroke

Recognition of an ink stroke

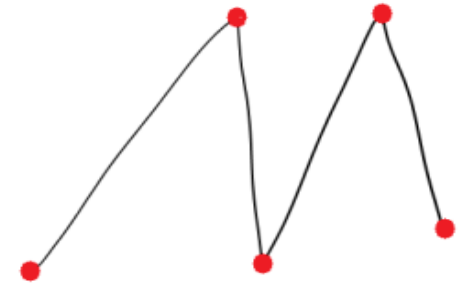
Enumerate all cusps [Istraw (Xiong and LaViola, 2010)]

Use heuristics to classify stroke

Circle or Line Segment

Assign numerical ordering

Left to right, then top to bottom





Inference of Constraints

For each pair of recognized components (Line Segments/Circles)

Infer geometric constraints

Examples: Equal Length/Radius, Parallel, Perpendicular, Collinear, Connected, Tangent, etc

Help in understanding user intent

What happens when an error occurs?



Beautification Algorithm

A = set of attributes of all components

B = Empty Set

While (A is not empty)

 If an attribute a_i is computable using attributes in B

 Compute its value by using associated constraint

 else

 Select highest ranked a_i from A

 Read its value from sketch

 B += { a_i }, A -= { a_i }

Construct beautified components from attributes in B

Beautification Example

Recognition

4 line segments

Inferred Constraints

2 vertical and 2 horizontal lines

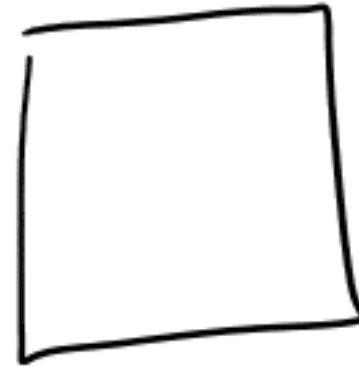
Same length

Vertical lines are parallel

Horizontal lines are parallel

Connected path

Same perpendicular distance same between horizontal and vertical line segments



Beautification Example

Based on ordering

Compute the slope of left line segment

Compute slopes of all other line segments

Read an endpoint from the sketch

Yields intercept

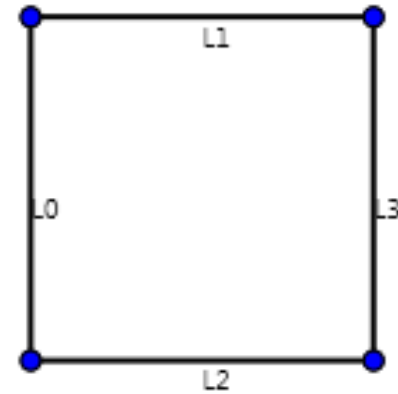
Read length from sketch

Beautify left line segment

Beautify top line segment

Beautify bottom line segment

Beautify right line segment





User Study

Compared QuickDraw with existing tools

Cabri II Plus

Geometer's Sketchpad

Geometry Expressions

Microsoft PowerPoint

19 participants

17 male

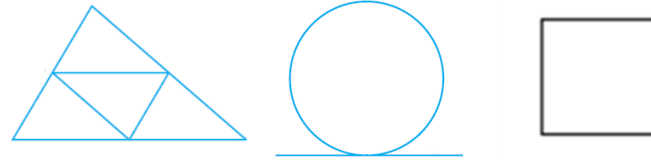
2 female



User Study (cont'd)

Training Session

3 practice diagrams



Experiment Task

9 diagrams split into easy, medium and hard difficulty levels

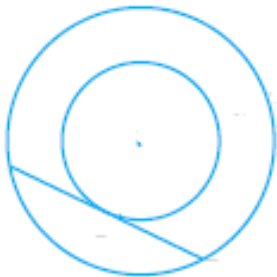
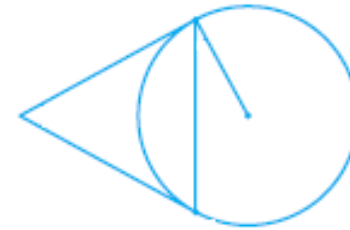
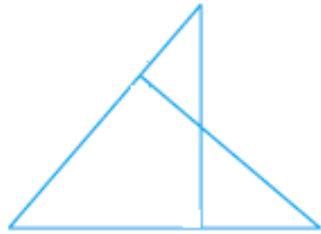
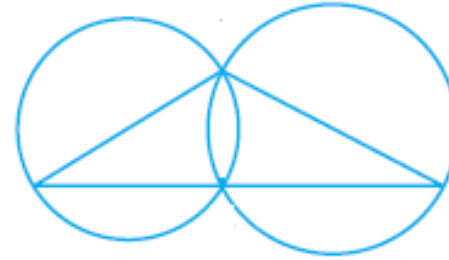
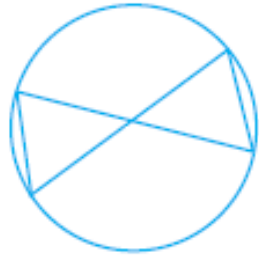
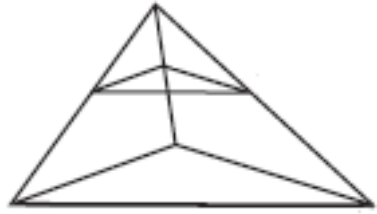
Procedure

- Randomized order of tools
- Randomized order of diagrams for each tool
- Collected feedback at the end
- 3 minutes to draw a given diagram

Quantitative Metrics

- Mean Completion Time
- Mean number of editing operations

Diagrams used in the Study



Source : NCERT Mathematics Book



Quantitative Analysis

Recorded failure rate of 11% and 13% for medium and hard difficulty diagrams

Statistical Analysis of Metrics via ANOVA and t-tests

Diagram Difficulty	Easy	Medium	Hard
QuickDraw performed better than	PowerPoint	PowerPoint, Cabri II Plus, Geometer's Sketchpad	PowerPoint, Cabri II Plus, Geometer's Sketchpad

At all levels of difficulty, QuickDraw was no worse than Geometry Expressions



Qualitative Analysis

No significant difference in drawing capabilities of each tool

No significant difference in perceived drawing performance (except Microsoft PowerPoint)

No less difficult to correct mistakes in QuickDraw than any other tool

Recognition in QuickDraw was rated highly

QuickDraw rated higher in overall reaction

Fairly even split between the two sketching modes



Feedback & Suggestions

QuickDraw enables fast drawing

Editing/Correcting a diagram in QuickDraw is cumbersome

Grid for snapping and manipulation

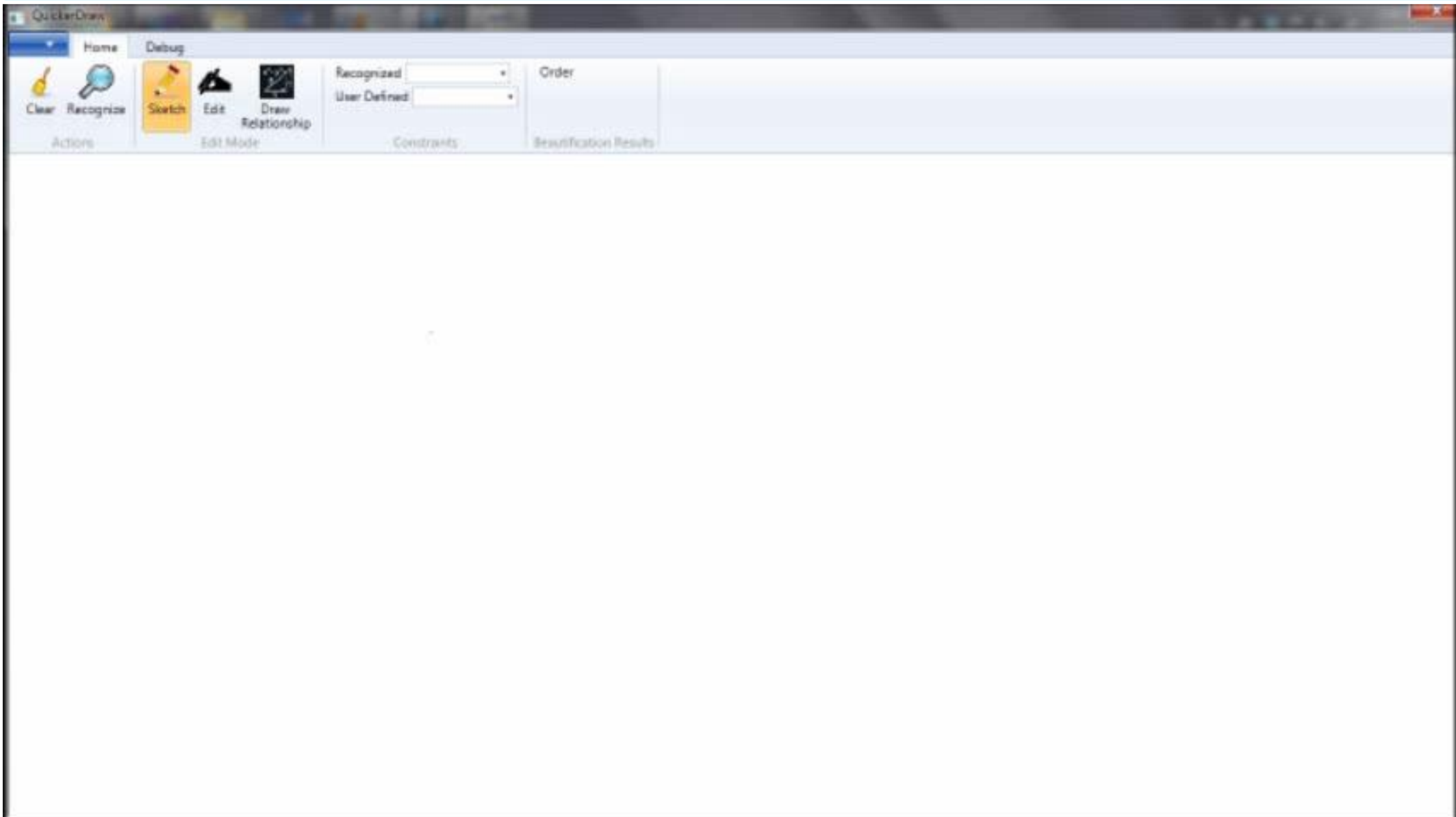
Keyboard shortcuts

Math recognition engine for specifying angles/dimensions

Ability to sketch constraints on the diagram

Majority of participants want to use sketch-based interfaces in the future

QuickDraw Video 2





Conclusion

Diagramming Tool with natural mode of interaction

Novel, real-time beautification algorithm based on lightweight constraint solving

Usability study demonstrating superior or comparable performance to state-of-the-art tools

Need to improve constraint inference and beautification systems

Second study underway (with editing capabilities)



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For More Information

Cheema, S., Gulwani, S., and LaViola, J. "QuickDraw: Improving Drawing Experience for Geometric Diagrams", *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems (CHI 2012)*, 1037-1046, May 2012.

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