APGV06 applied perception in graphics and visualization

Symposium on Applied Perception in Graphics and Visualization

Effects of 2D Geometric Transformation on Visual Memory

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July 30, 2006

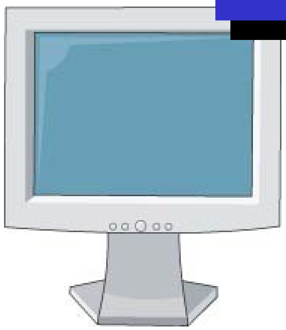
The screen space challenge

Data

IT WAS the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, we were all going direct to Heaven, we were all going direct the other way.

Screens

Too much data to fit on any screen



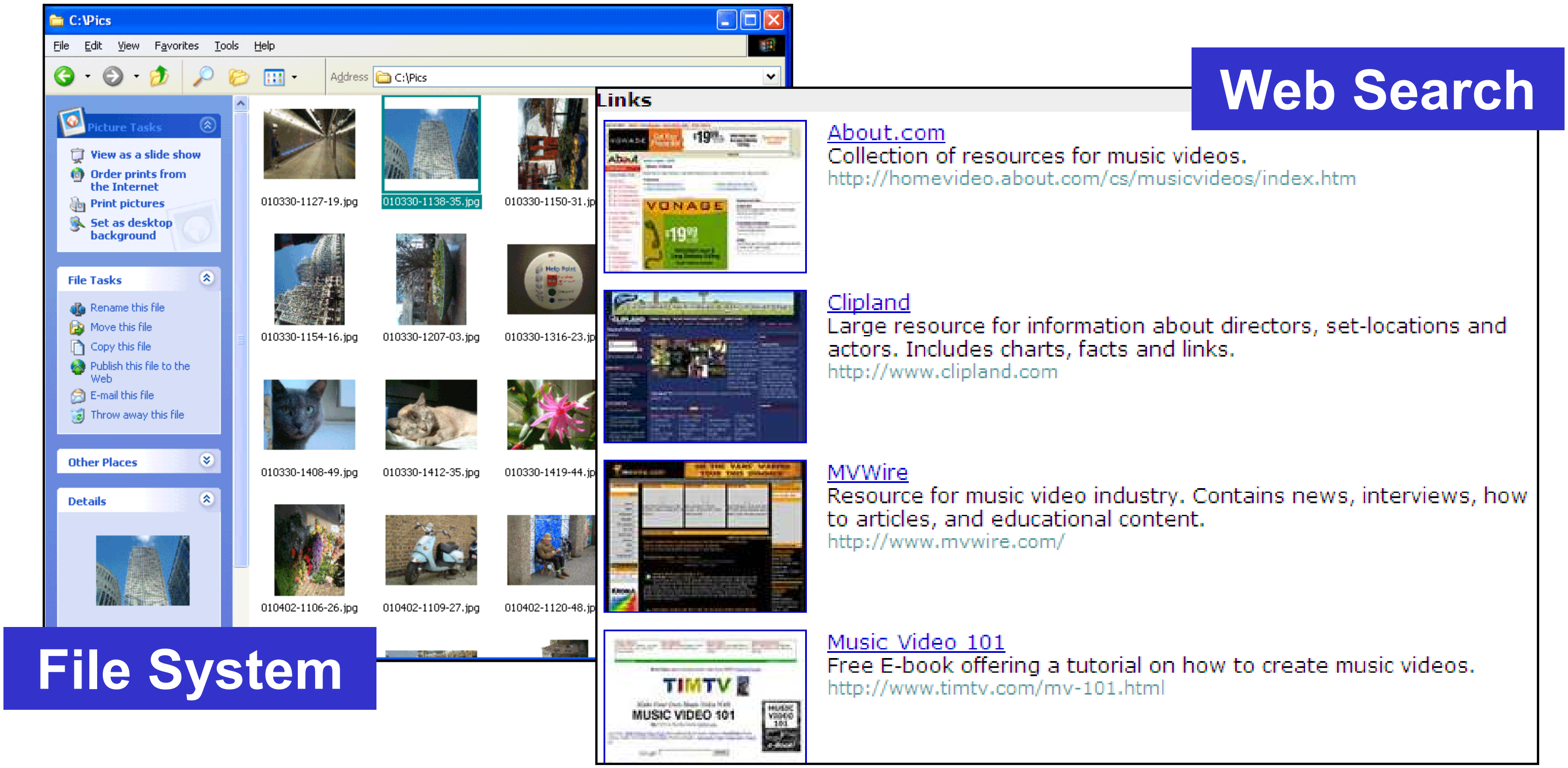
Device has severe screen space limitations

Geometric transformations

are a commonly used solution in interface design

Geometric transformation: Scaling

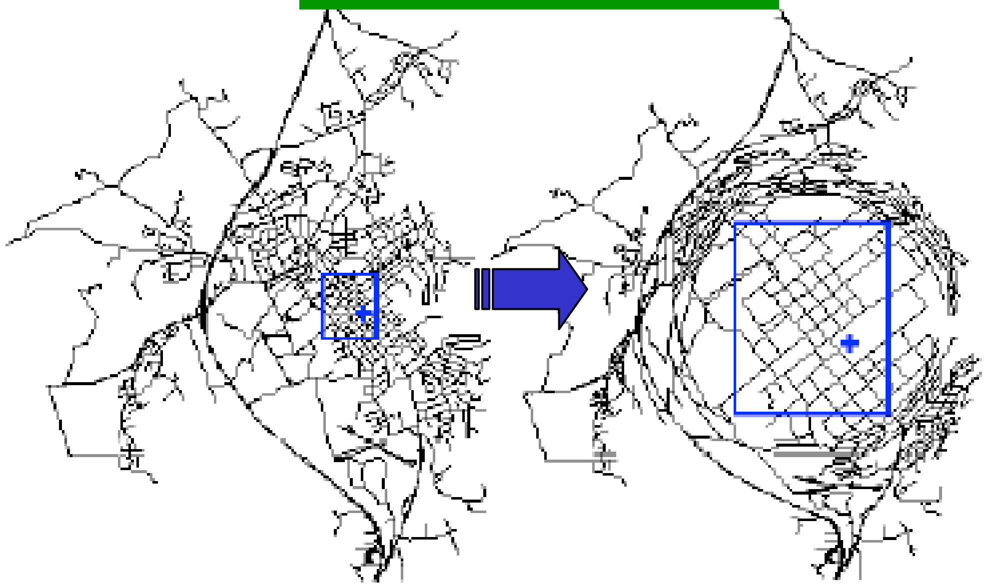
Scaling: Thumbnails are widely used



Geometric transformation: Fisheye

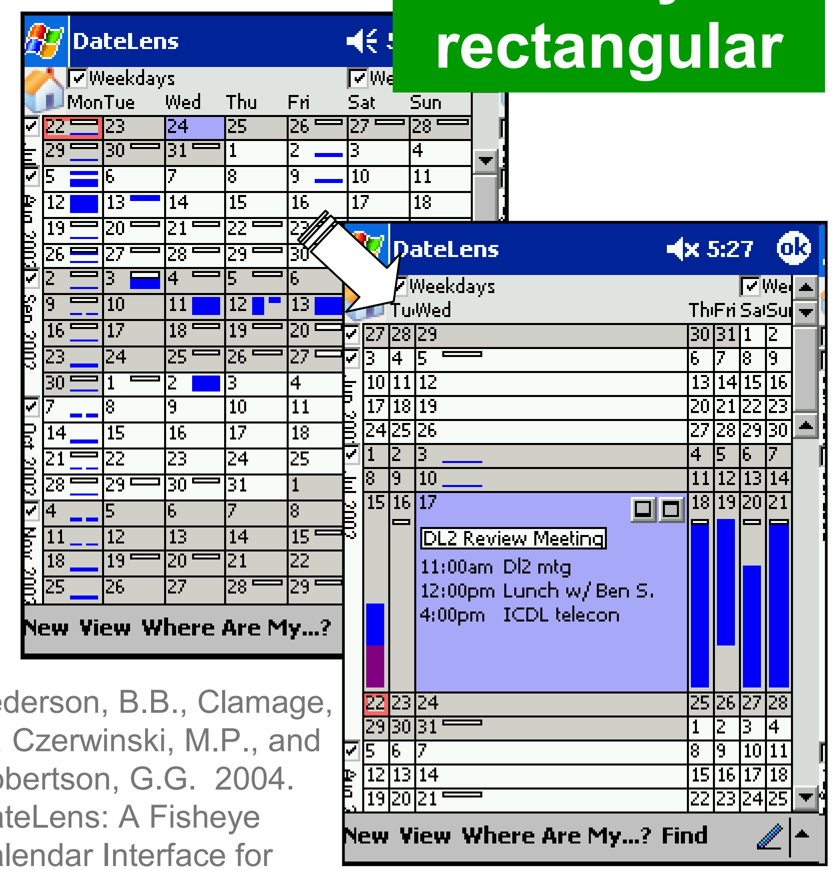
Fisheye: Example of Focus+Context from InfoVis

Fisheye polar



Schafer, W.A., Bowman, D.A. A Comparison of Traditional and Fisheye Radar View Techniques for Spatial Collaboration. Graphics Interface, 2003, 39-46.

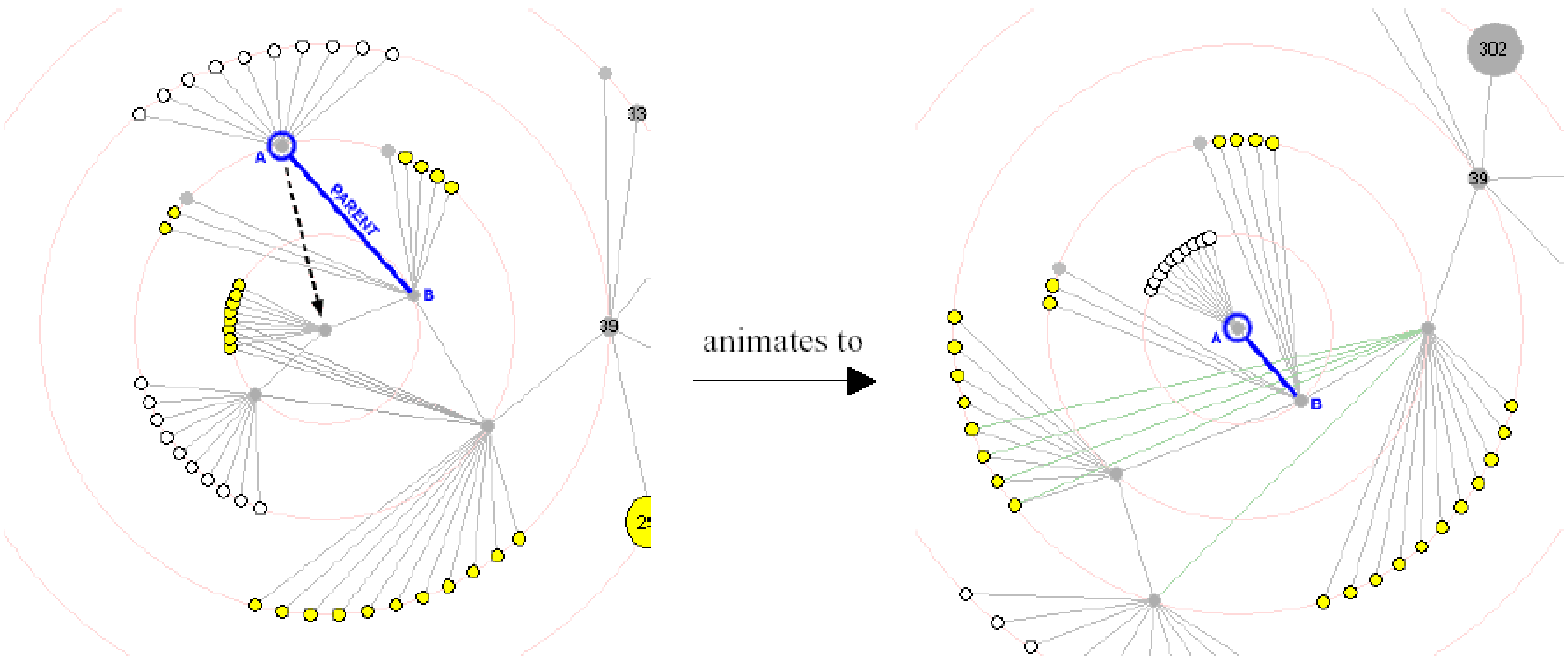
Fisheye rectangular



Bederson, B.B., Clamage, A., Czerwinski, M.P., and Robertson, G.G. 2004. DateLens: A Fisheye Calendar Interface for PDAs. ACM ToCHI 11(1), 90-119.

Geometric transformation: Rotation

Rotation: Used for interactive visualization



Network Visualization

Yee, K.P., Fisher, D., Dhamija, R., Hearst, M. 2001. Animated Exploration of Graphs with Radial Layout. In *Proc IEEE InfoVis*, 45-50.

Transformation costs and benefits

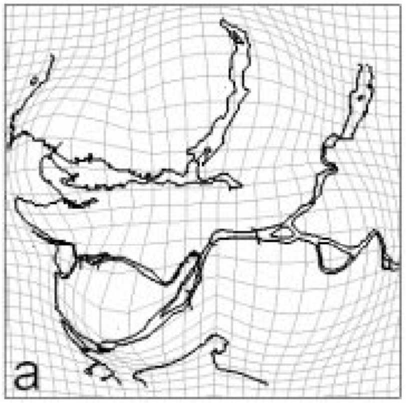
- **Benefit**:
  - Apportioned screen space to provide information required for the tasks
- **Costs**:
  - Transformed images may be too distorted to be recognizable
  - Users may not be able to associate the components in the original image to those in the transformed image
  - Users ***may*** still be able to perform the tasks, but with increased task time

Heuristics to minimize transformation costs

- Maintain… [Misue et al., 1995]
  - Orthogonal ordering: left-right, up-down ordering
  - Proximity: distance relationships between objects
  - Topology: inside-outside relationships

- Use…
  - Visual cue: landmarks, grids
    [Carpendale et al., 1997, Zanella et al., 2002]
  - Animation: supports object constancy to retain components relationships during transformation
    [Robertson et al., 1989]

- Rules are…
  - Too vague
  - Largely unquantified



Our motivation: To guide interface design

- Quantified perceptual costs of geometric transformations on **visual memory**
  - Different transformation types
  - Different transformation levels
- Studied the commonly used transformations in interface design:
  - Scaling
  - Rotation
  - Fisheye (rectangular and polar)
- Measured the effects of background grids

Related work

- Current work is an extension of previous studies on perceptual effects of geometric transformation on visual search
  - Rensink (2004) The Invariance of Visual Search to Geometric Transformation. *Journal of Vision 4.*
    - Translation, rotation, scaling
  - Lau, Rensink, Munzner (2004) Perceptual Invariance of Nonlinear Focus+Context Transformations. In *Proc ACM APGV*, 65-72.
    - Rectangular fisheye transformation
  - Found *no-cost zones* for all geometric transformations studied
    - Translation was found to be robust within range studied

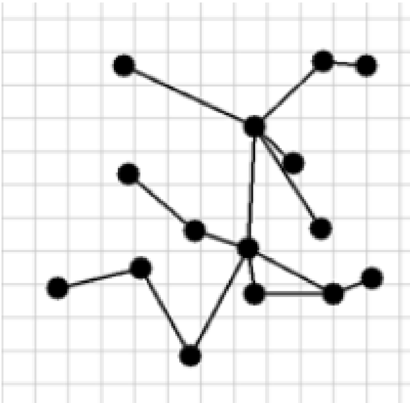
- Skopik and Gutwin (2005) looked at the effects of rectangular fisheye transformation on visual memory
  - Participants could compensate the distortions with longer task time in a task to remember and find target nodes in a graph

Experimental design

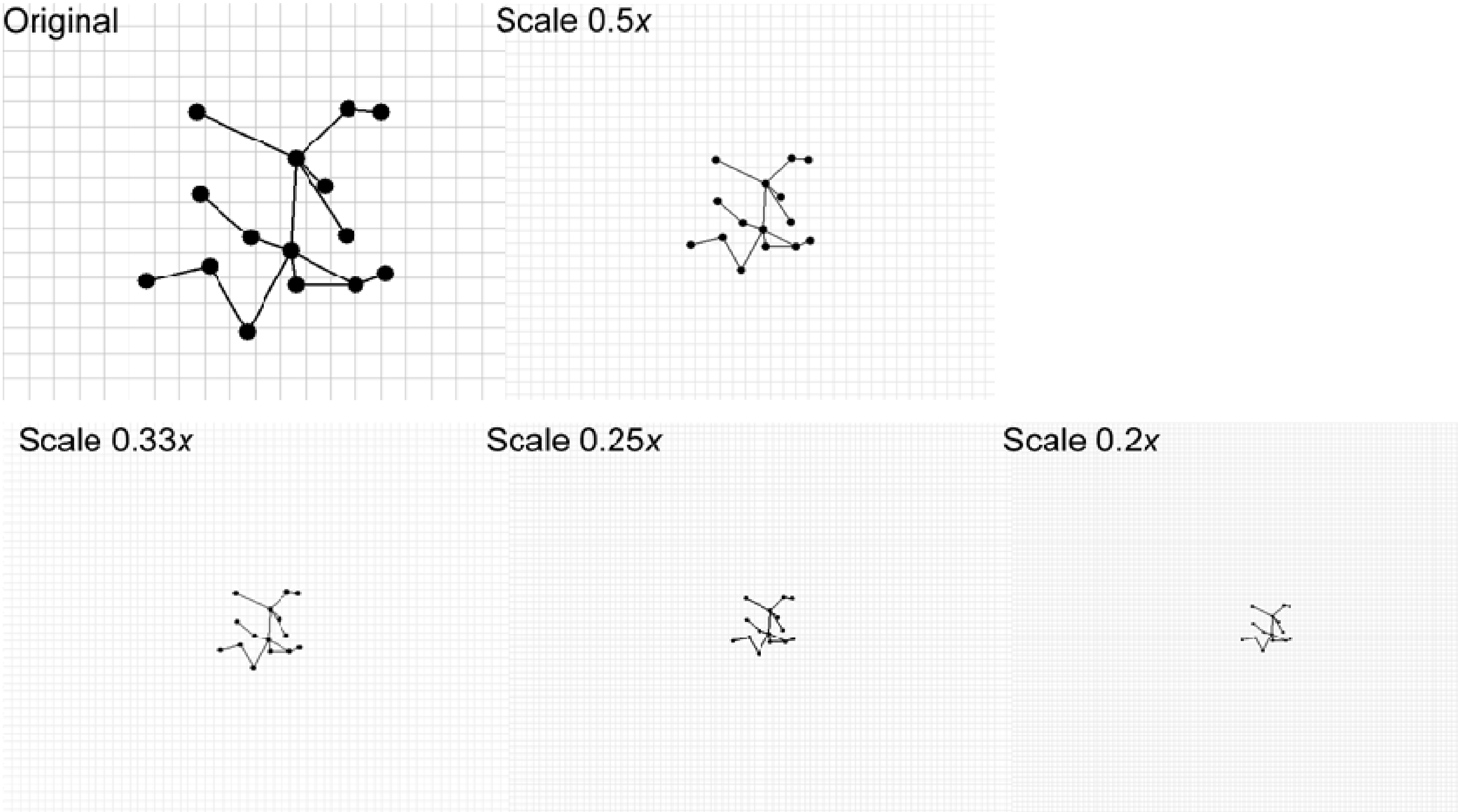
- 10 experiments
- Single-factor with the transformation type being the only factor
- 5 levels of transformation, counterbalanced between participants
- 8 trials per level, randomized
- 20 participants per experiment
- Measured reaction time and task accuracy

Experiment: Stimuli

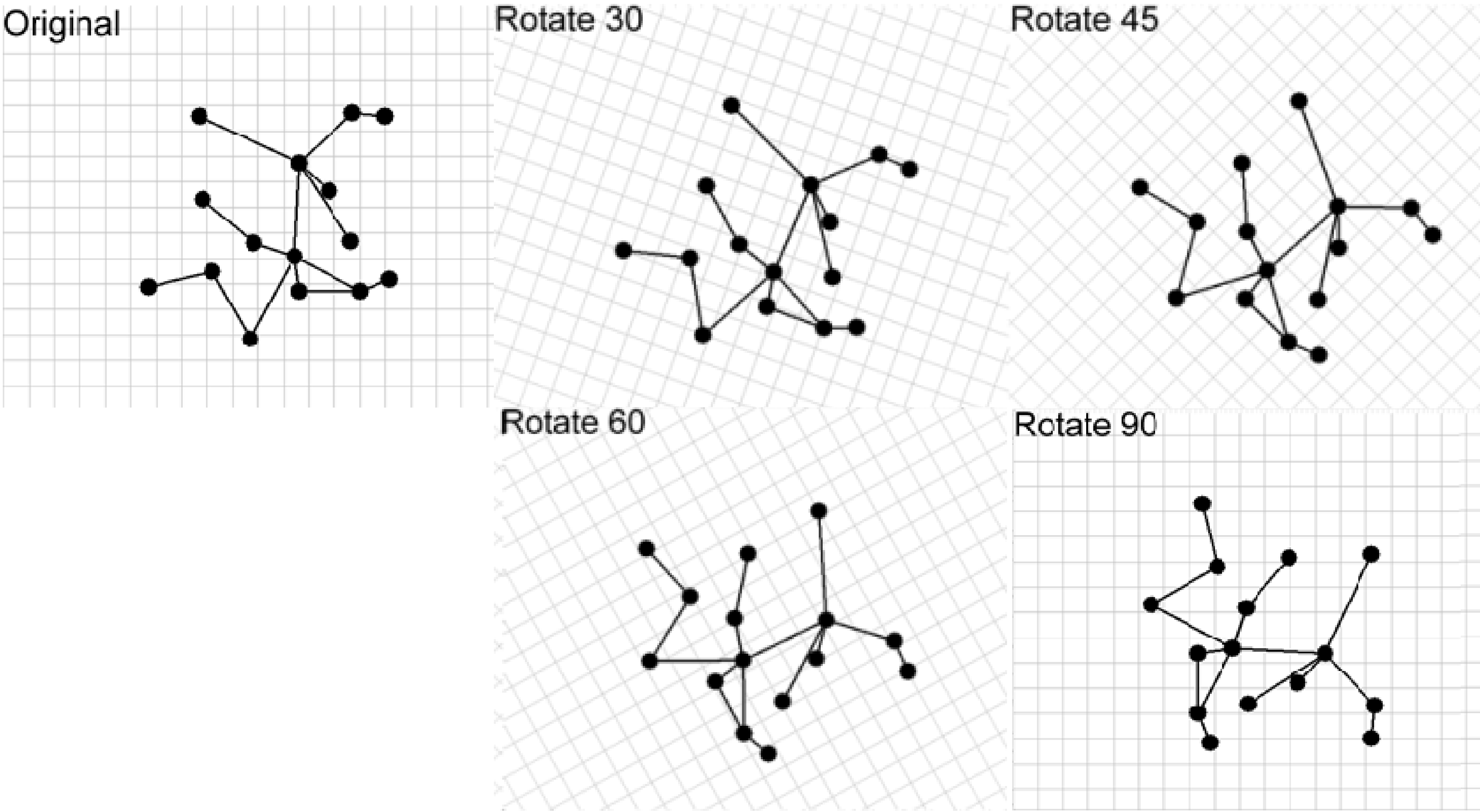
- Abstract images of 15 dots connected by straight lines
- Dots:
  - Randomly placed within the 300x300 pixel area
  - Avoided collision
- Lines:
  - Joined the dots to at least one nearest neighbour
  - Used heuristic to avoid line crossing



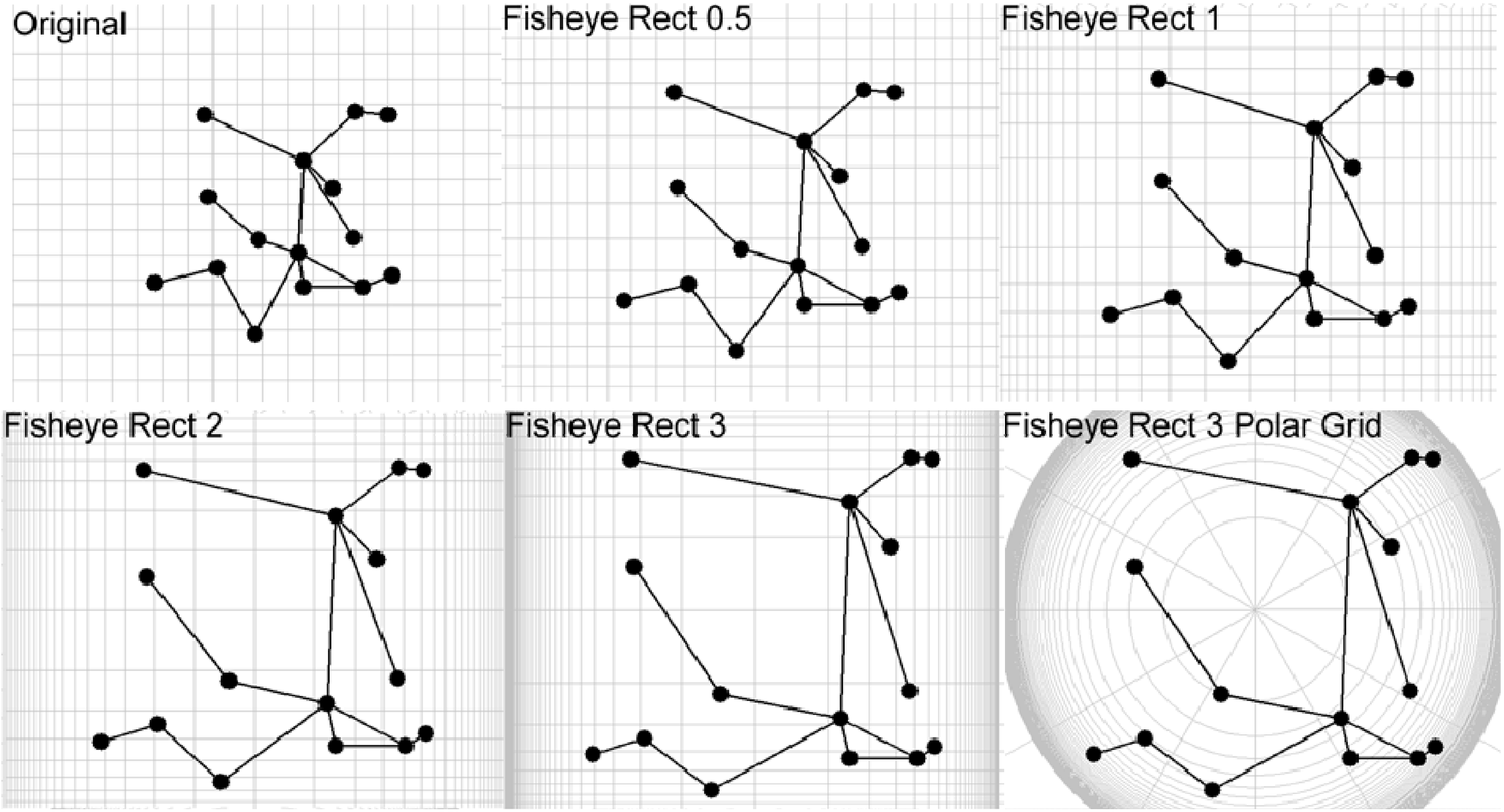
Experiment stimuli: Scaling



Experiment stimuli: Rotation



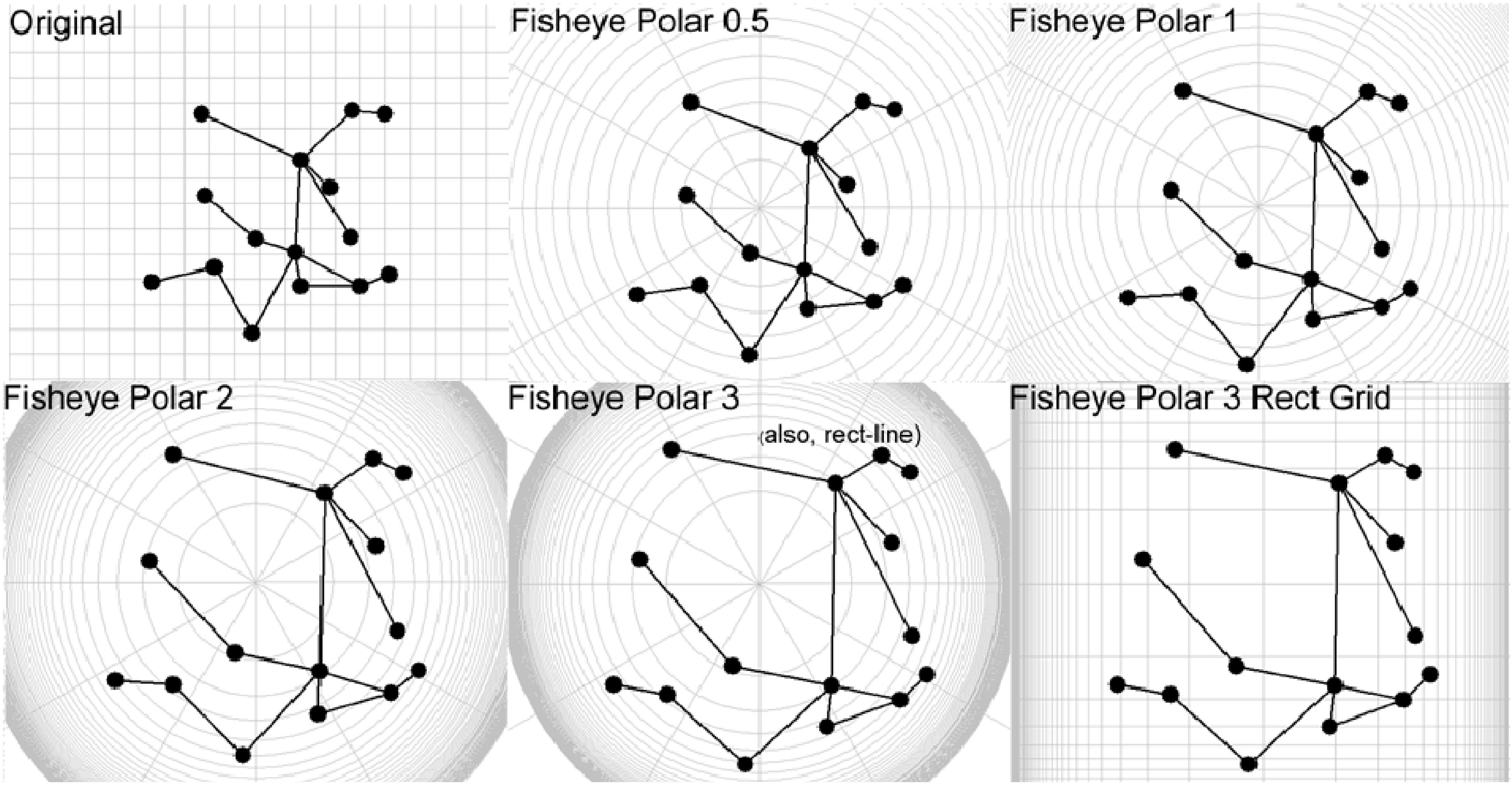
Experiment stimuli: Fisheye rectangular



$$T(x) = \frac{(d+1)x}{(dx+1)}$$

Leung, Y.K. and Apperley, M.D. 1994. A Review and Taxonomy of Distortion-Oriented Presentation Techniques. *ACM ToCHI*, 1(2), 126-160.

Experiment stimuli: Fisheye polar



$$T(x) = \frac{(d+1)x}{(dx+1)}$$

Leung, Y.K. and Apperley, M.D. 1994. A Review and Taxonomy of Distortion-Oriented Presentation Techniques. *ACM ToCHI*, 1(2), 126-160.

Experiment: Procedure

- For each experimental level:

1. Learning: 8 original, untransformed images @ 12 seconds, separated by blank screens

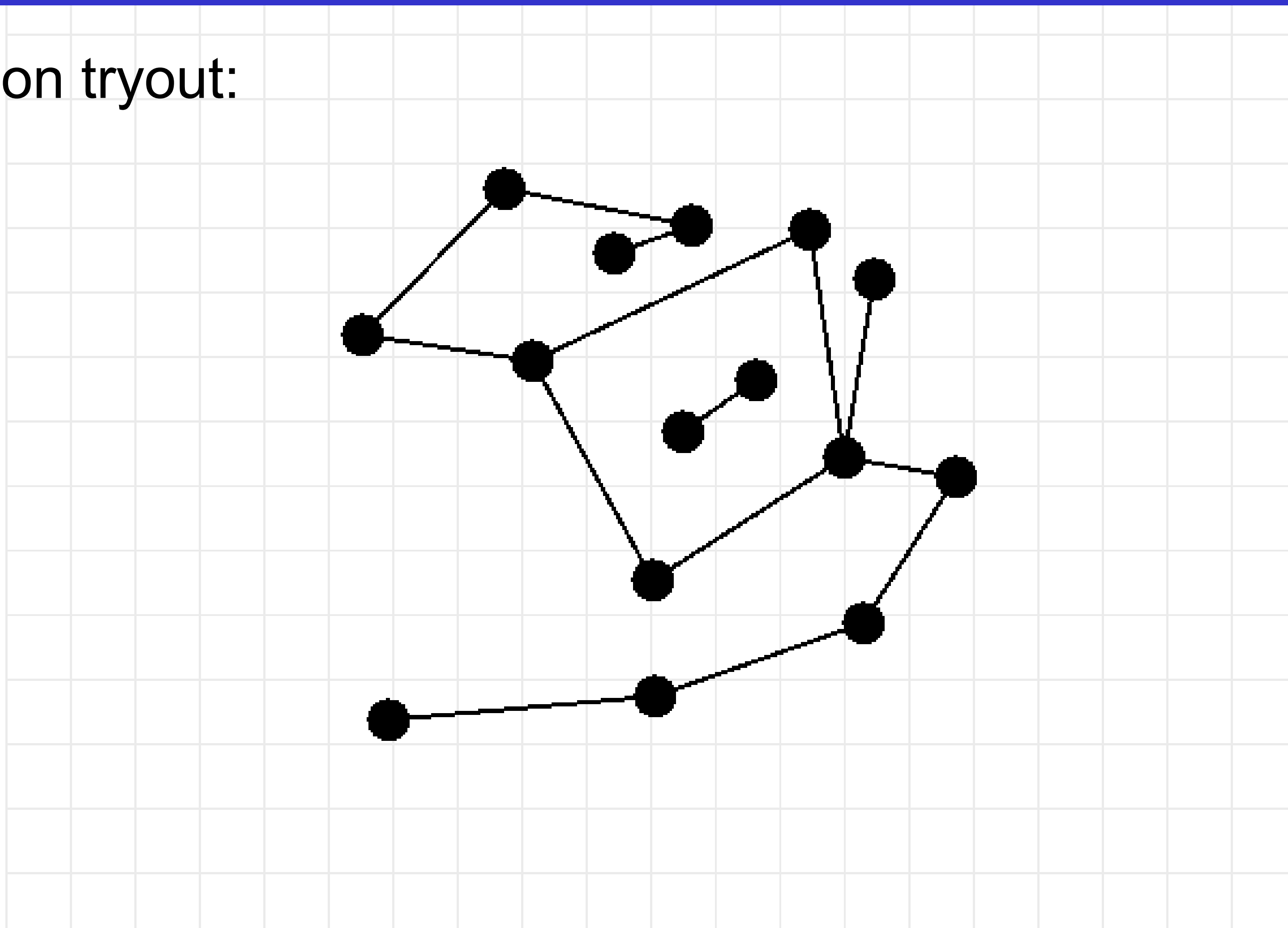
2. Recognition: 8 images transformed at one of the 5 levels, half were shown in the original form in the *learning* phase
   - Participants needed to answer if image was seen before in learning phase
   - Measured reaction time and task accuracy

Experiment: Procedure

- Participant preparation and training:
  - Shown examples of transformed images
  - Informed of the need to recognize images in second phase of the study
  - Had up to two training sessions using the baseline untranformed level to obtain at least 80% accuracy

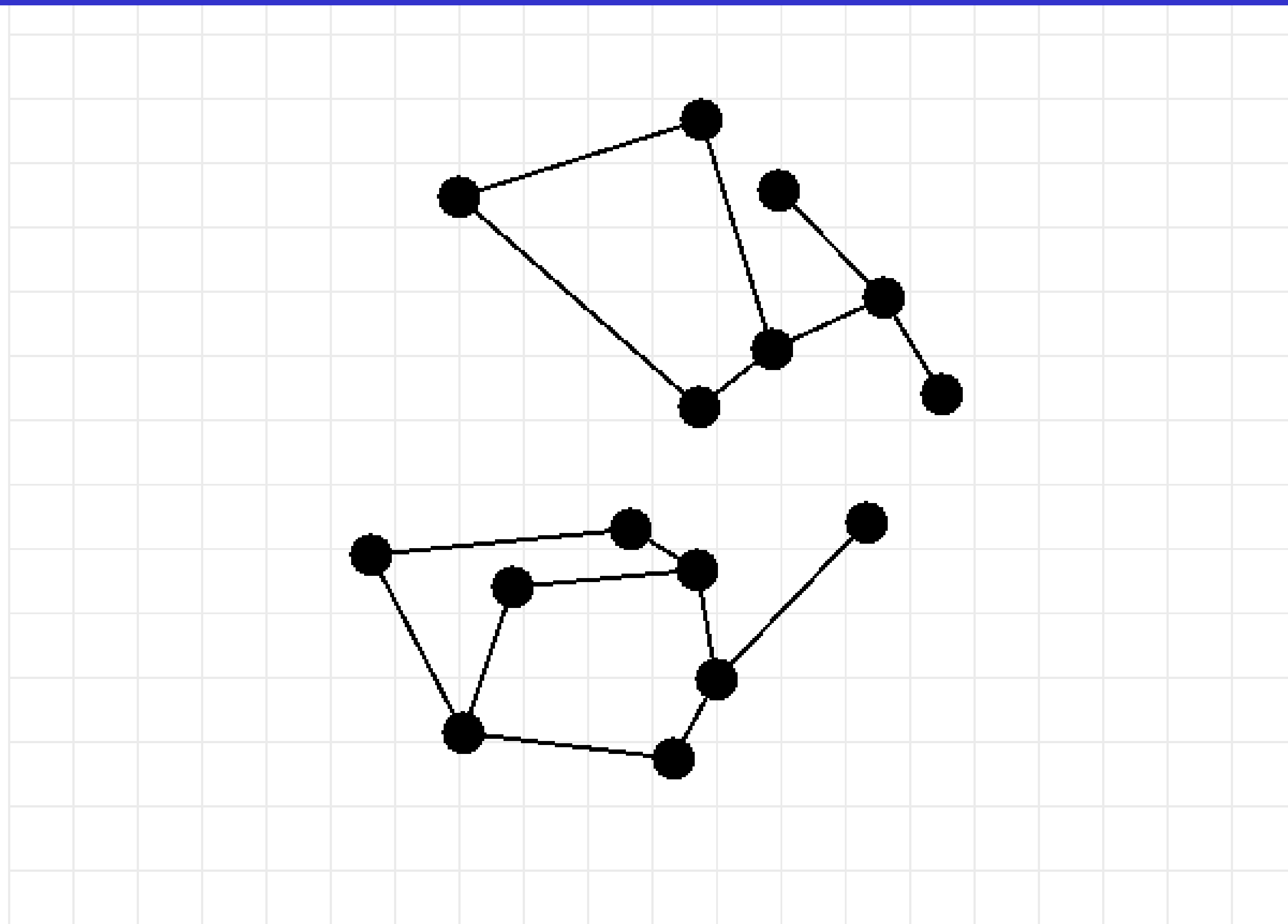
Experiment: Procedure

Rotation tryout:



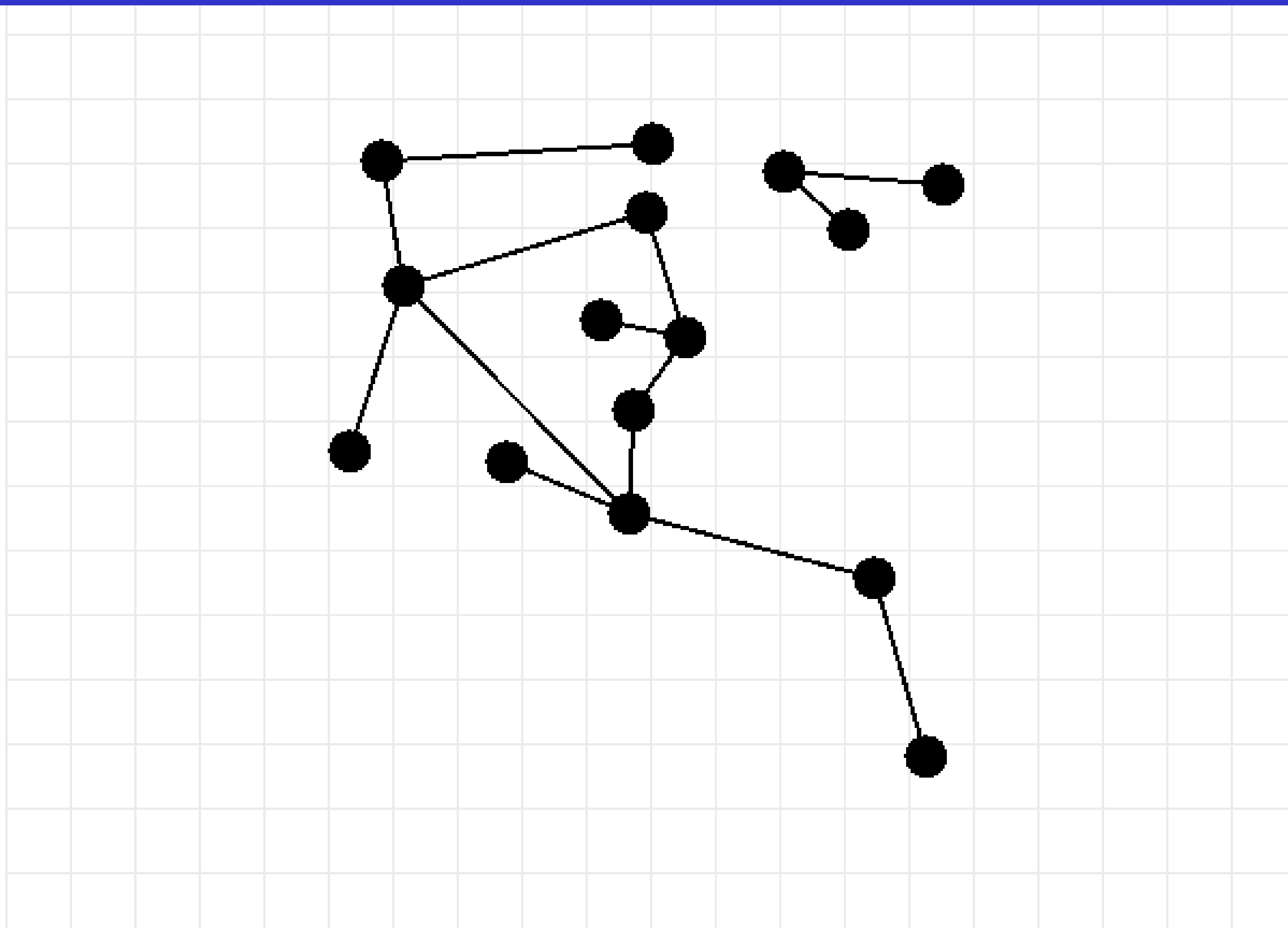
Experiment: Procedure

Experiment: Procedure



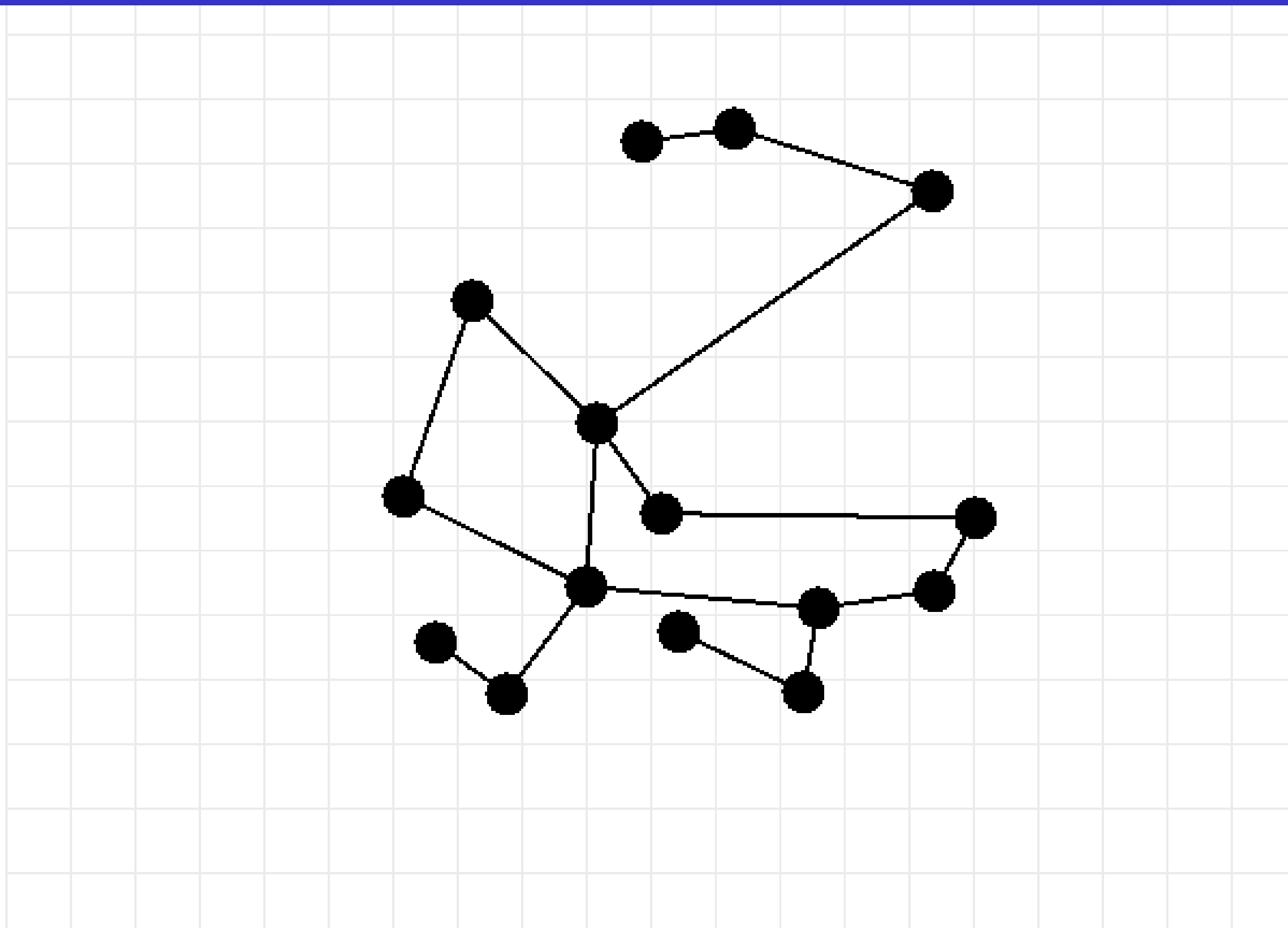
Experiment: Procedure

Experiment: Procedure



Experiment: Procedure

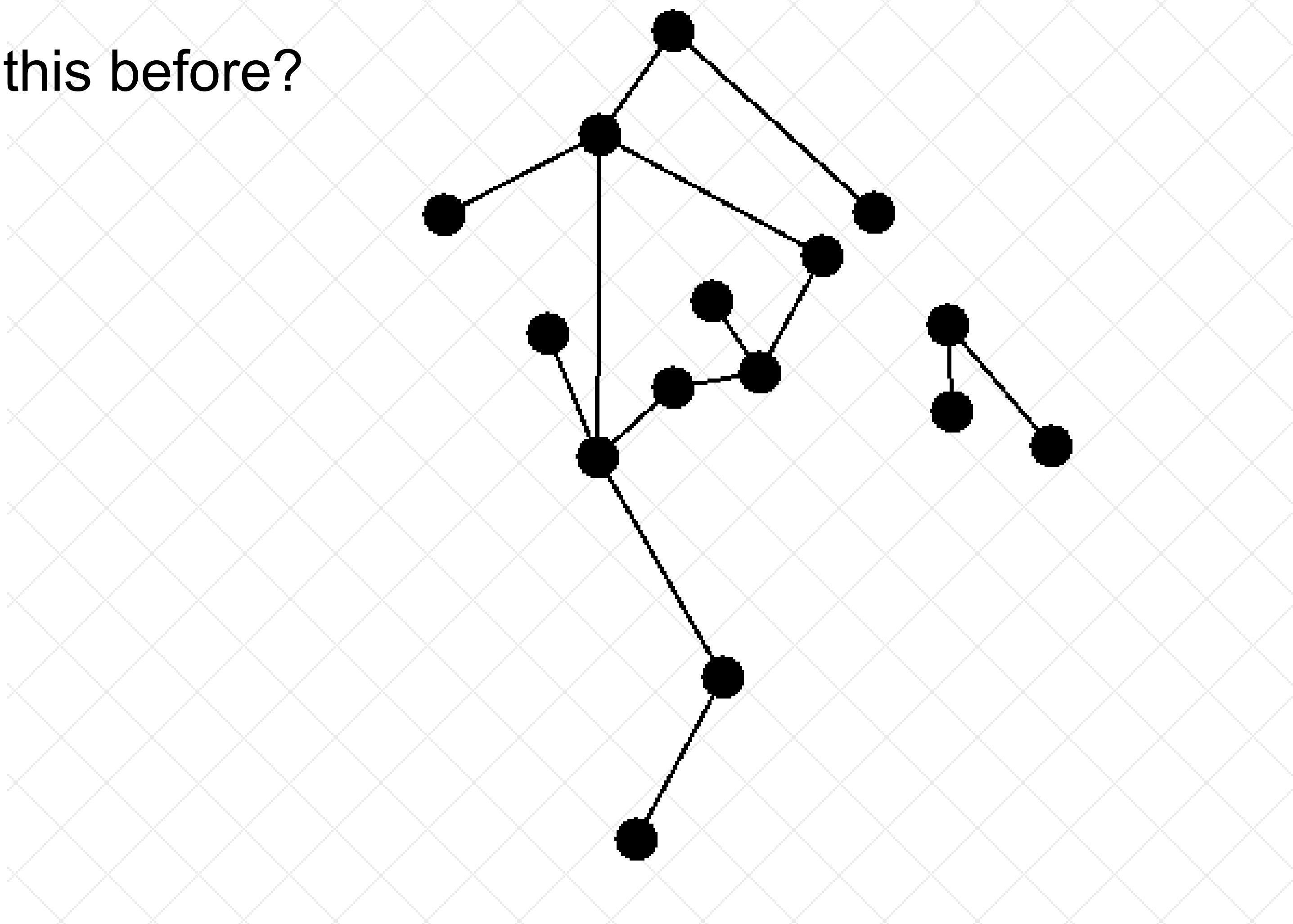
Experiment: Procedure



Experiment: Procedure

Experiment: Procedure

Seen this before?



Experiment: Analysis

- Response time results:
  - Initial analysis: repeated-measure ANOVA with the transformation type as the only factor
  - Post-hoc analysis: multiple comparisons with Bonferroni correction
- Accuracy results:
  - Initial analysis: Friedman test
  - Post-hoc analysis: Mann-Whitney test
- Defined *no-cost zone* for each transformation type

Our set of 10 experiments

Scaling (1, 0.5, 0.33, 0.25, 0.2*x*)

Exp 1.	no grid	no limit found (0.2*x*)
Exp 2.	rectangular grid	no limit found (0.2*x*)

Rotation (0, 30, 45, 60, 90 degrees clockwise rotation)

Exp 3.	no grid	*45°*
Exp 4.	rectangular grid	*60°, improved accuracy by 10%*

Fisheye rectangular (0, 0.5, 1, 2, 3 transformation level)

Exp 5.	no grid	*1*
Exp 6.	rectangular grid	*2*
Exp 7.	polar grid	*2*

Improved accuracy from chance to >75%

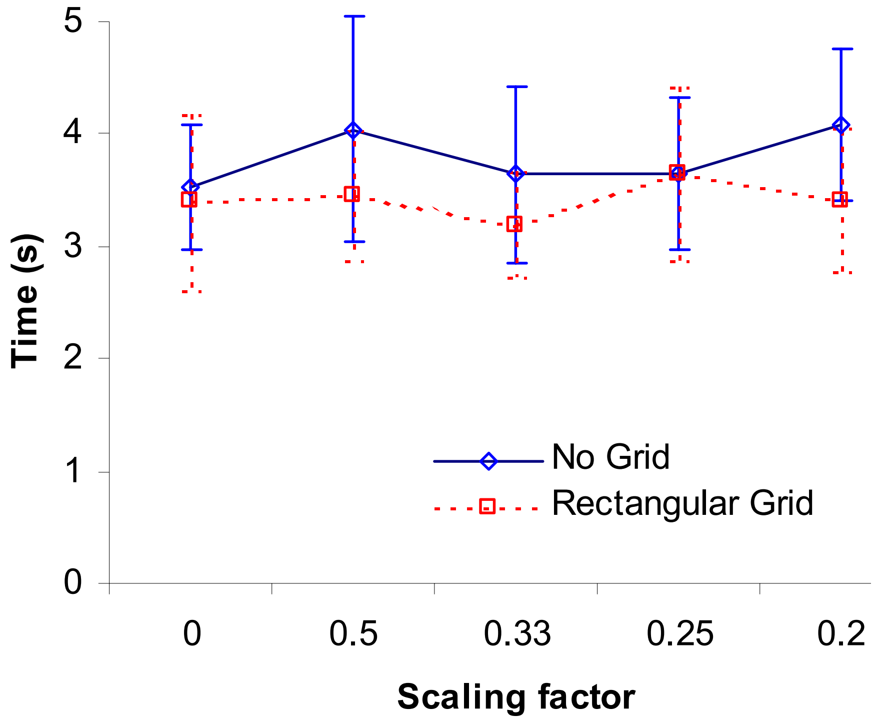
Fisheye polar (0, 0.5, 1, 2, 3 transformation level)

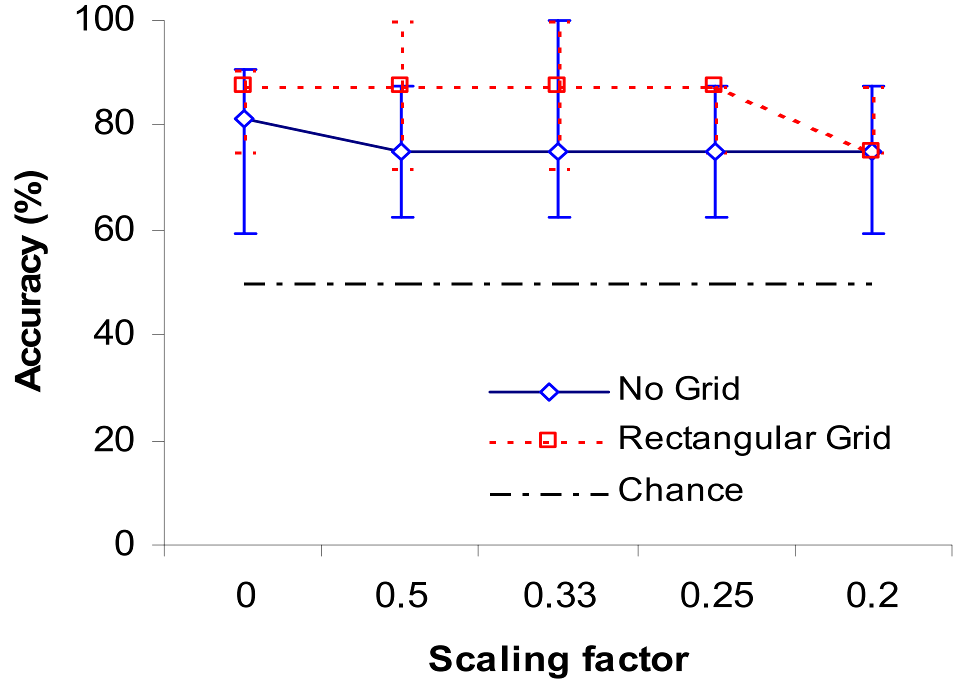
Exp 8.	no grid	*1*
Exp 9.	rectangular grid	*2*
Exp 10.	polar grid	*2*

did not improve accuracy

NO–COST ZONES

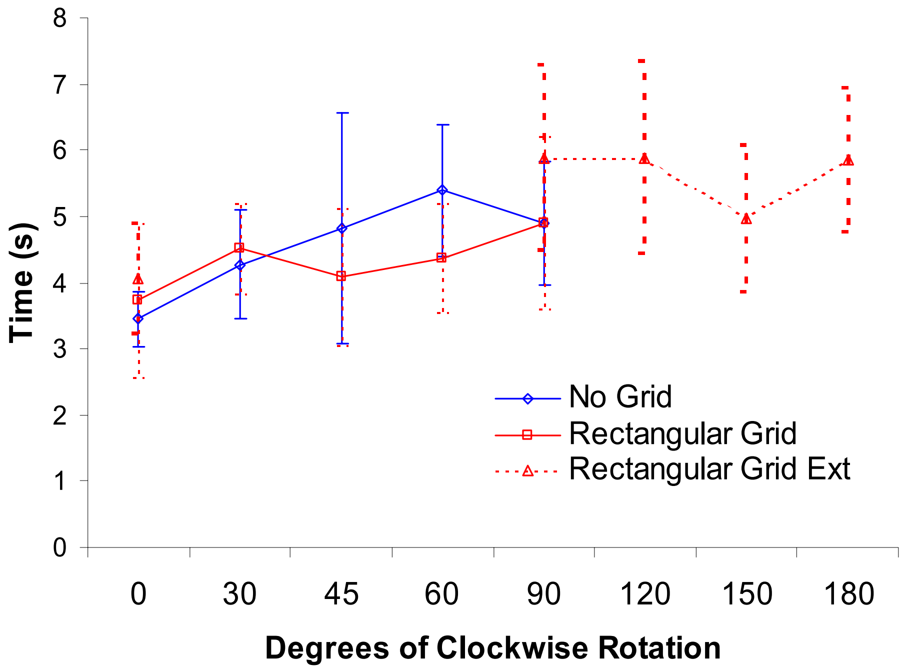
Experiment: Scaling results

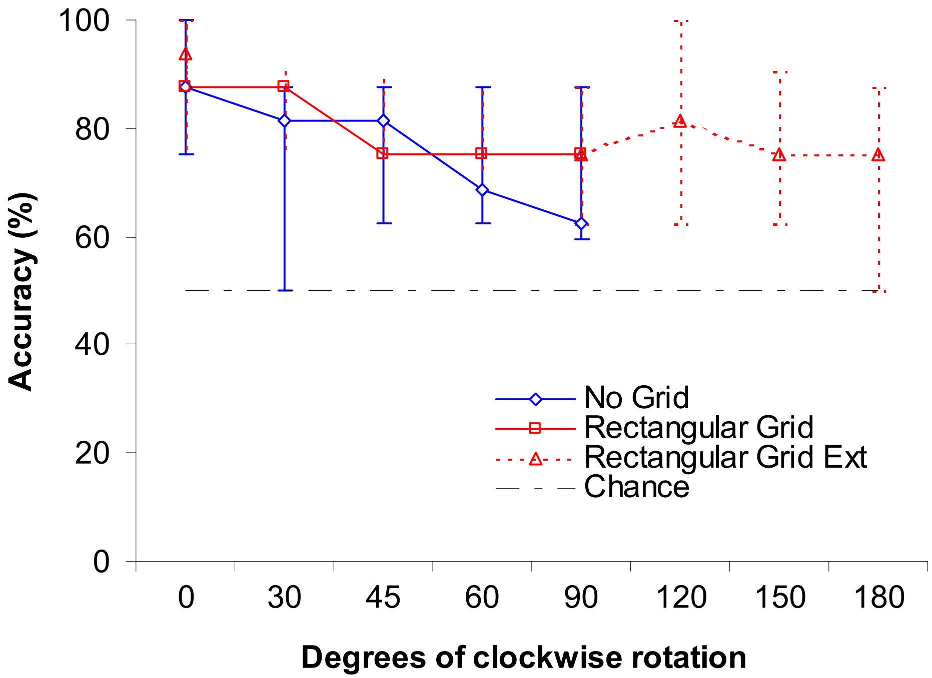




- No significant difference between the 5 scaling levels, with or without grids
- No-cost zone: at least 0.2*x*

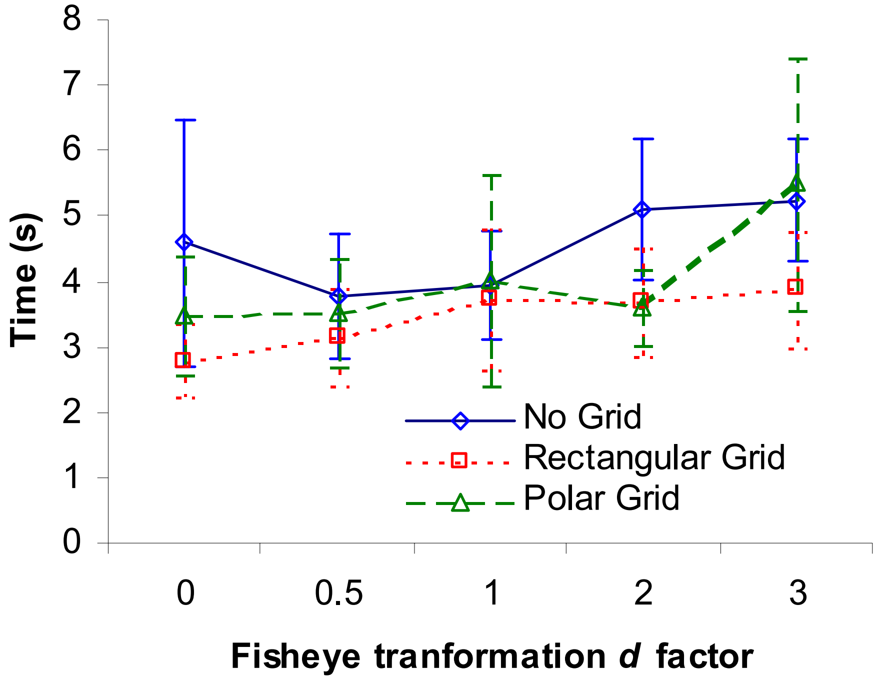
Experiment: Rotation results

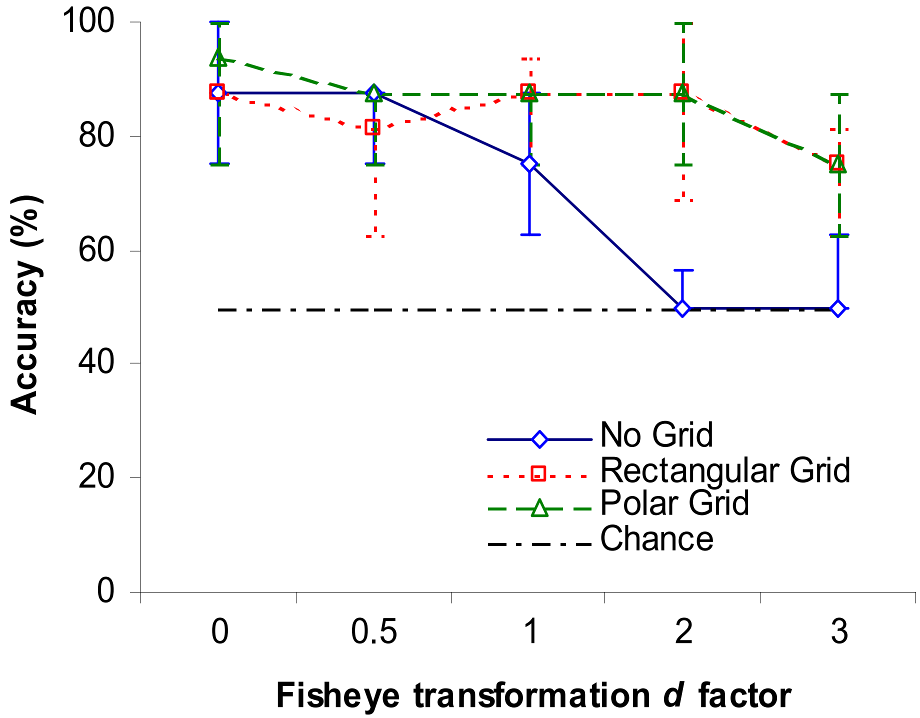




- No grid: marginal time and accuracy effects
  time: $F(1.9, 35.8) = 2.92$, $p = .070$; accuracy: $\chi^2(4, N=20) = 8.75$, $p = .070$)
- Rectangular grid:
  - Extended the study range to 180° to better identify the no-cost zone boundary
  - Extended the boundary from 45° at 60°
  - Improved accuracy by 10%

Experiment: Fisheye rectangular results

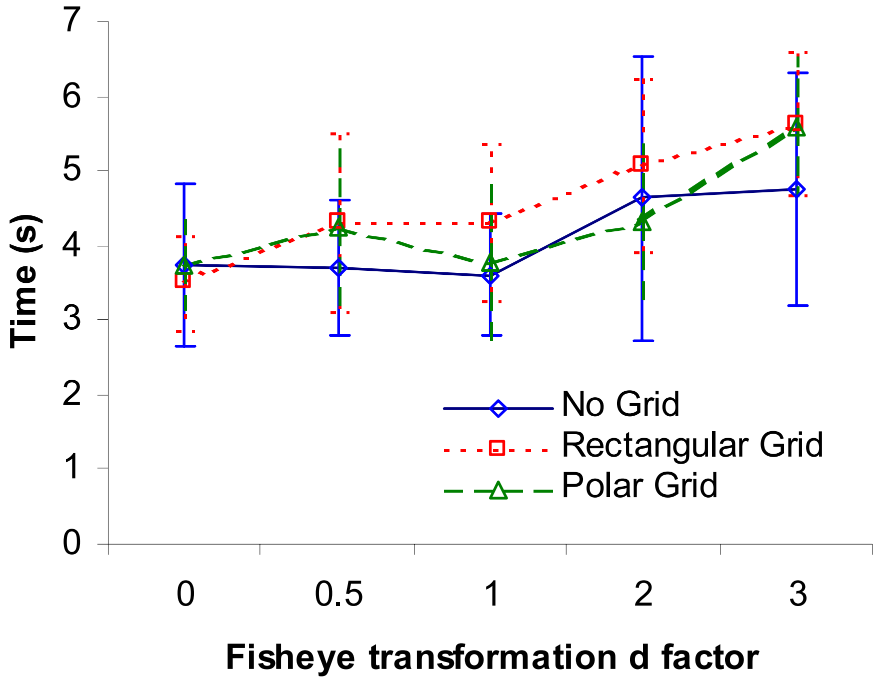


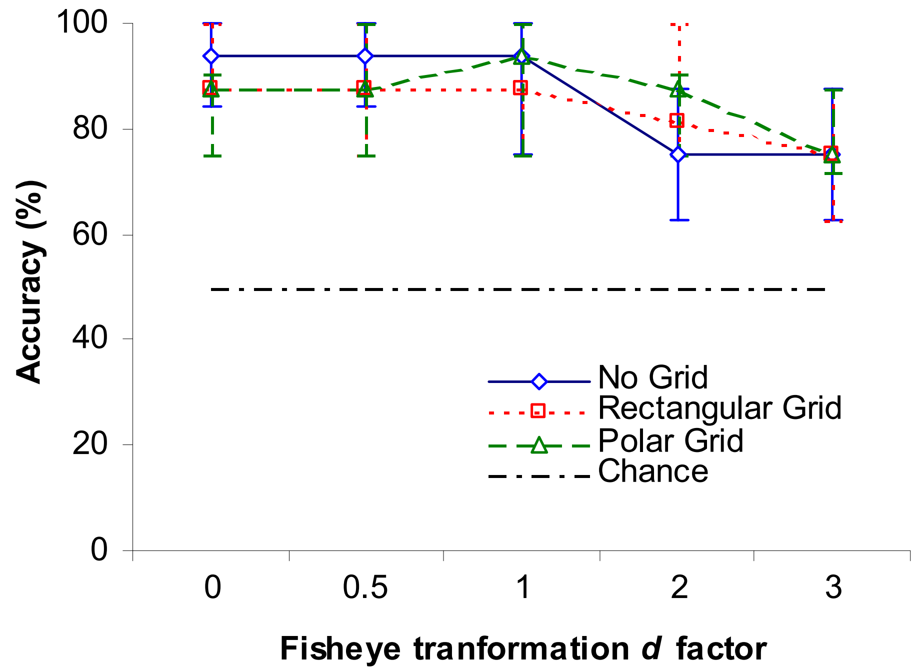


- No grid: marginal time and significant accuracy effect
  time: $F(1.9, 36.2) = 2.83$, $p = .074$; accuracy: ($\chi^2(4, N=20) = 43.80$, $p < .001$)

- Polar or rectangular grids:
  - Extended the boundary to from $d = 1$ to $d = 2$
  - Improved accuracy from chance to at least 75%

Experiment: Fisheye polar results

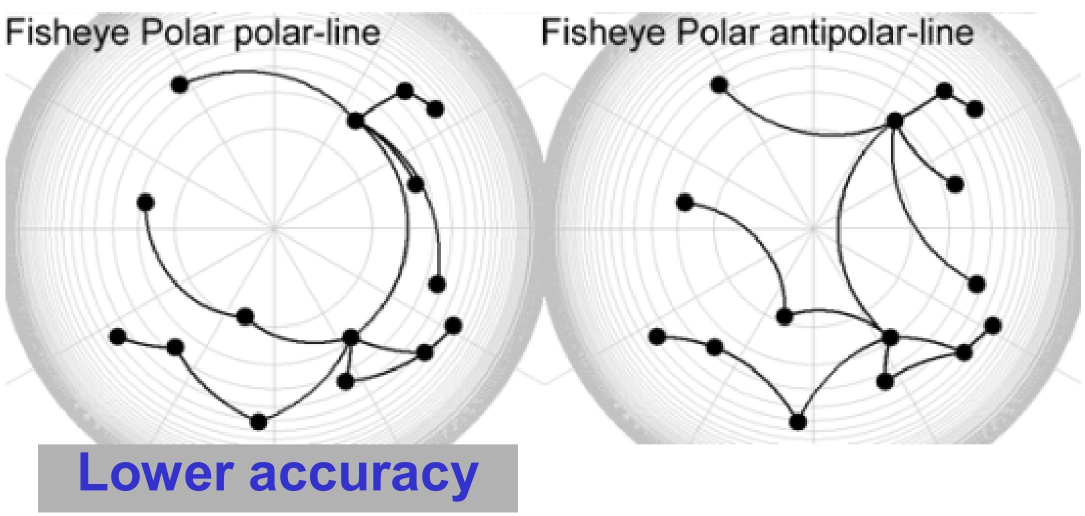




- No grid: significant accuracy effect ($\chi^2(4, N=20) = 17.16$, $p = .002$)
- Polar or rectangular grids:
  - Extended the boundary from $d = 1$ to $d = 2$
  - Did *not* significantly improve accuracy

A Fisheye polar follow-up study

- Should line curvature match the transformation?
  - Previous experiment drew straight lines with polar transformation
  - Tried lines with same curvature, and opposite curvature
- Distinctiveness may be more important than consistency
  - Same curvature was less accurate
  - Opposite curvature made no difference



Experiment: Result summary

- Scaling:
  - No-cost zone to at least $0.2x$

- Rotation:
  - Grid extended the no-cost zone boundary from 45° to 60°
  - Grid improved accuracy by 10%

- Fisheye Rectangular:
  - Grid extended the no-cost zone boundary from $d = 1$ to 2
  - Grid improved accuracy from chance to at least 75%

- Fisheye Polar:
  - Grid extended the no-cost zone boundary from $d = 1$ to 2
  - Accuracy was not at chance
  - Grid had no significant effects on accuracy

Interpretation: Effects of transformation

- Our results corroborated our previous finding that no-cost zones exist for all studied geometric transformations

- No-cost zone boundaries were found to be further in visual memory than visual search studies [Lau et al., 2004; Rensink, 2004]

- Preliminary work suggests image distinctiveness is more important for memorability than global consistency with the underlying transformation and object coordinate systems

Interpretation: Effects of grids

- Verified that grids helped:
  - Extended no-cost zone boundaries
  - Improved accuracy
- The type of grid did not seem to matter
  - Consistency between grid and transformation coordinate system was not necessary
- Grids should not be visually intrusive
  - Grids were too visually prominent in previous work; results were detrimental [Lau et al., 2004]

Interpretation: Revisiting design guidelines

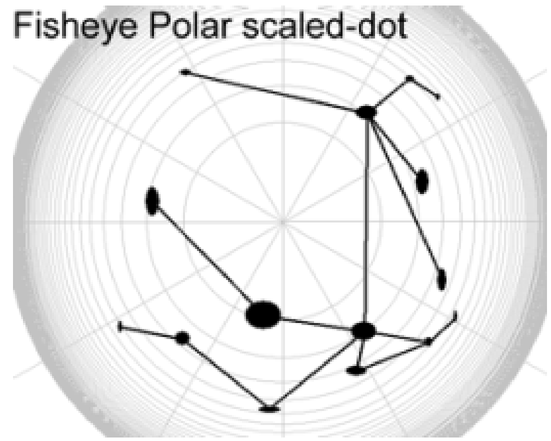
- Guidelines recommend maintaining: [Misue et al., 1995]
  - Orthogonal ordering: left-right, up-down ordering
  - Proximity: distance relationships between objects
  - Topology: inside-outside relationships
- Scaling preserves all three
  - Our visual memory is robust against scaling transformation within our tested range
- Rotation violates up-down ordering
  - Grid failed to help starting at 90°
  - Orthogonality generalization: need a principal axis with a clear up/down direction

Interpretation: Revisiting design guidelines

- Fisheye transformation violates proximity
  - Relative distance estimation is difficult
  - Fisheye rectangular transformation
    - Grids greatly improved task accuracy
  - Fisheye polar transformation
    - Better task accuracy, even without grids
    - Grids had no significant effects
    - Easier for participants to estimate distance as the widths and heights were integrated in the transformation?

Future directions

- In this work, we transformed the location of objects within the space
  - What if we also transform the objects themselves?
  - Preliminary results were inconclusive



- Our experiments looked at single and uniform transformations
  - In some applications, images may transform by parts, and independently

Conclusions

- Systematically studied the effects of geometric transformations on visual memory
- Mapped out *no-cost zones* within which performance in terms of reaction time and task accuracy were unaffected by the transformation:
  - Scaling: robust within range studied
  - Rotation and fisheyes: found boundaries
- Verified positive effects of grids:
  - Extended no-cost zone boundaries
  - Improved accuracy