Modeling the Use of Multiple Frames of Reference

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Research Objectives

- Computational model of the architecture of spatial cognition
- Embedded in ACT-R as a spatial module
- Theory-driven
    - FORMS theory based on existing empirical data
- Empirically Driven
  - Bottom-up approach
    - Spatial attention
    - Representation of objects, features, and locations
    - Object-to-object relationships and multiple frames of reference
    - Map tasks
      - Screen based objects and relations as representations of objects around you
      - Saliency, spatial updating

FORMS: Psychological Space is Segmented, Compressed, and Distorted

- Egocentric
  - Eye-centered space
  - Hand-centered space
  - Body-centered space
- Allocentric
  - World-centered space
  - Special case: screen-based

Psy Space is Compressed: Maps of Salience

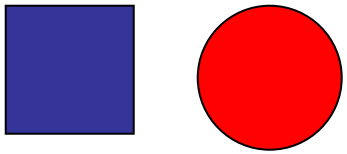
- Each segment of space is represented as a map of salience
- Represents
  - behaviorally significant information (top-down influence)
  - perceptually outstanding information

Objects, Features, and Location

- How are objects, object features and object locations represented?
- ACT-R uses a unified representation:

```
Drawing93
    isa DRAWING
    screen-pos Loc41
    value Tie
    status nil
    color Black
```

Evidence for Independent Encoding of Object Features: Illusory Conjunctions

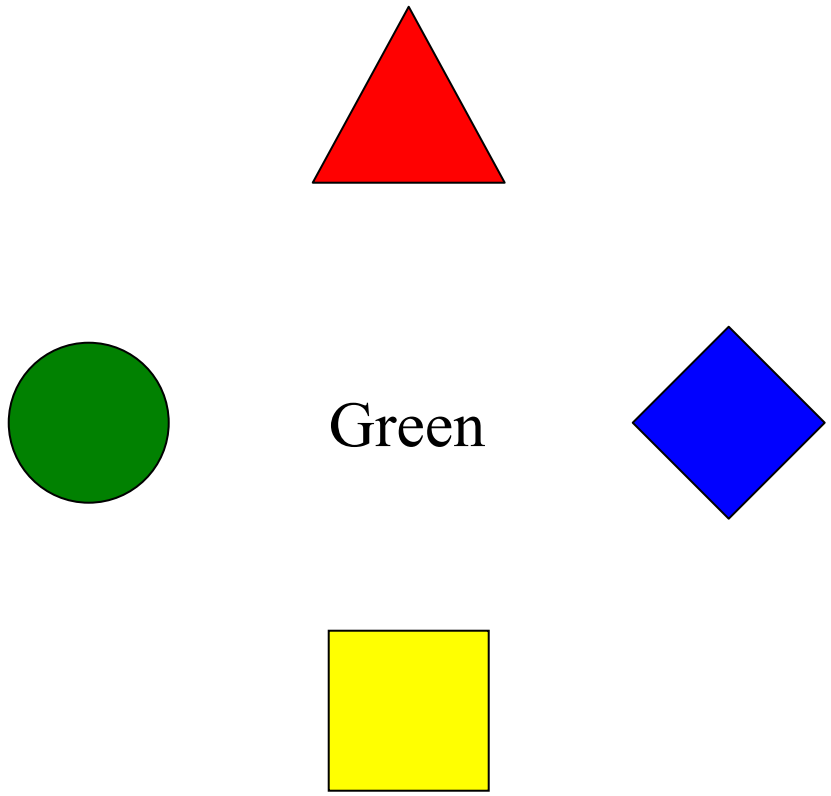
- Typically brief presentation time (50-120ms) with mask
  - See: 
  - Report: blue circle
- May be due to
  - Misperception
  - Binding errors
  - Error in recombining features from memory
- Memory Conjunction Errors
  - Even with no mask and long (5 sec) presentation time

Evidence for Independent Encoding: Memory Conjunction Errors

- Longer presentation times, no mask
  - Stefurak and Boynton (1986)
  - 5 colored forms for 5 seconds, no mask
  - Controlled for verbalization using mental arithmetic task
  - 1 old or new target
  - Found complete independence of color and shape (No conjunction memory)

Nissen Task (1985)

- Stimuli:
  - 4 shapes
  - 4 colors
  - 4 locations
- Duration 60-190 ms
- Mask
- Replaced with cue:
  - Conditions:
    - Color cue
    - Location cue

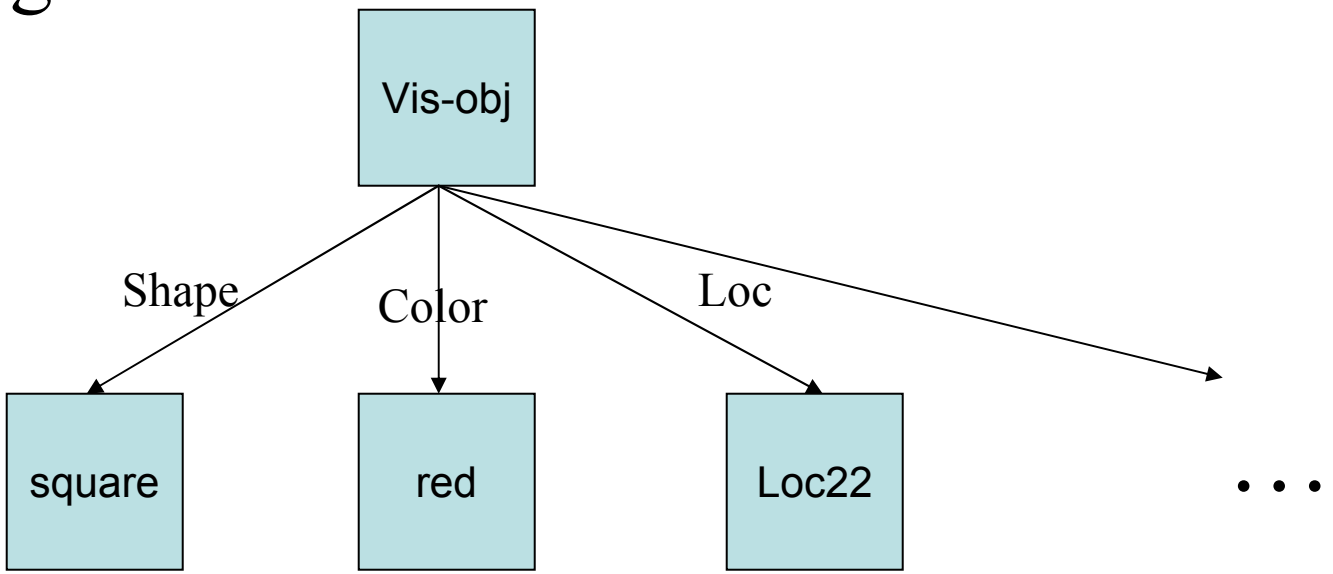


Nissen Results

- Location cue
  - Correct recall of color and shape is statistically independent
- Color cue
  - Correct recall of shape is statistically dependent on recall of location
- Nissen argued that features were stored independently, but tagged or indexed by location

ACT-R Predicts Dependence

- ACT-R produces an integrated representation
- Predicts complete dependence of color and shape given location



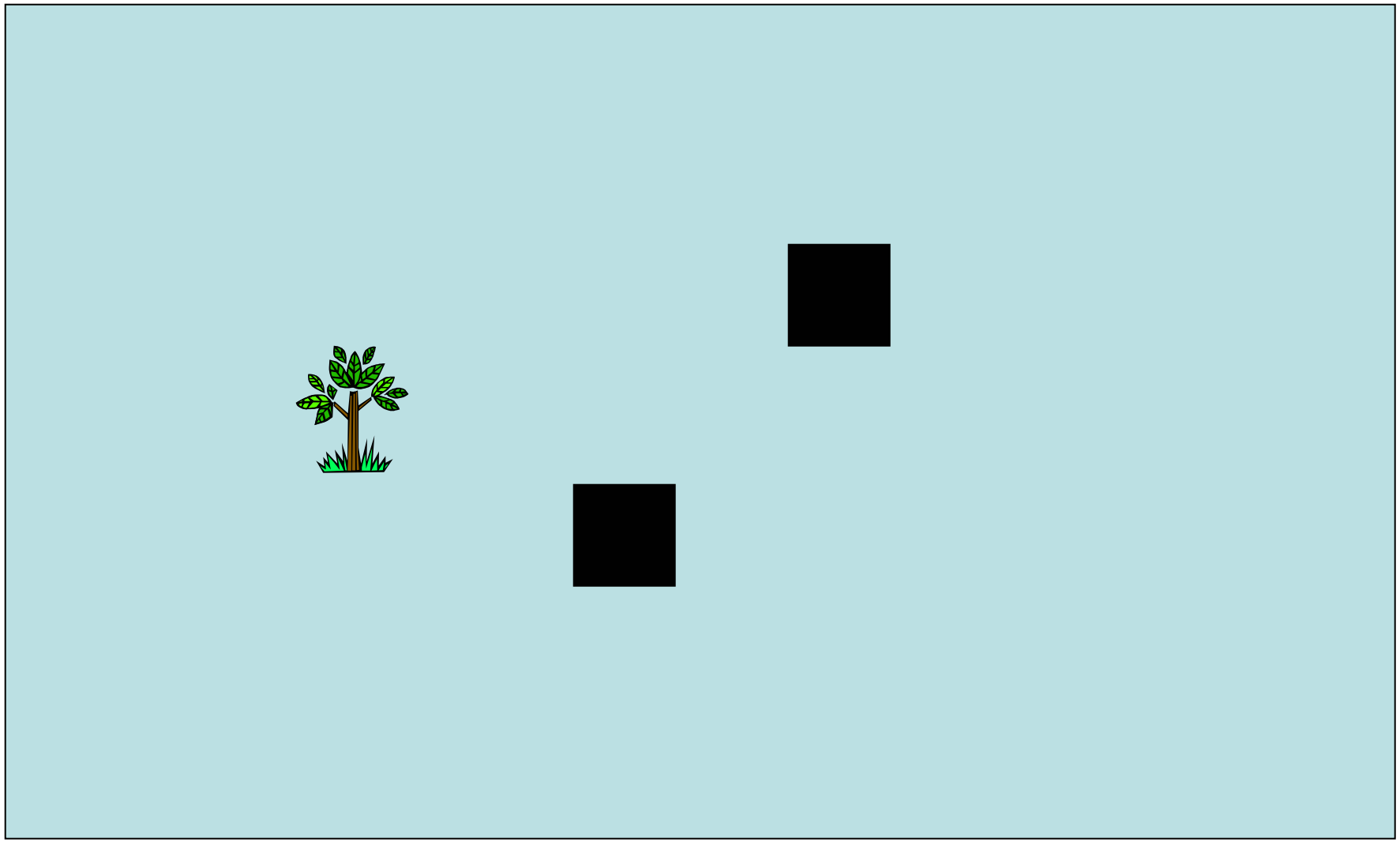
Distributed, Location-Bound Repr.

- Visual representation is feature based, but features are bound by spatial location
- Location may use one or more FOR

Object-to-Object Spatial Relations: The Milner Task

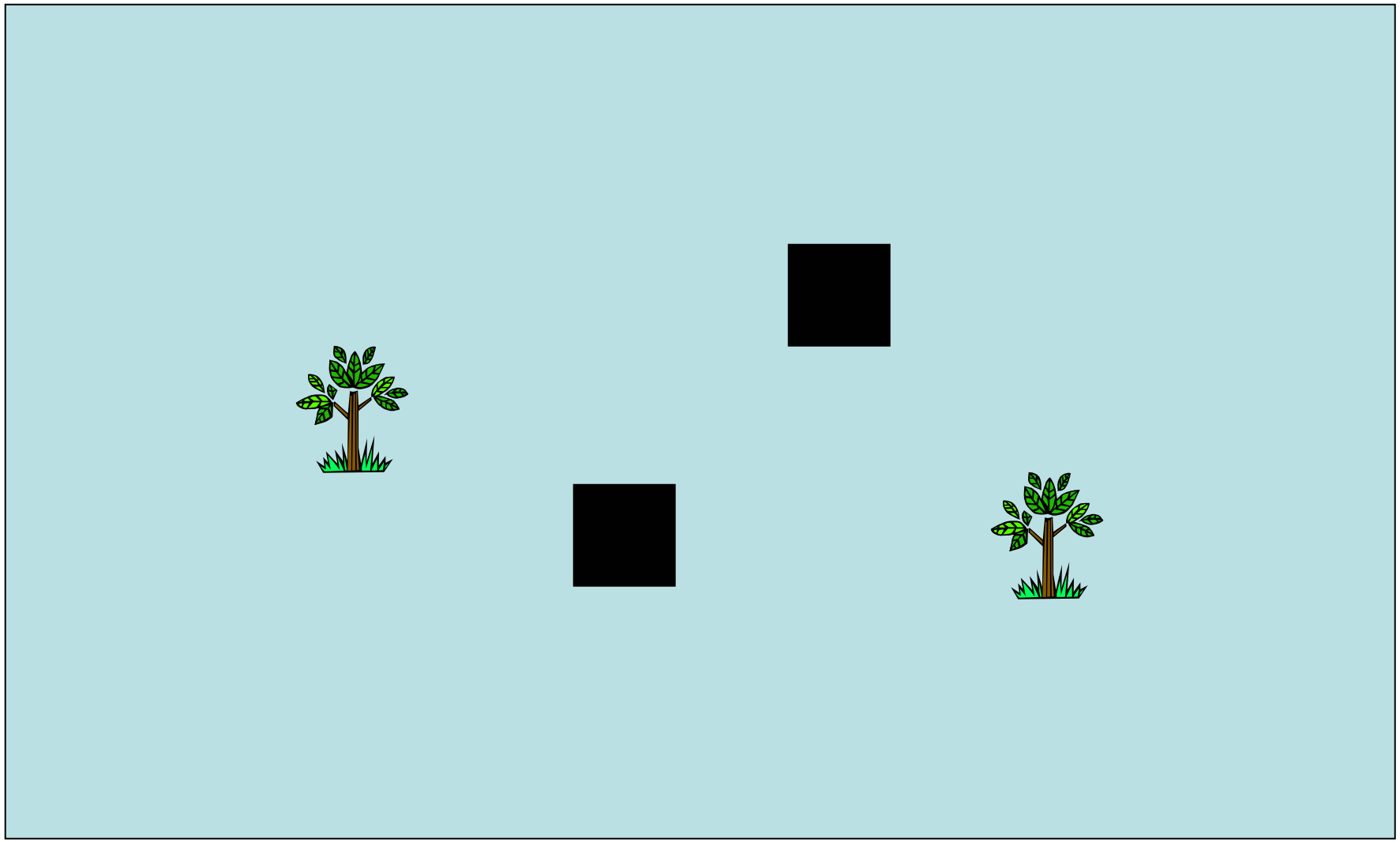
- Developed by Milner and Colleagues (1997, 1999)
- Explores use of different frames of reference for object locations
  - screen-based
  - landmark-based
  - object-based
- Early computation vs late computation
  - What kind of spatial relationships are available early in the process (and should be provided architecturally in modeling)?

Design: Study Phase



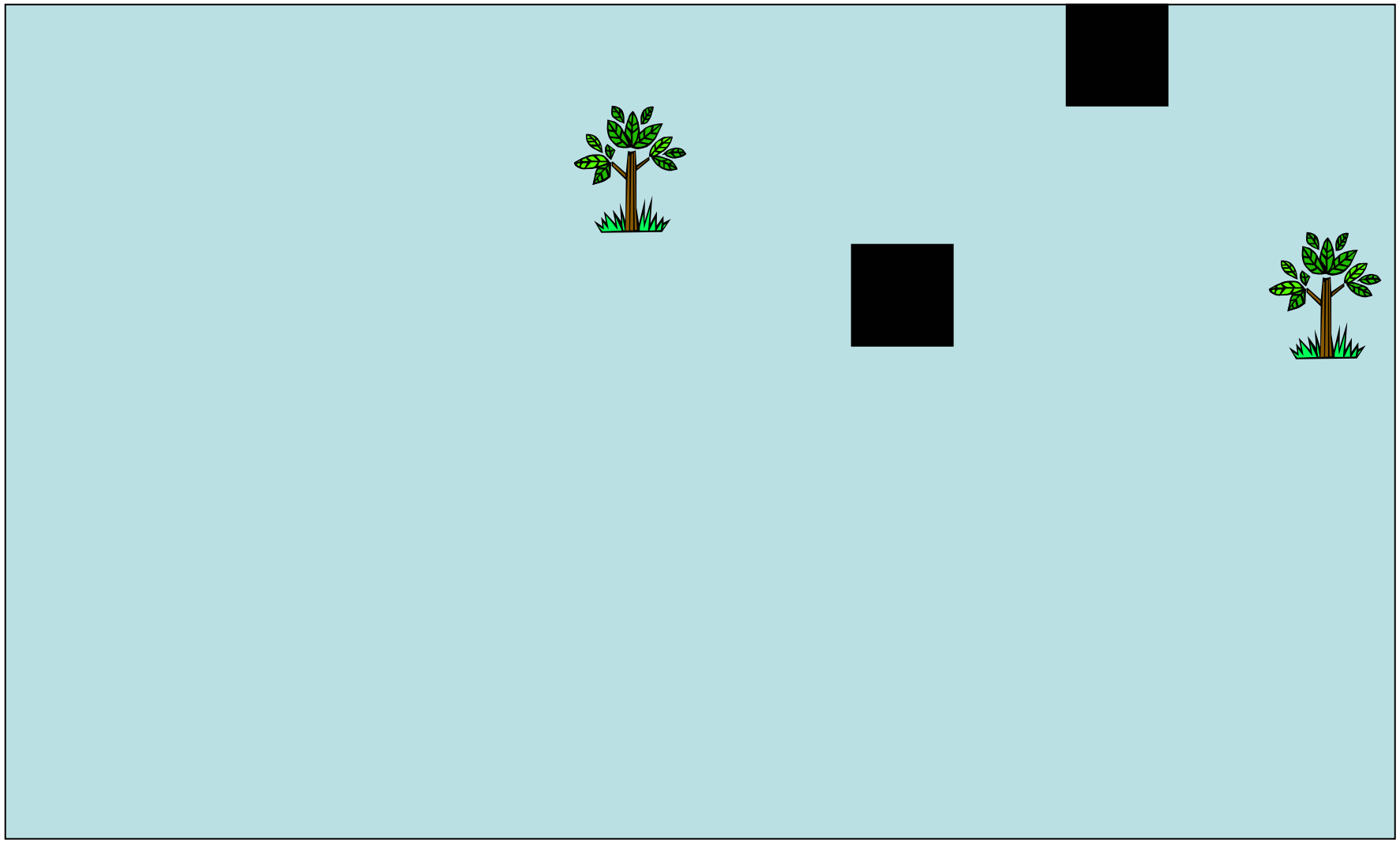
Testing: Fixed-No cue

Testing: Fixed-Landmark



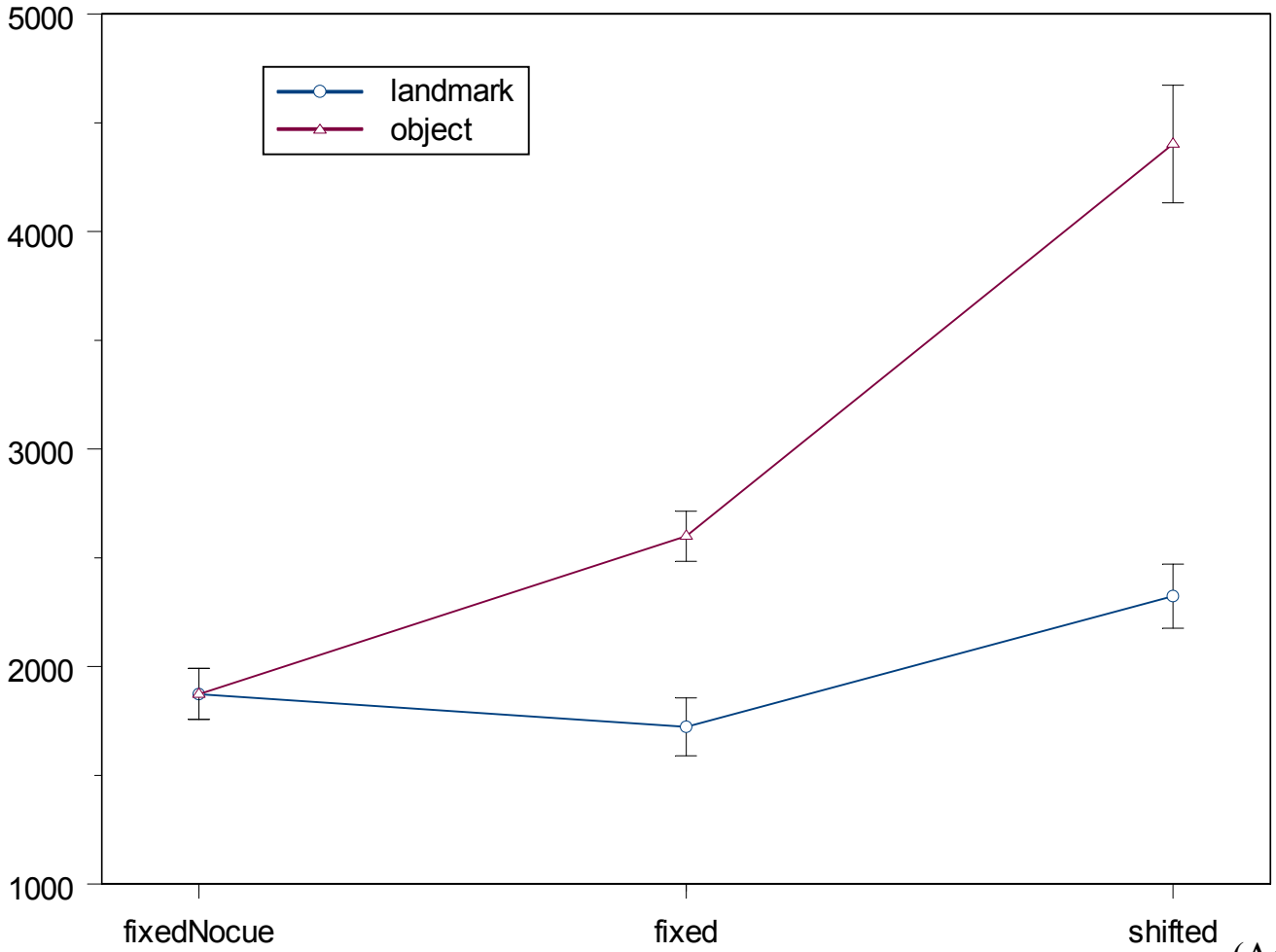
Testing: Fixed-Object

Testing: Shifted-Landmark



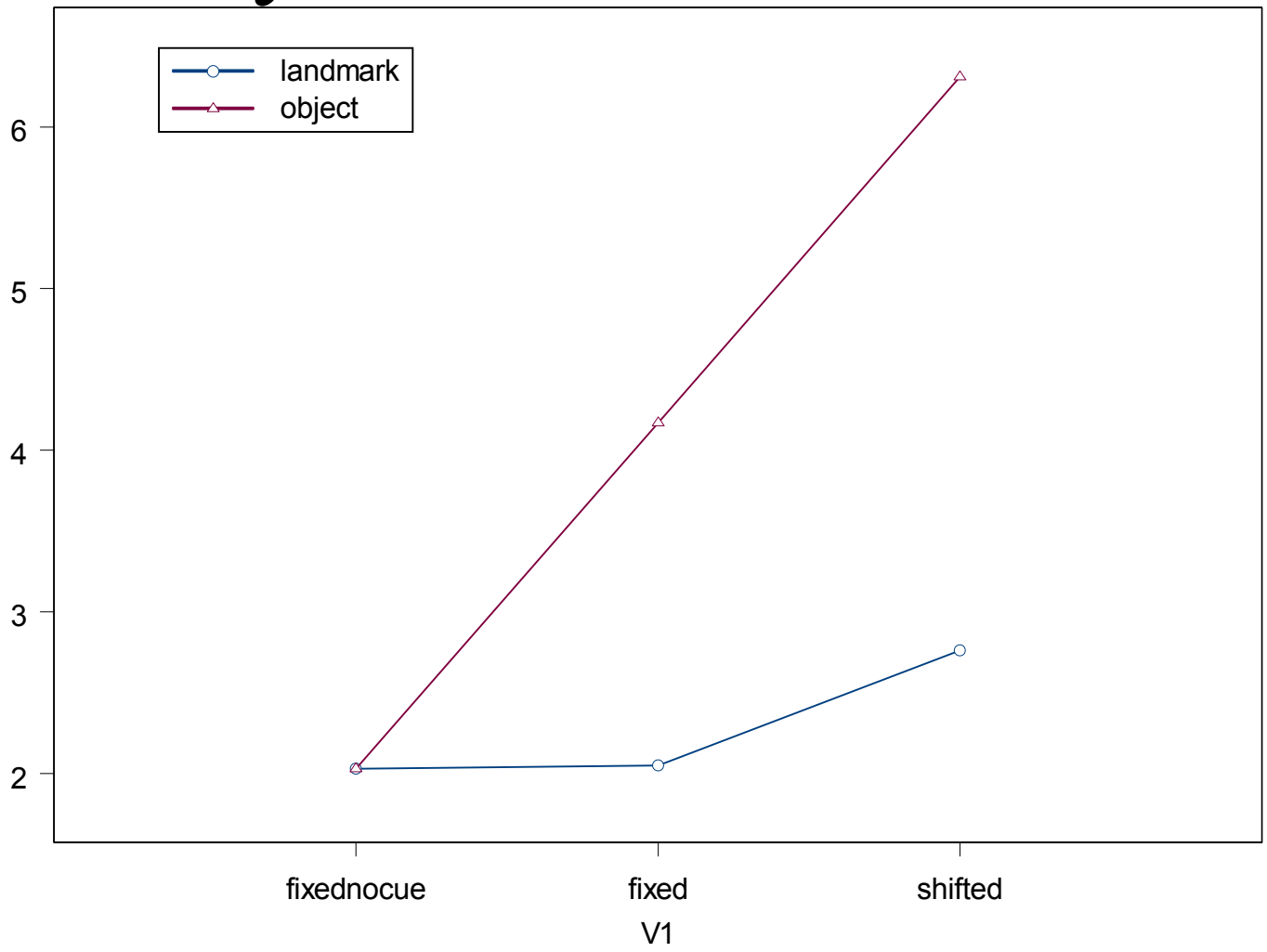
Testing: Shifted-Object

Experiment 1: RT data



(Accuracy>93%)

Experiment 1:
Eye Fixation Data



Which Object-to-Object Relations and When?

- Our solution:
  - Switching attention from one object to another builds a spatial relation between the two objects
  - Attending to a blank space returns a “blank” visual object
  - This also provides a trace of visual attentional shifts

ACT-R Model Strategy: Study

- Find and attend to the study drawing
- Note that the visual object (drawing) is a study object
- Attend to one landmark (Results in a spatial relation)
- Retrieve relation and note it as a study relation
- Reattend drawing
- Attend to second landmark
- Retrieve relation and note it as a study relation

Model Strategy: Fixed-no cue and Fixed-Landmark

- Find and attend to a drawing
- Retrieve the study version of the drawing
- If locations match, click drawing
- Otherwise,
  - Find and attend to other drawing and click it

Model Strategy: Shifted Landmark

- Find and attend to a drawing
- Find and attend to a landmark
- Retrieve the spatial relation just created between the drawing and landmark
- Try to retrieve a similar study spatial relation (same angle and distance)
- If study relation is retrieved and matches the test relation, then reattend drawing and click it
- Otherwise, find, attend and click the other drawing

Model Strategy: Fixed-Object

- Search for target-distractor drawing
  - Find and attend to a drawing
  - Find and attend to another unattended drawing
  - If the drawings are the same, pair is found, otherwise use current drawing as next possible target-distractor drawing

Fixed Object Strategy, cont…

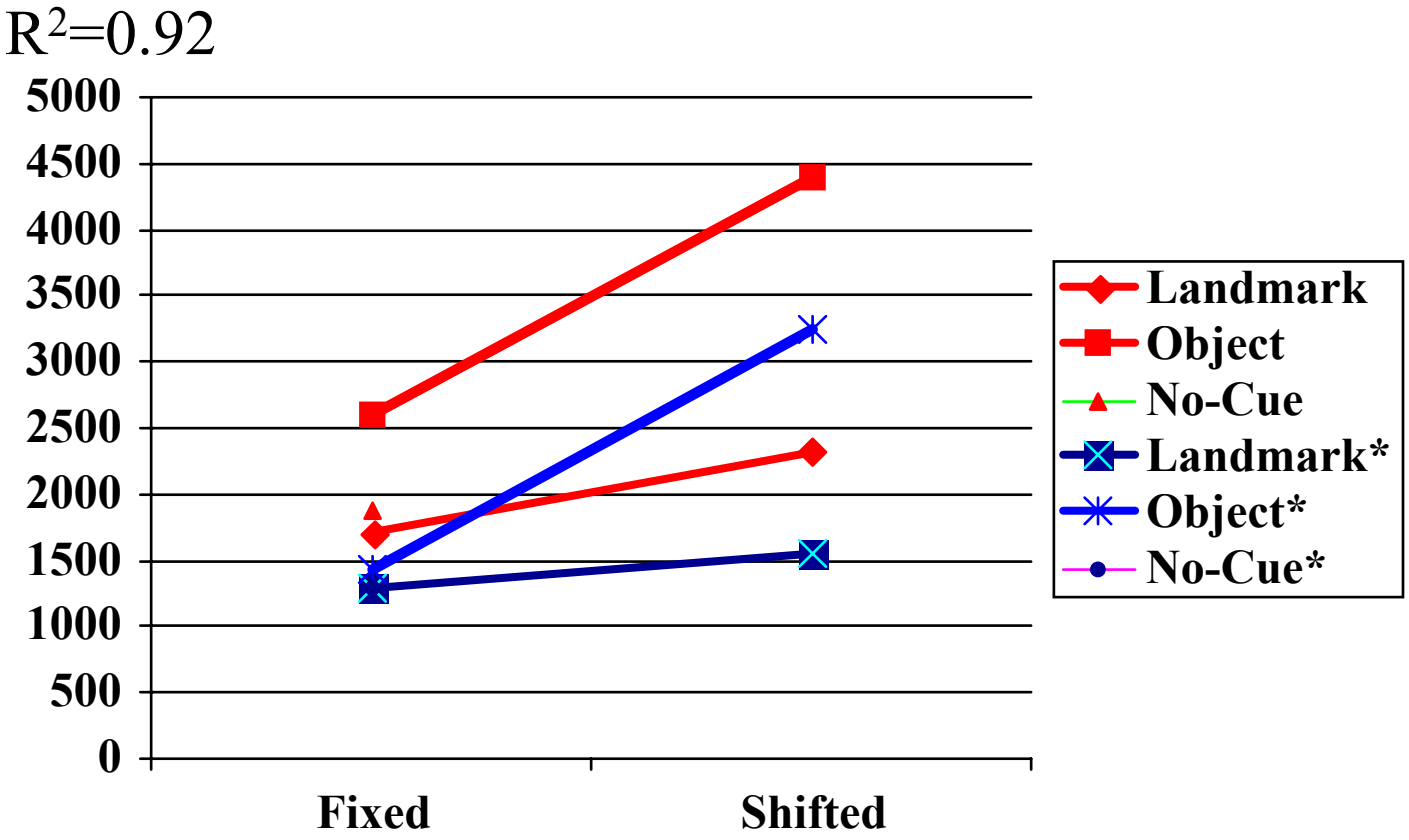
- Retrieve a study drawing matching the currently attended drawing
- If the retrieved drawing has the same location, click it
- Otherwise, attend to the other drawing and click it

Model Strategy: Shifted-Object

- Search for target-distractor pair
- Retrieve the study version of the drawing
- Retrieve a study object-to-object relation for the study drawing
- Attend to a cue drawing
- Use the retrieved study relation to attend to the expected location of one of landmarks
- Shift attention from this location to the cue drawing
- Retrieve the resulting “landmark” to anchor relation
- Try to retrieve a similar study relation
- If study relation matches test relation, reattend target drawing and click, otherwise attend to other duplicate drawing and click

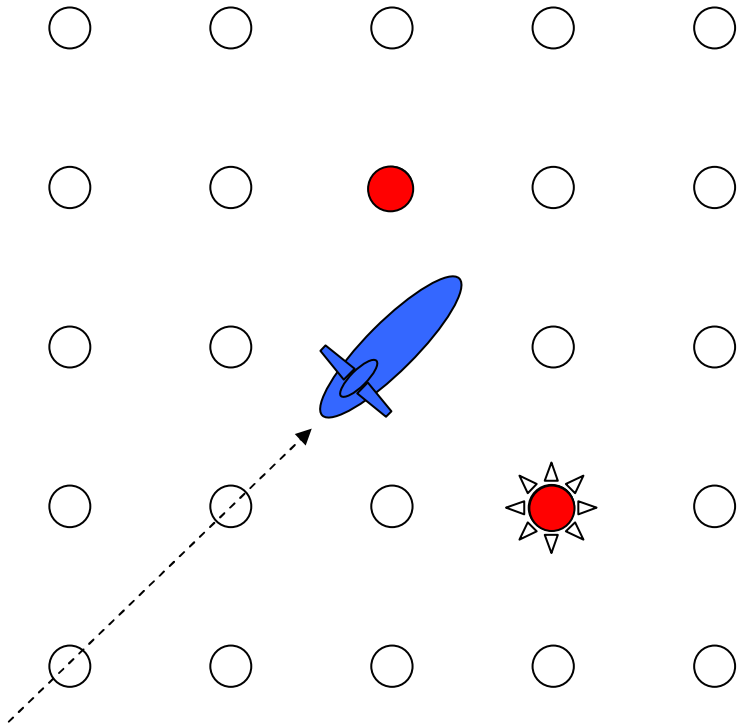
Testing: Shifted-Object

Results

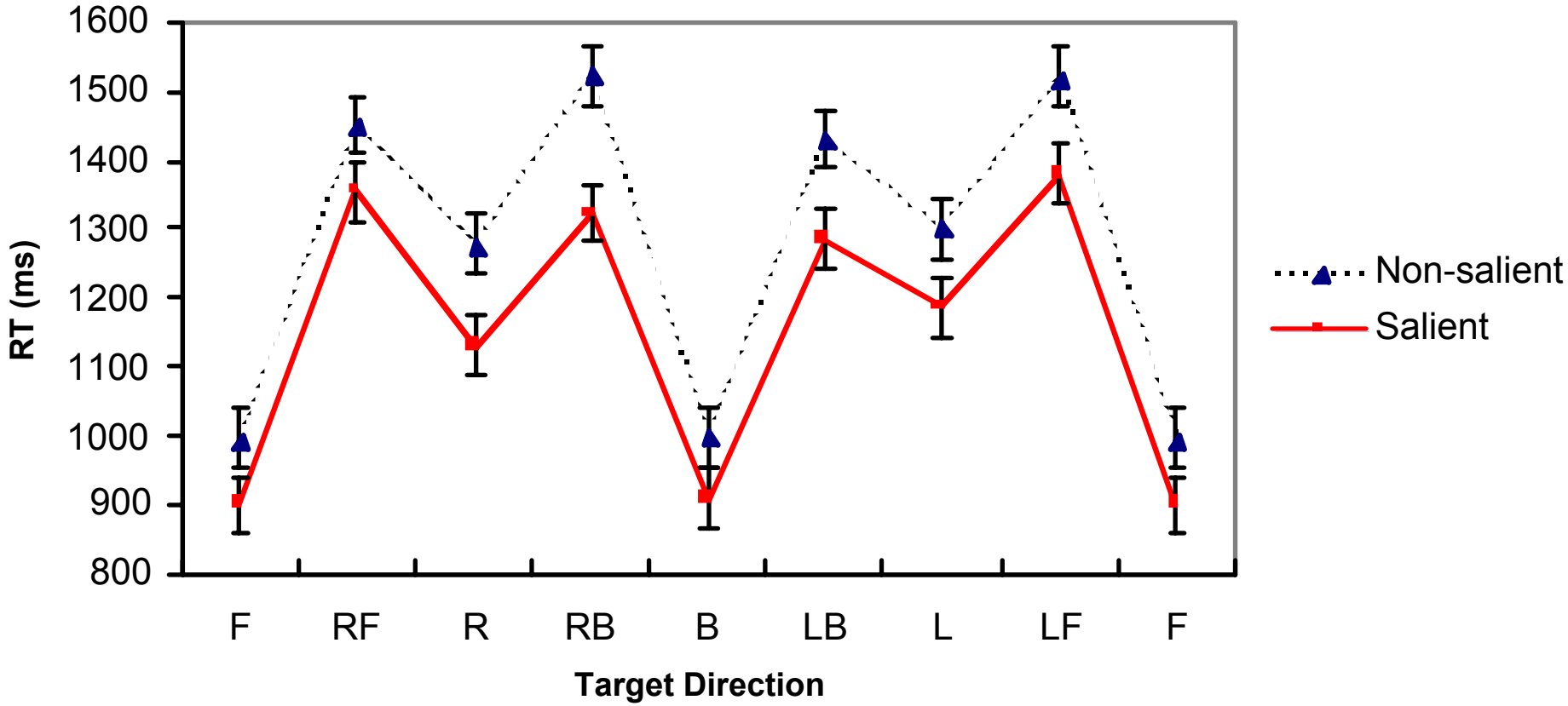

R2=0.92
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Fixed
Shifted
Landmark
Object
No-Cue
Landmark*
Object*
No-Cue*

Map Tasks: Saliency, Multiple FOR, Movement

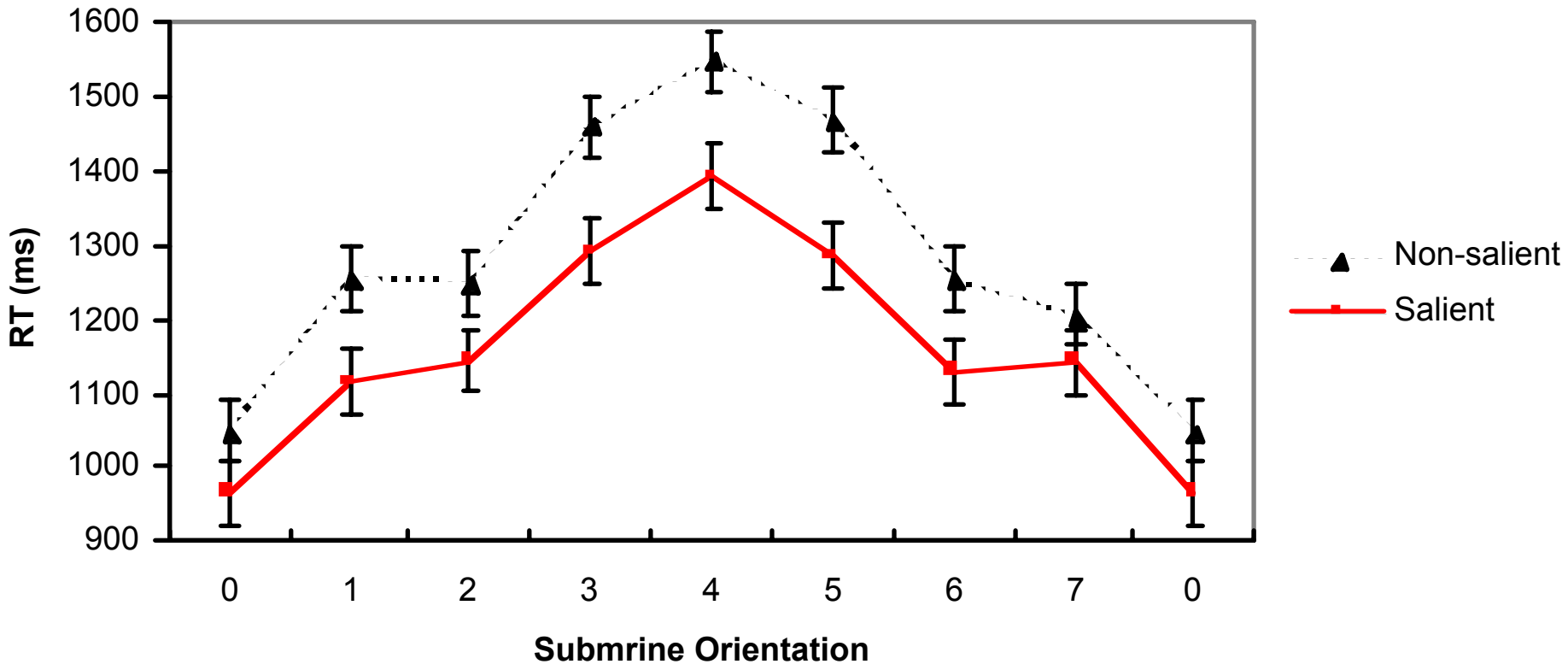
- With Yanlong Sun and Ye Yuan
- Experiment 1



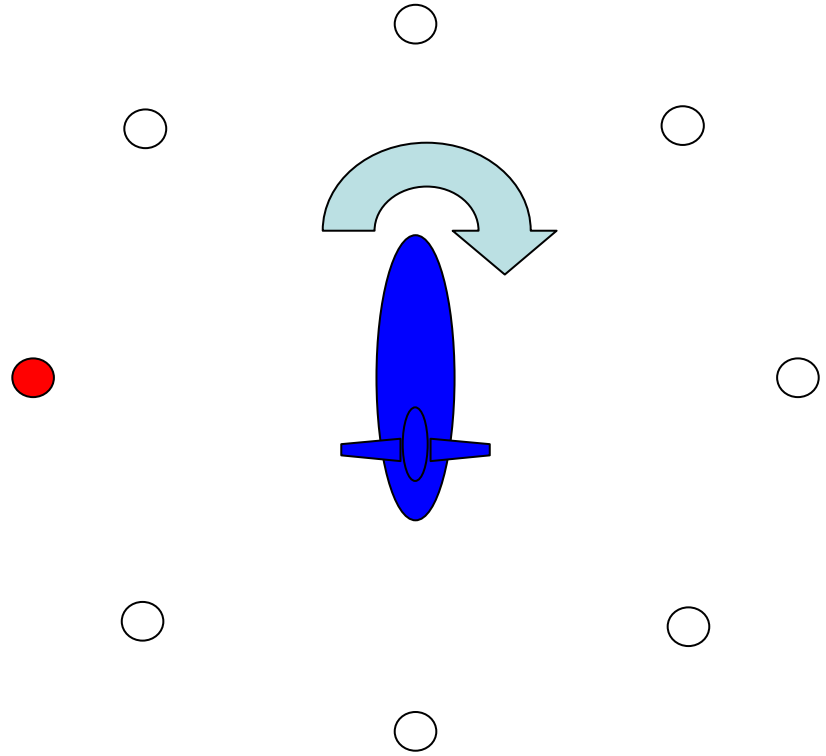
Exp 1 Results: Saliency Effect
Target Direction Effect



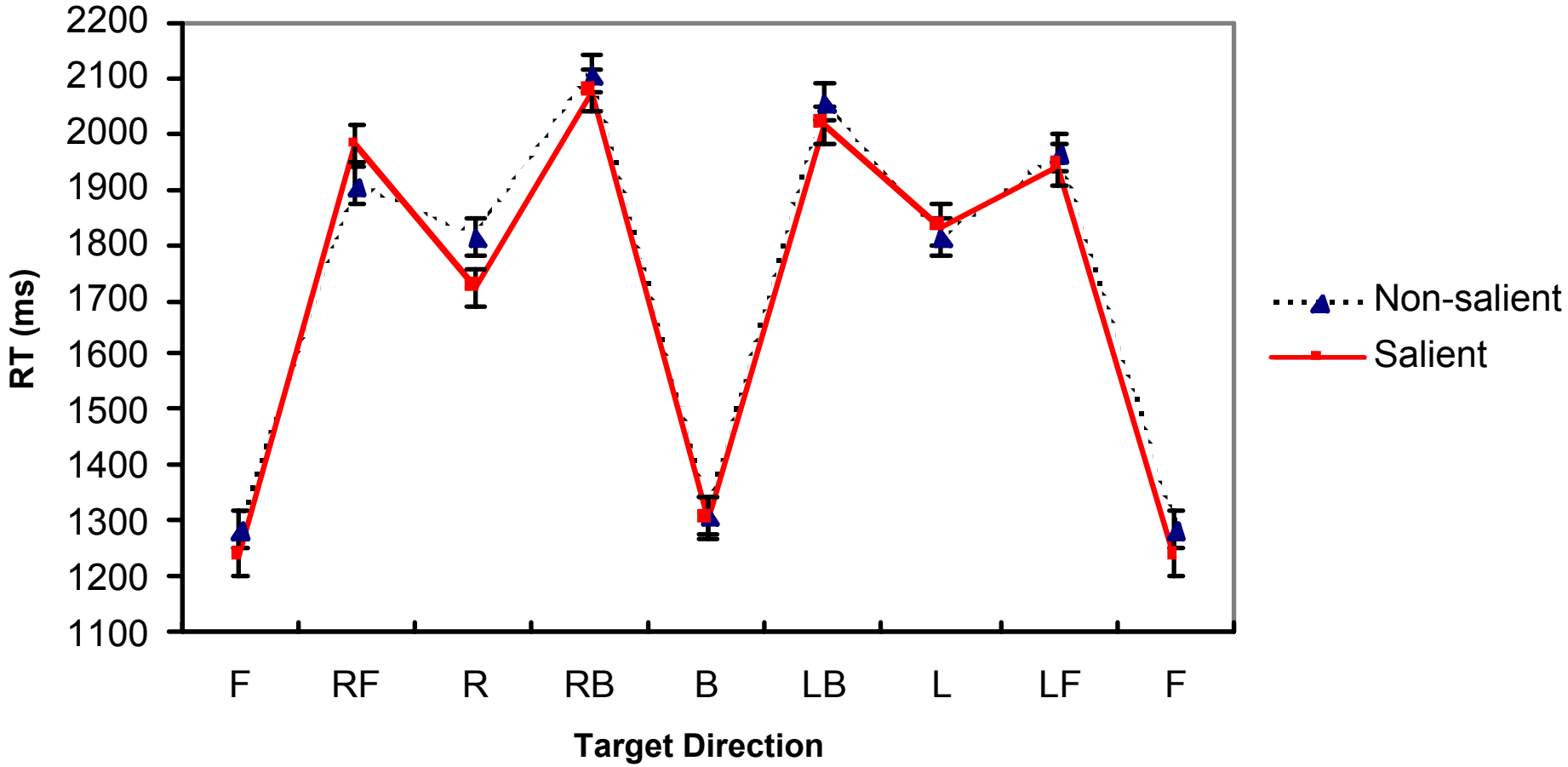
Exp 1 Results: Orientation Effect



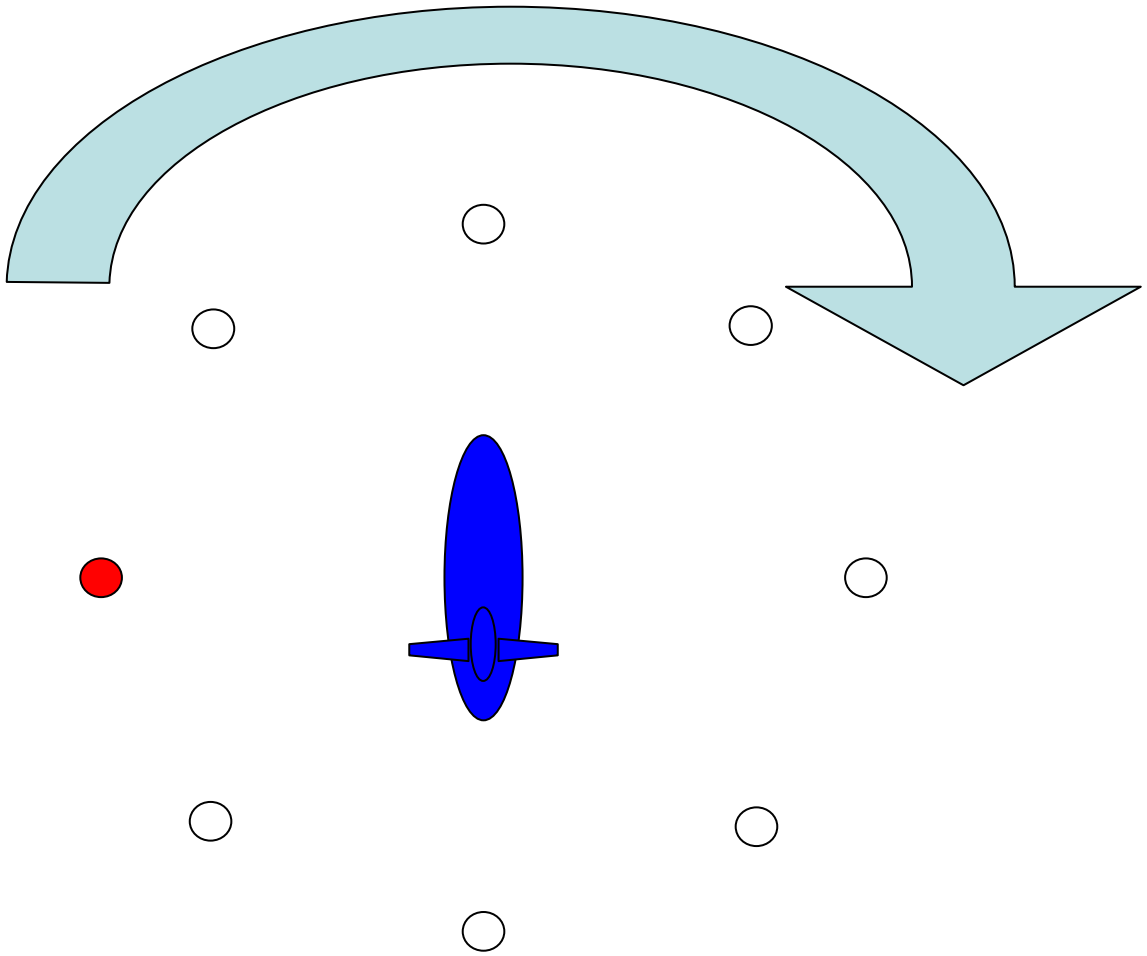
Experiment 2: Rotating FOR



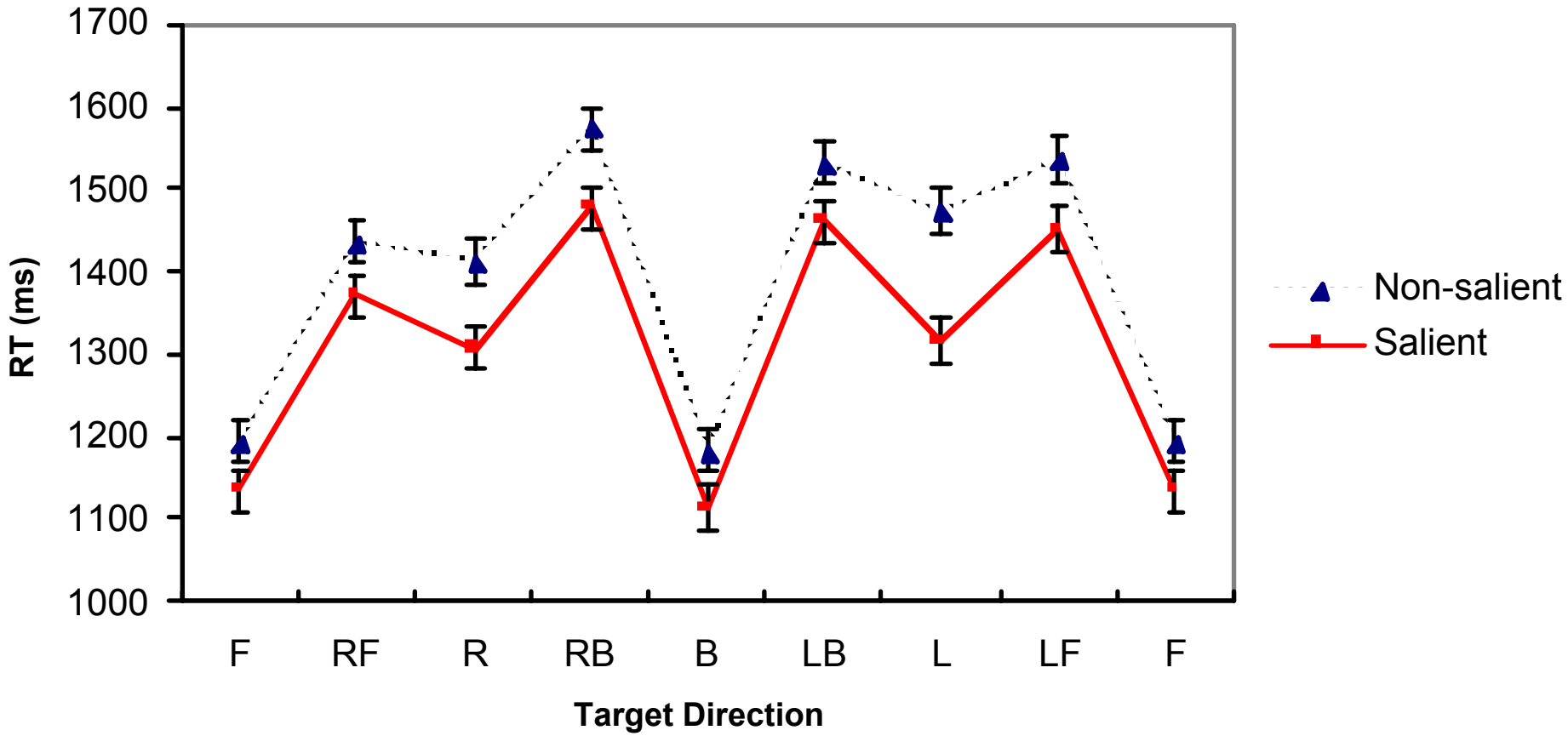
Exp 2 Results: No Saliency Effect



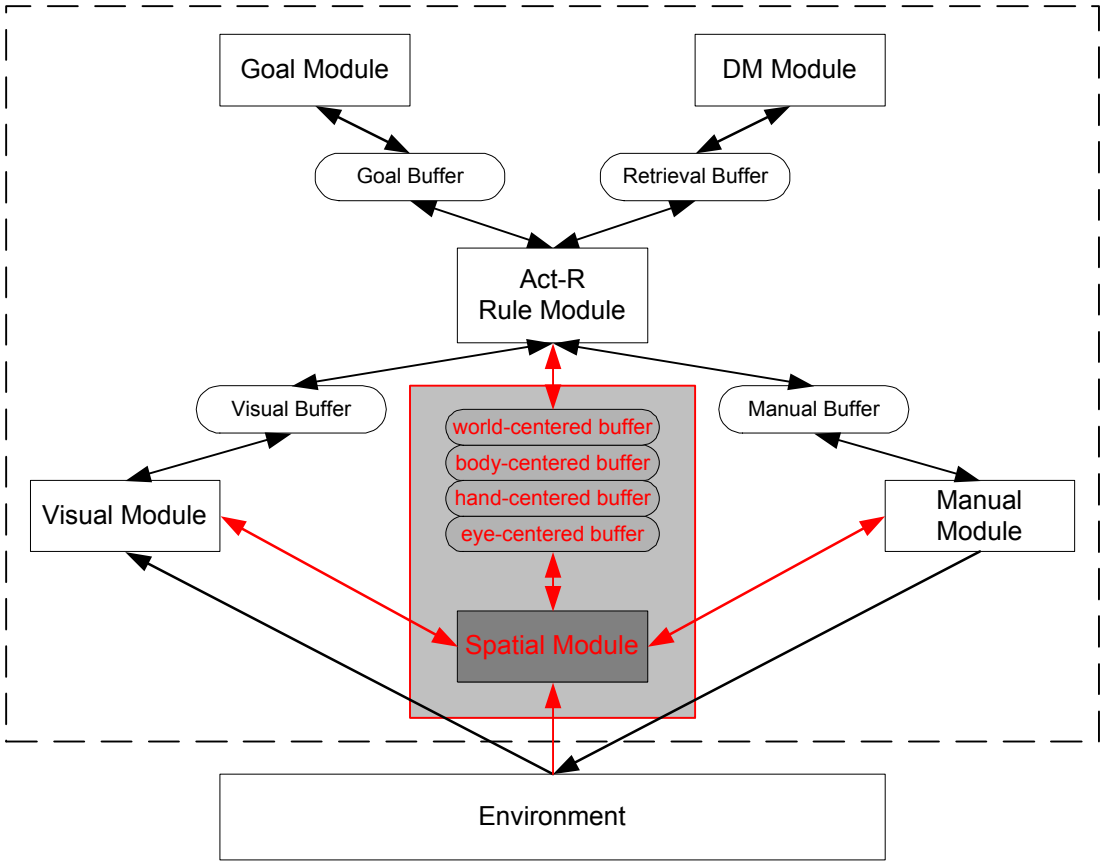
Experiment 3: Rotating Targets



Saliency Effect Returns



The Spatial Module



Key Features

- Visual Buffer: visual features
- Spatial buffers: Spatial location only
- Buffers (including visual buffer) are synchronized by default on finding locations
  - But looking at one location and pointing to another is possible
- Can find and attend to an empty spatial location
- When attention is moved from one location to another, a chunk representing the spatial relationship of the two is automatically generated.
- Different buffers with different frames of reference may explain many neuropsychological problems.
  - Patient who can name an object but cannot point to it: working visual module, but damaged hand-centered spatial represenation.
- Version 1-alpha, working only with MCL.

Example 1

;; find a red object on the screen and point to it

```
(p find-red-object-location
   "find-red-object-location"
   =goal>
      ISA   finding-and-pointing
      state  finding
==>
   =goal>
      state pointing
   +visual-location>
      ISA   visual-location
      kind  something
      color red
)
```

```
(p point-to-it
   "point-to-it"
   =goal>
      ISA   finding-and-pointing
      state  pointing
   =hand-centered-location>
      ISA   hand-centered-location
==>
   =goal>
      state done
   +manual>
      ISA   point-hand
      hand  right
      location =hand-centered-location>
)
```

Example 2

```
;; find the center of the screen
;; (nothing there) and look at it

(p find-location
   "find-location"
   =goal>
      ISA   finding-and-looking
      state  finding
==>
   =goal>
      state looking
   +screen-based-location>
      ISA   screen-based-location
      screen-x 512
      screen-y 384
)
```

```
(p look-at-it
   "look-at-it"
   =goal>
      ISA   finding-and-looking
      state  looking
   =eye-centered-location>
      ISA   eye-centered-location
==>
   =goal>
      state done
   +visual>
      ISA   visual-object
      screen-pos =eye-centered-location>
)
```

How does the approach support…

- Spatial localization of objects relative to self
  - Eye, body, and hand centered buffers
- Spatial relations among objects
  - World-centered buffer and shift of spatial attention
- Navigation
- Imaginary spatial problem solving
  - Spatial module will support functions for rotation, translation, etc.

Effects on Spatial Problem Solving

- Attentional shift method for producing object-to-object relationships affects strategies for
  - studying spatial arrays
  - comparing current spatial configurations to past configurations
- Requires deliberate effort to tag spatial objects and relations with contextual information (e.g., study, test)