Application Scenarios for Visual Prediction

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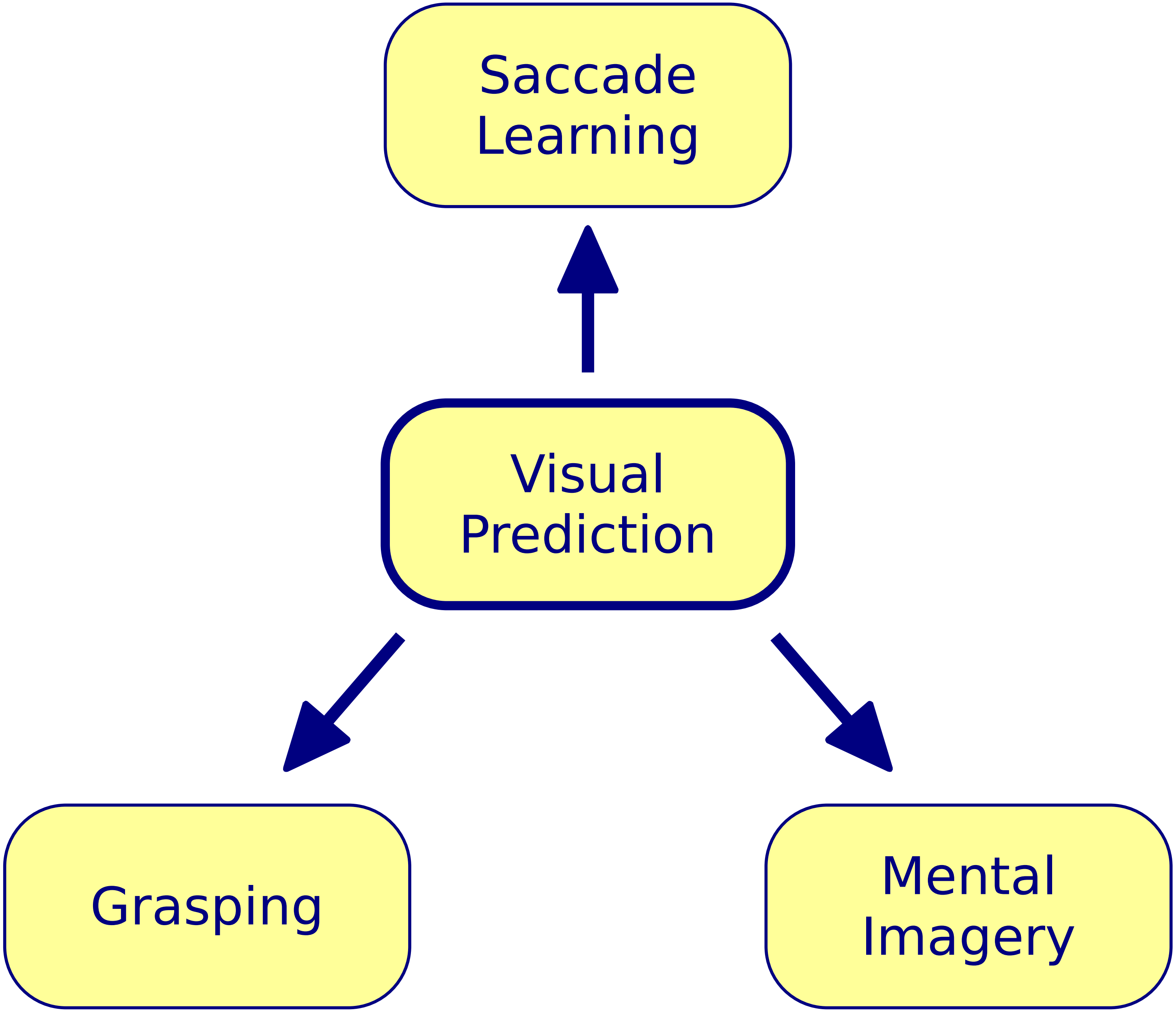
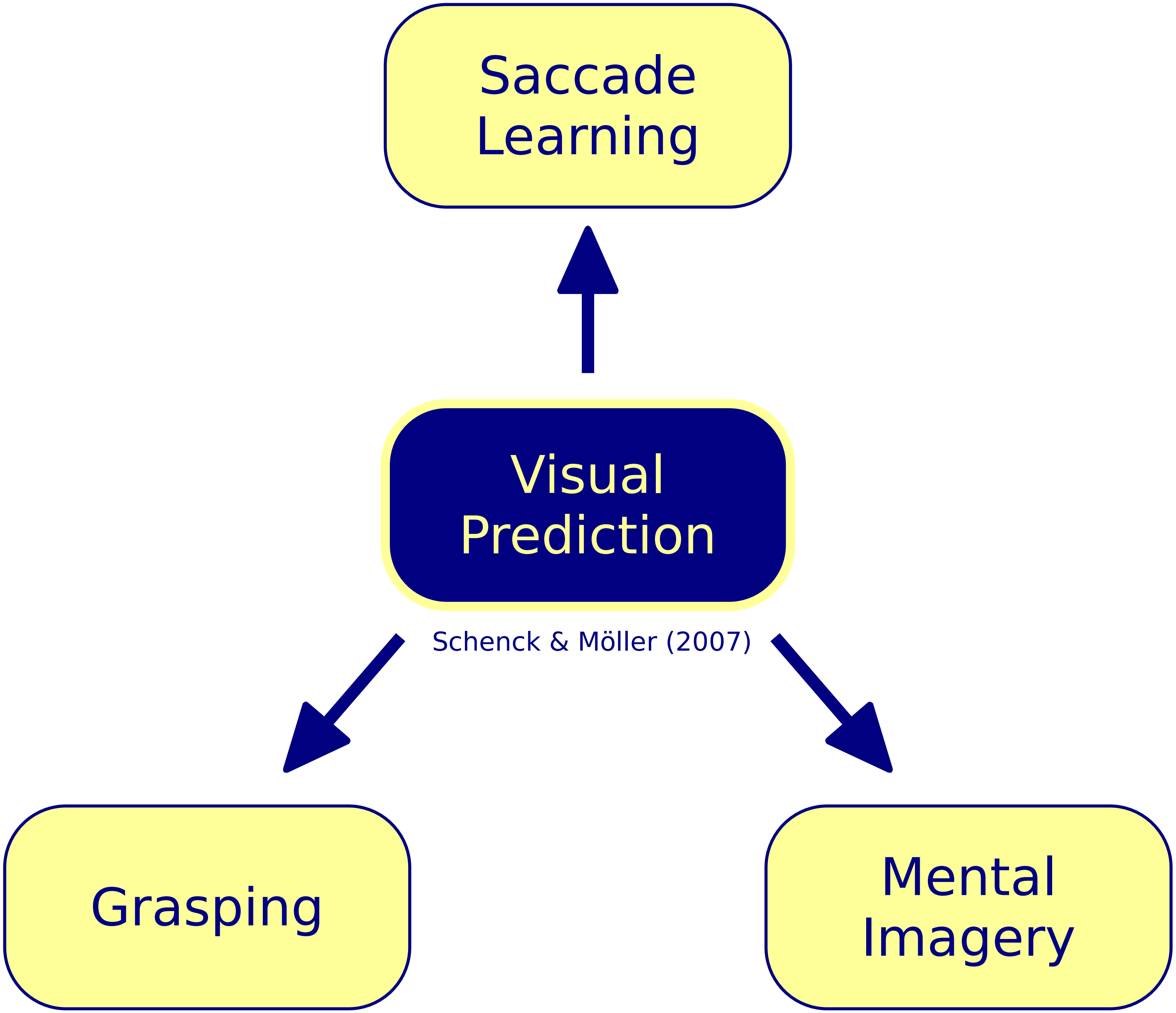
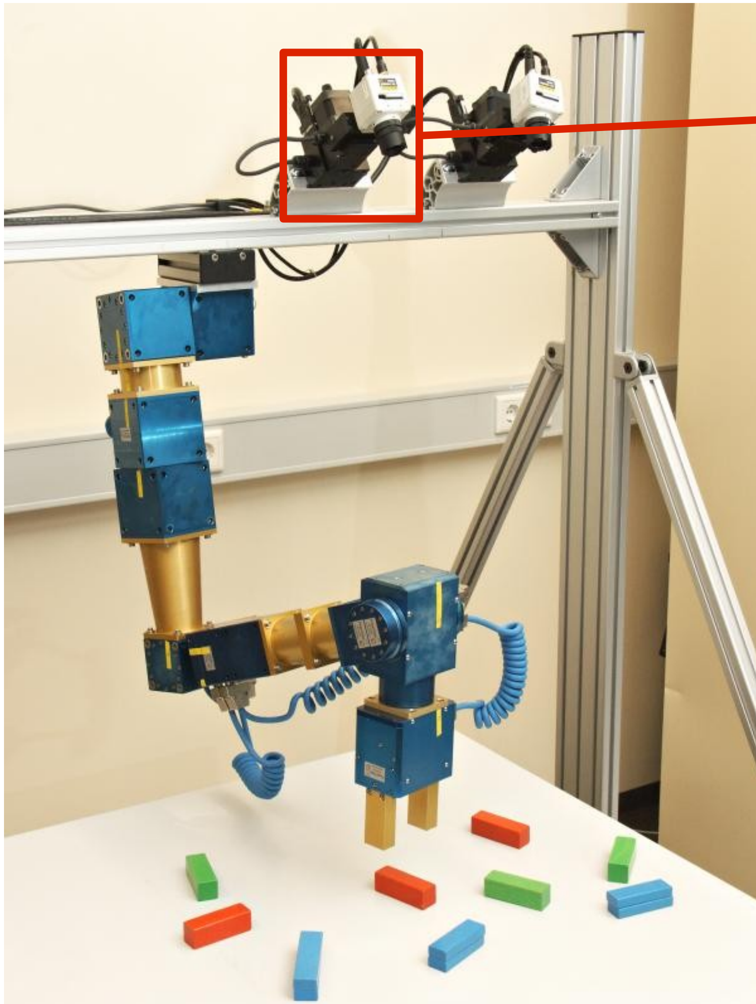

Saccade
Learning
Visual
Prediction
Grasping
Mental
Imagery

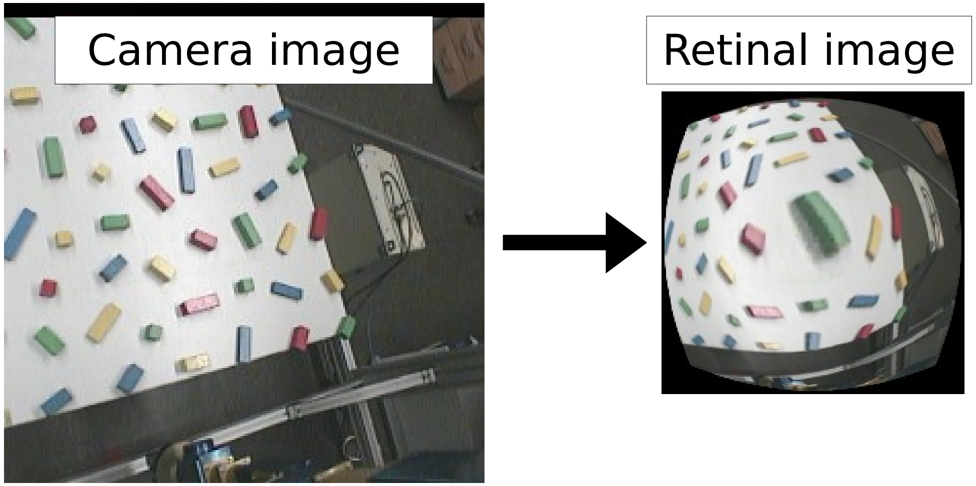


Saccade Learning
Visual Prediction
Schenck & Möller (2007)
Grasping
Mental Imagery

Setup

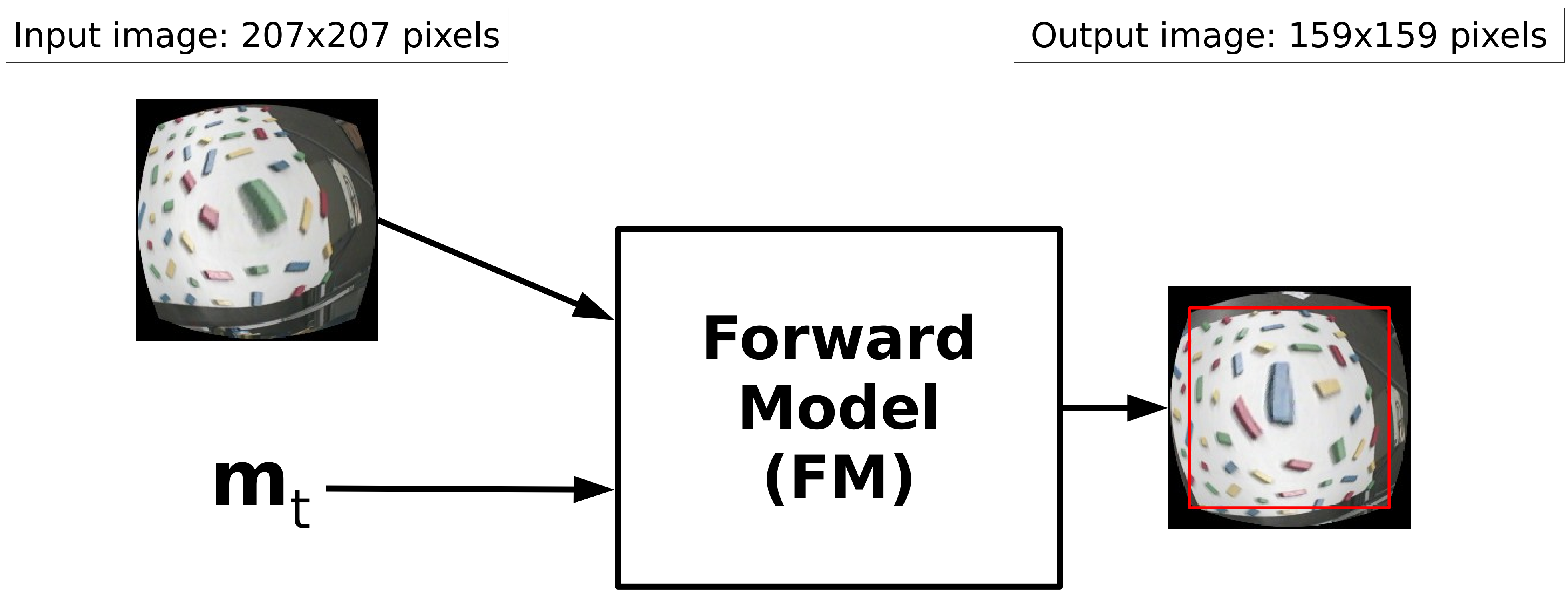


Two degrees of freedom:
- Δpan
- Δtilt



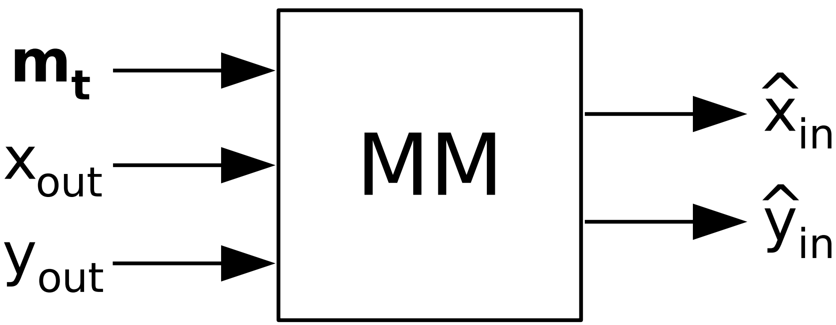
- Power function: $r_C = \lambda r_R^{\gamma} + (1-\lambda) r_R$
  - r_C: Normalized radius in camera image
  - r_R: Normalized radius in retinal image
  - $\lambda = 0.8$, $\gamma = 2.5$

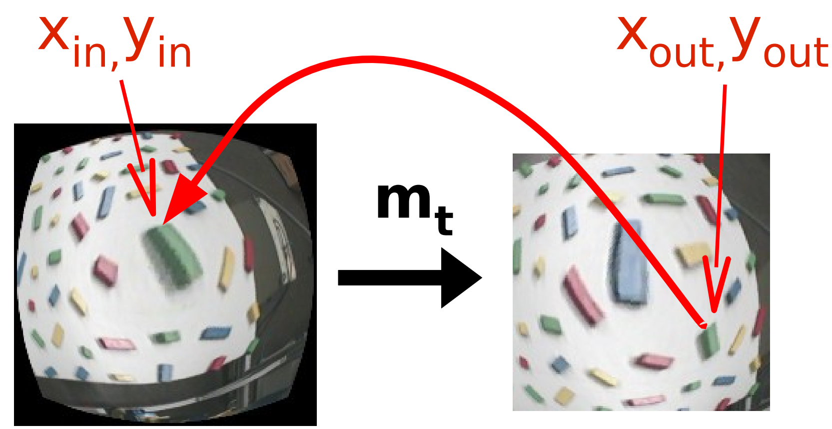
Visual Forward Model for Saccades



$\mathbf{m}_t = (\Delta pan_t, \Delta tilt_t)$

Mapping and Validator Model

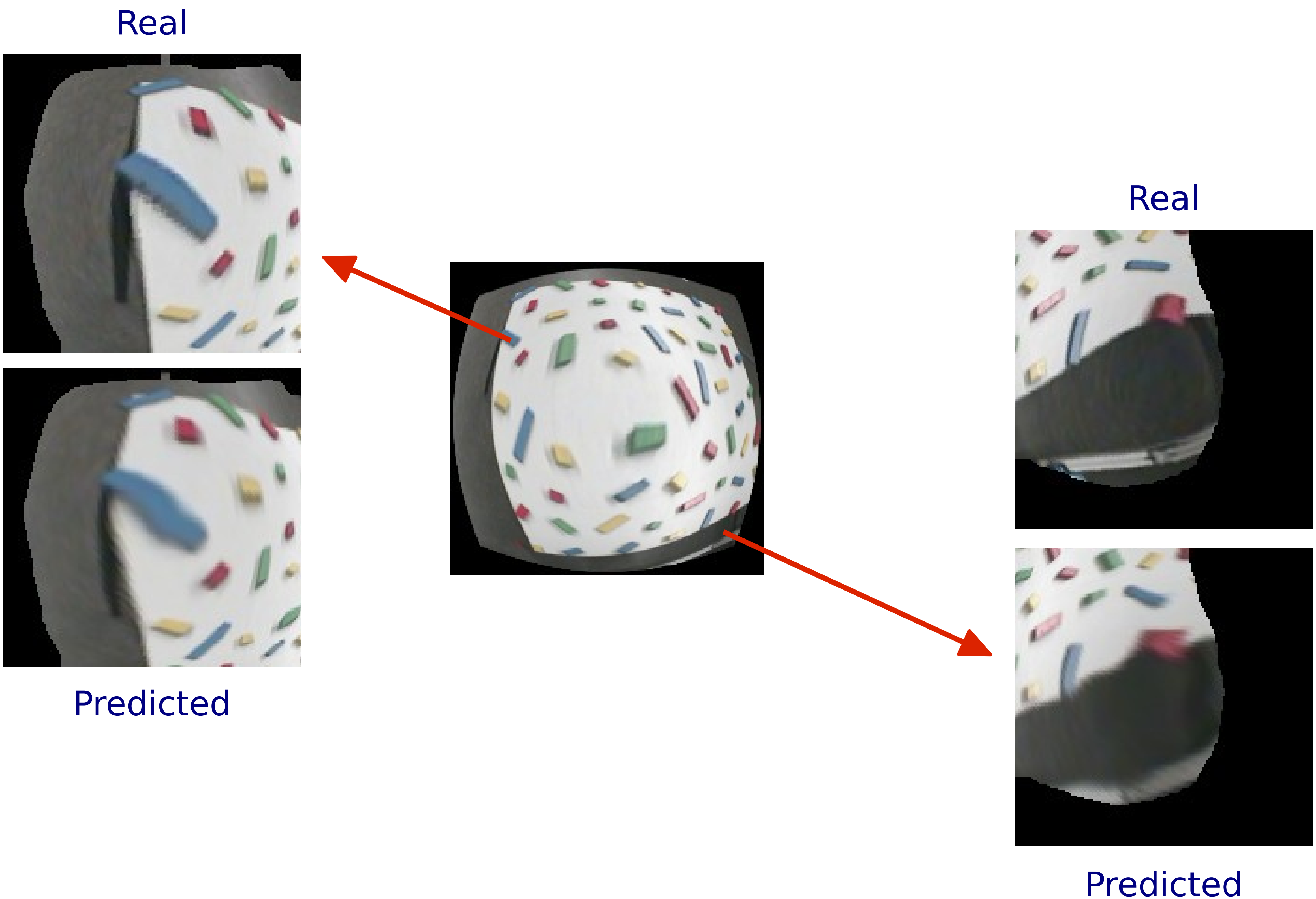


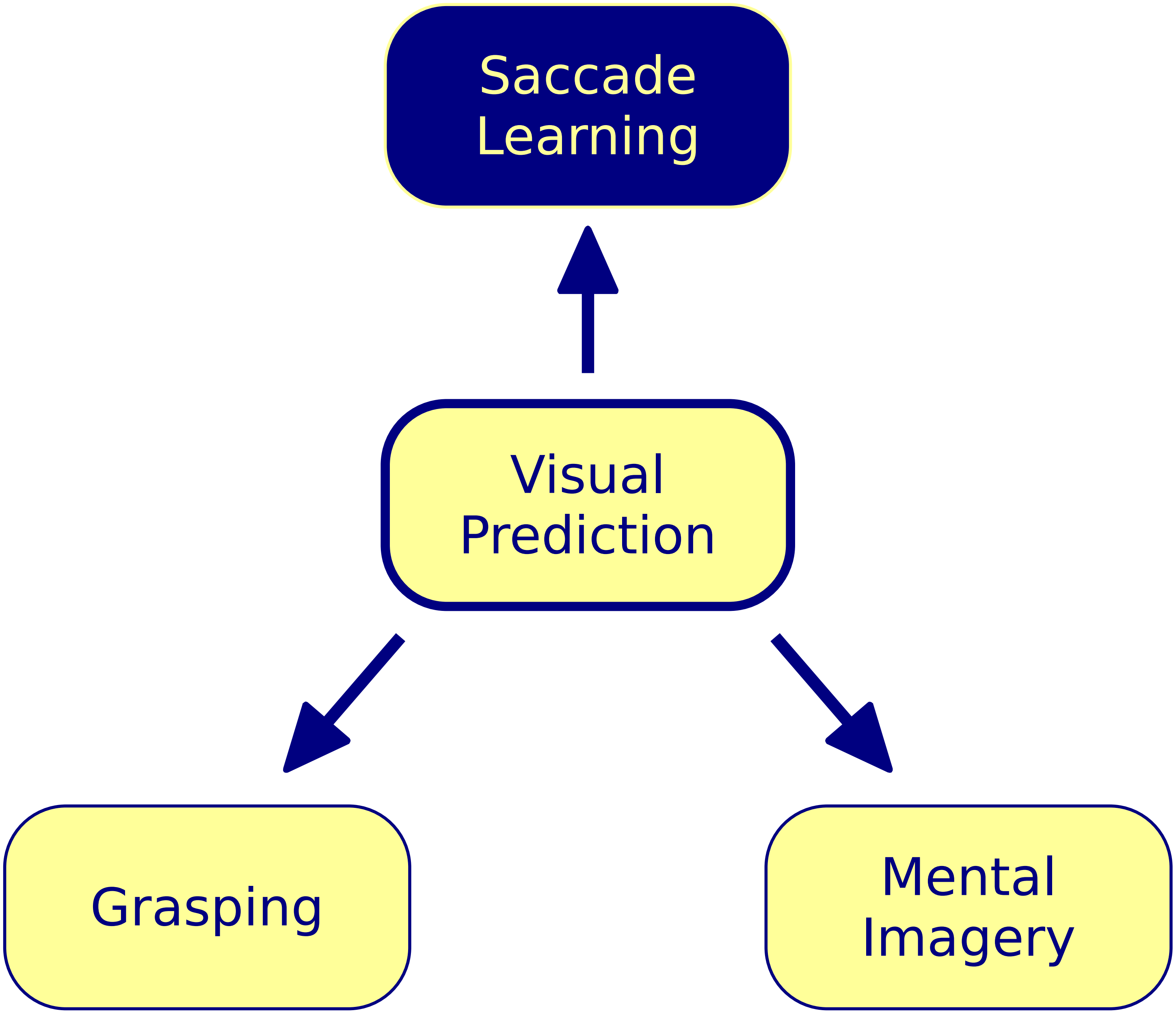


Predictive remapping: Visual prediction in the brain by shifting receptive fields (e.g., Duhamel et al., 1992; Umeno & Goldberg, 1997)

$\mathbf{m}_t = (\Delta pan_t, \Delta tilt_t)$

Prediction Examples

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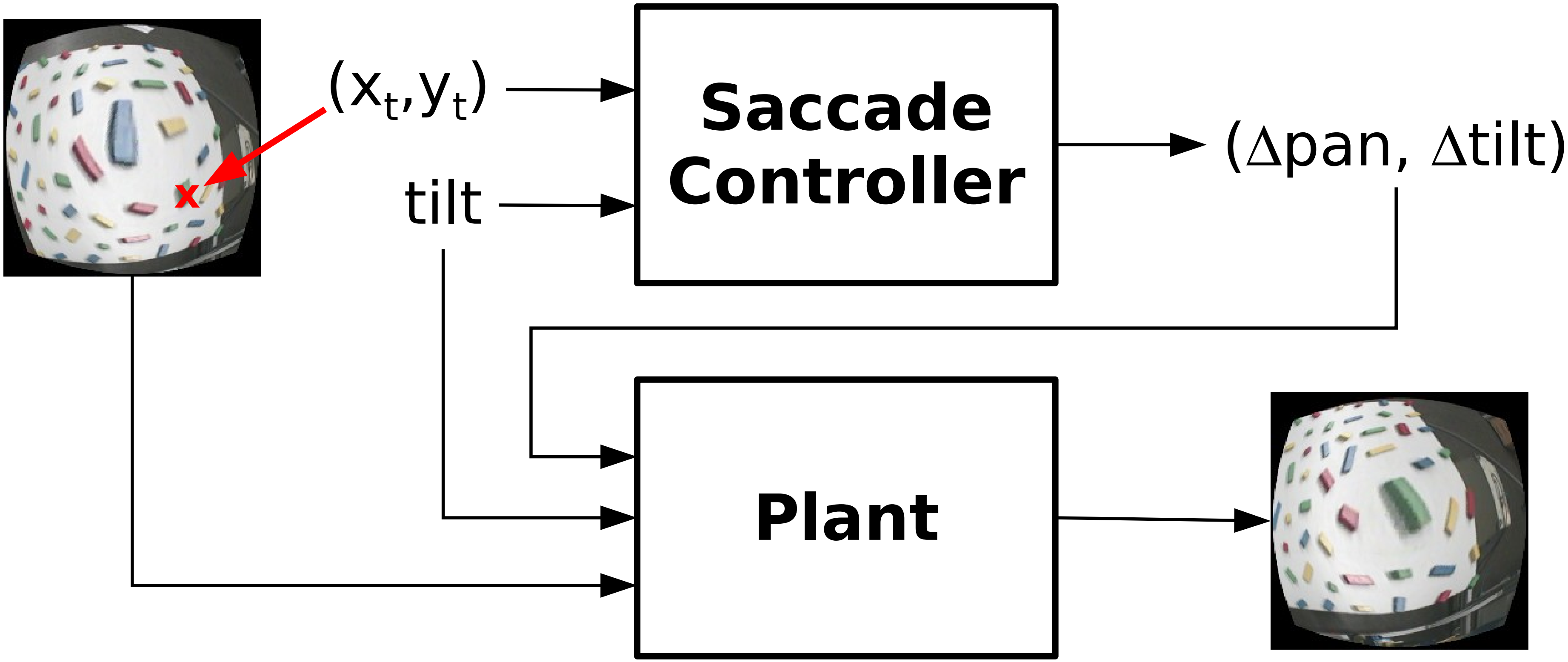
Saccade Control Task

- **Task:** Schedule commands (Δpan, Δtilt) such that a target object is projected onto the center of the camera image

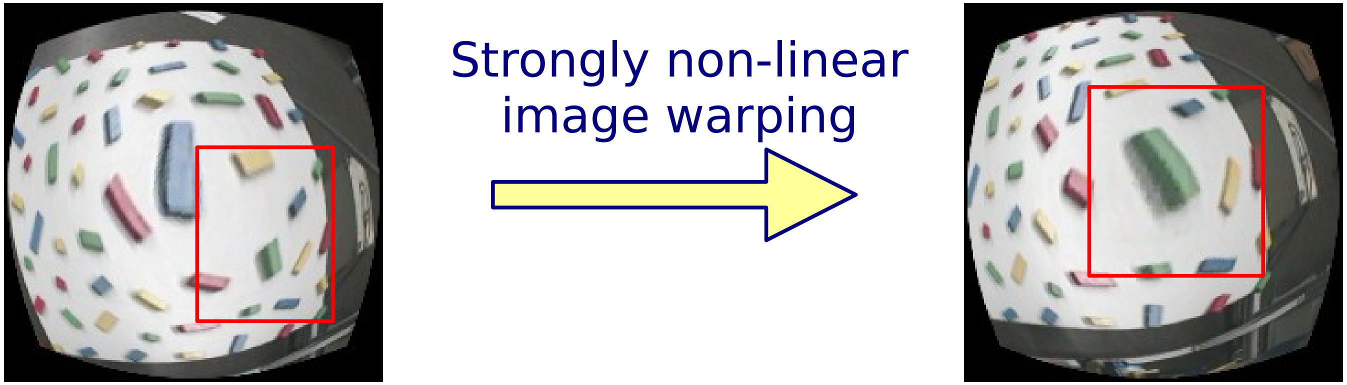


Problem of the Missing Teacher Signal

- **Goal:** Train an adaptive saccade controller
- **Required:** Learning examples associating sensory input and the correct motor output
- **Problem:** The correct motor output (and thus the motor error $\Delta\mathbf{m}$) is unknown...
- **Solution:** “Direct Inverse Modeling” (DIM) (e.g., Kuperstein, 1990)
- **But:** DIM requires $\mathbf{s}_t$ and $\mathbf{s}_{t+1}$

Target Re-Identification Problem

- Sensory state for the saccade learning task: target position $\mathbf{s}_t = (x_t, y_t)$
- To determine $\mathbf{s}_{t+1}$ after saccade excution:
  - Target re-identification necessary
  - In past studies with plain camera images: By correlation approach
- Problem: Correlation approach not applicable to retinal images



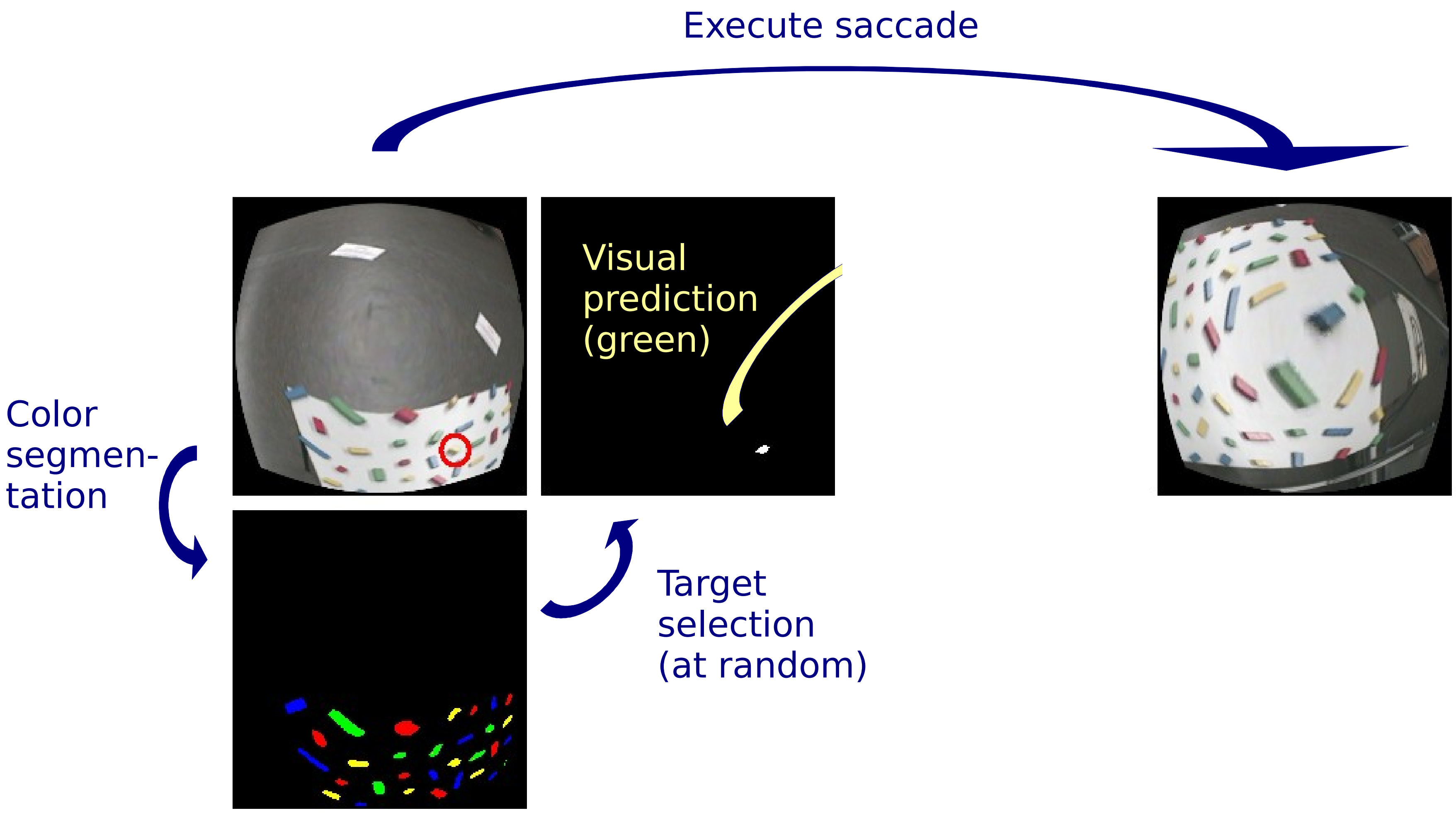
Visual Prediction for Target Re-Ident.

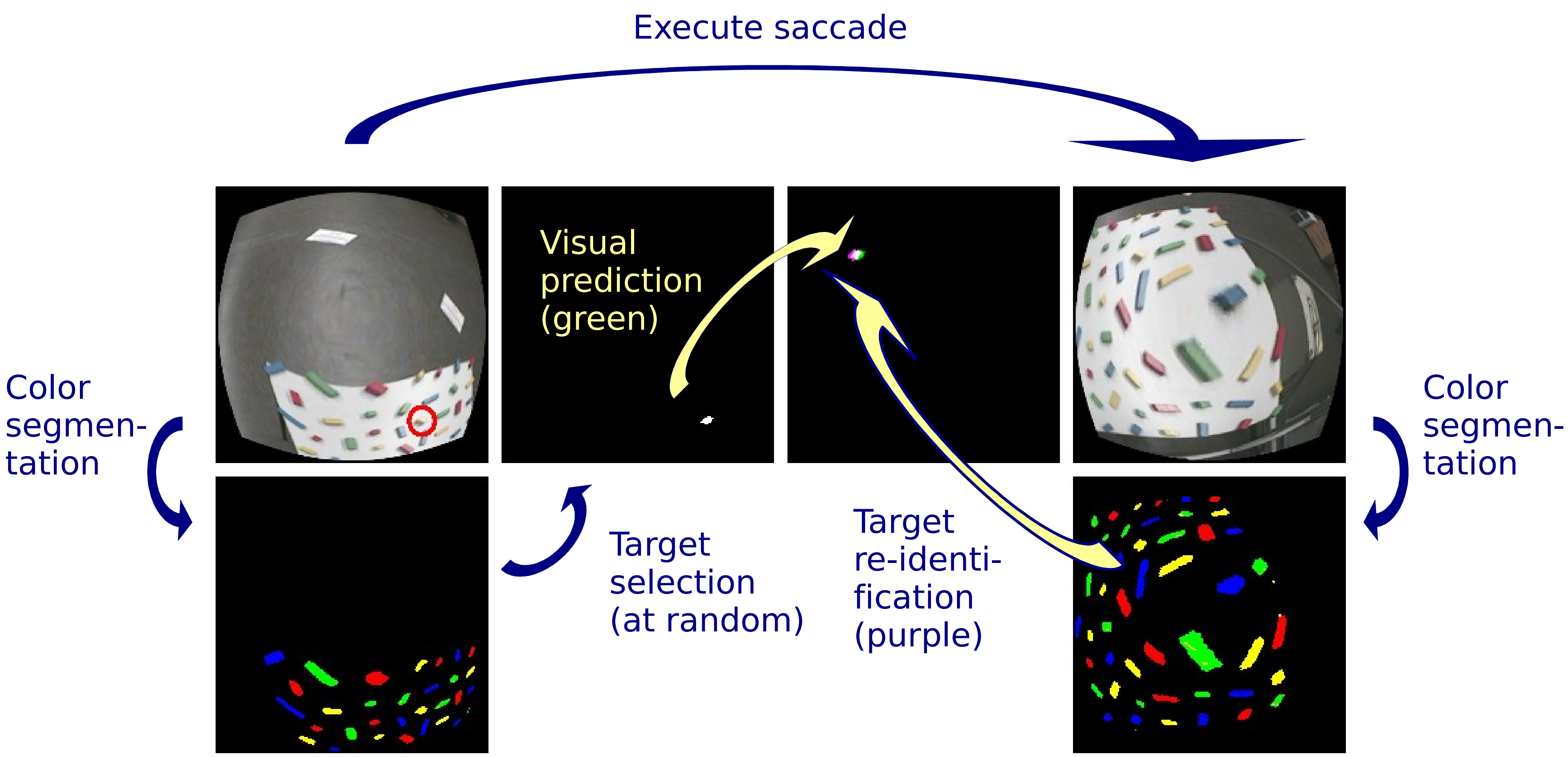
- **Solution:**
  - Predict location of target object after saccade by visual FM
  - Search for real target in close vicinity of the predicted location
    - Use other distinct features like color or shape for final re-identification

Basic Image Processing Steps

Color segmen-tation

Basic Image Processing Steps



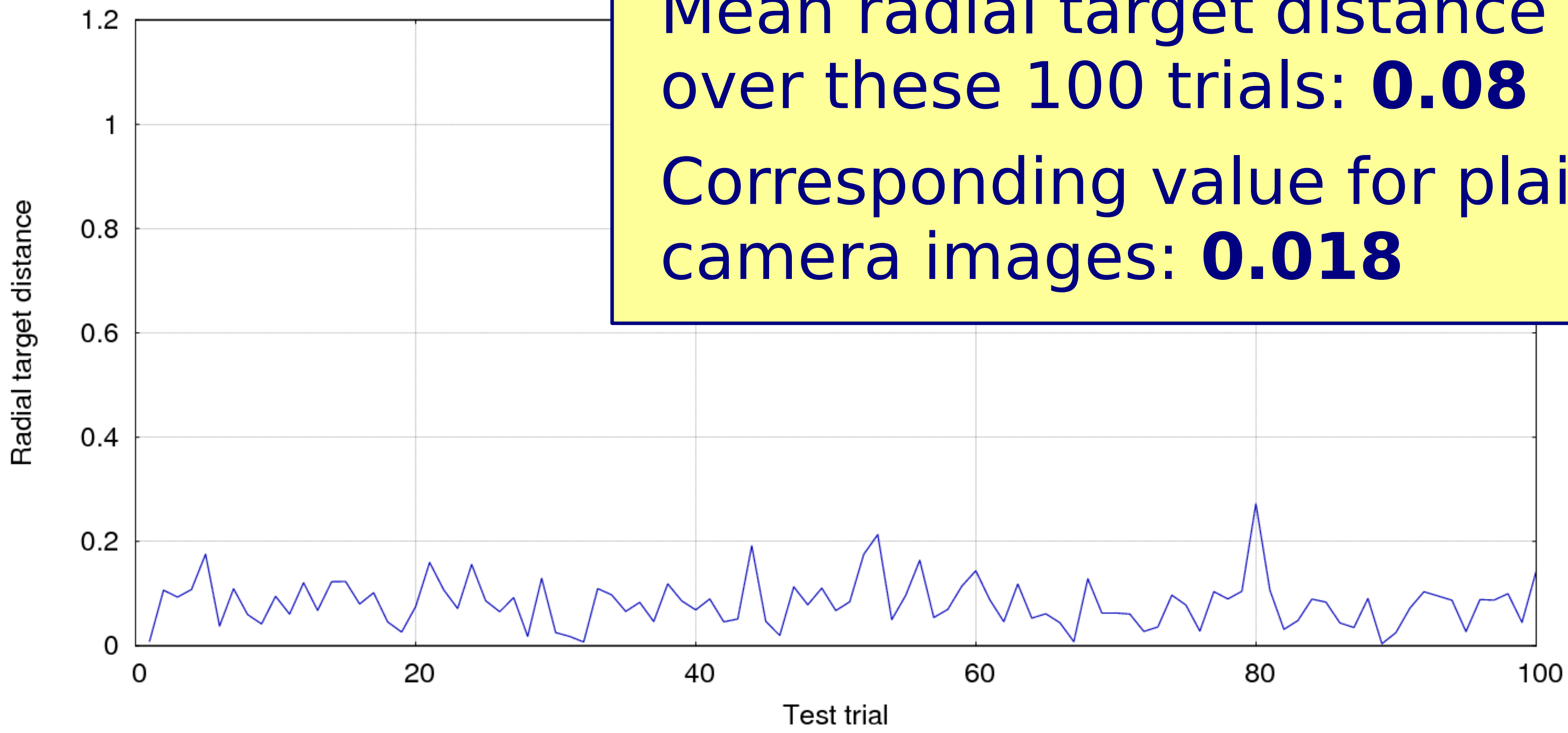

Execute saccade
Visual prediction (green)
Color segmen-tation
Color segmen-tation
Target selection (at random)
Target re-identi-fication (purple)

Experiments

- Controller network:
  - Multi-Layer Perceptron (MLP)
  - Weight adaptation by online back-propagation
  - Training set: 6000 randomly collected learning examples
- Indicator for saccade precision:
  Radial target distance
  - Distance between center of mass of target object and image center
    (normalized to range [0;1] along the horizontal/vertical direction)

Training Results

- Controller training over 3,000 epochs:
  $\Rightarrow$ Test error down from 0.09 to 0.0002
- Controller network performance over 100 trials:

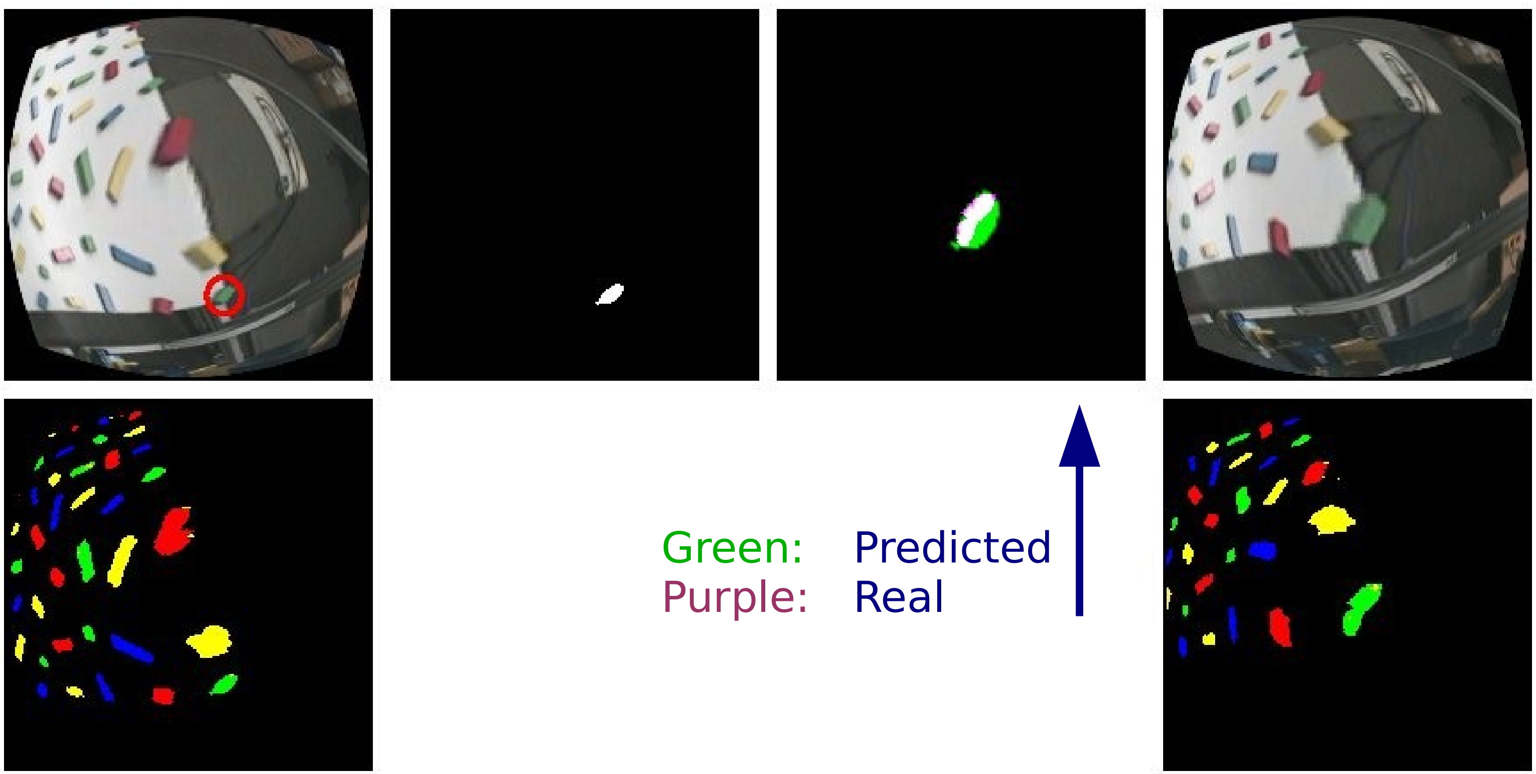


Mean radial target distance over these 100 trials: **0.08**

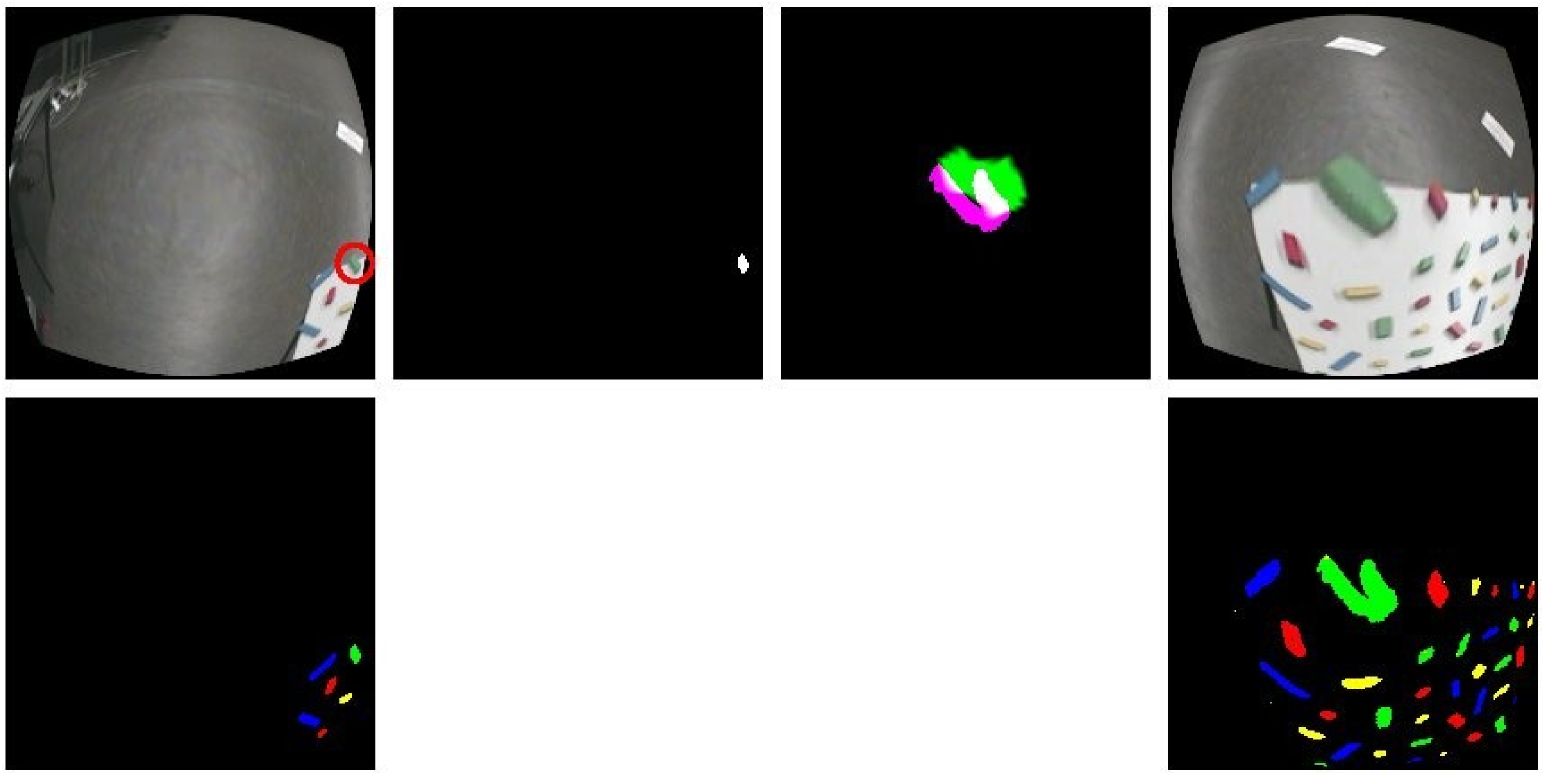
Corresponding value for plain camera images: **0.018**

Results for DIM: Examples

Pre-saccadic **Post-saccadic**



Pre-saccadic **Post-saccadic**

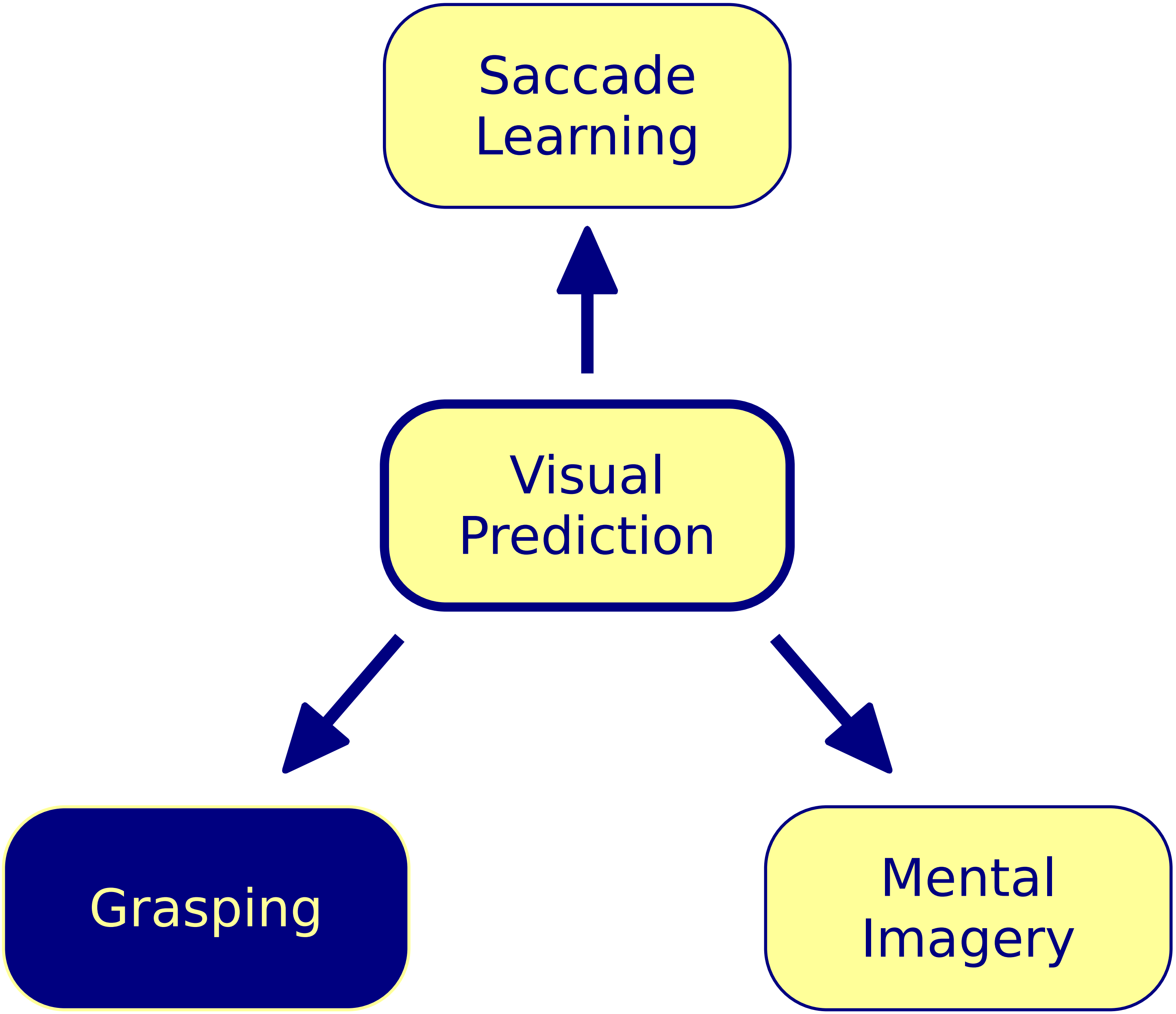


Intermediate Discussion

- Successful saccade learning on retinal images
- Problem of the missing teacher signal solved by direct inverse modeling
- Problem of target re-identification solved by visual prediction

Link to “spatial representations and dynamic interactions”:

Visual prediction enables the agent to shift freely between different eye-centered frames of reference (“different” with respect to the gaze direction)

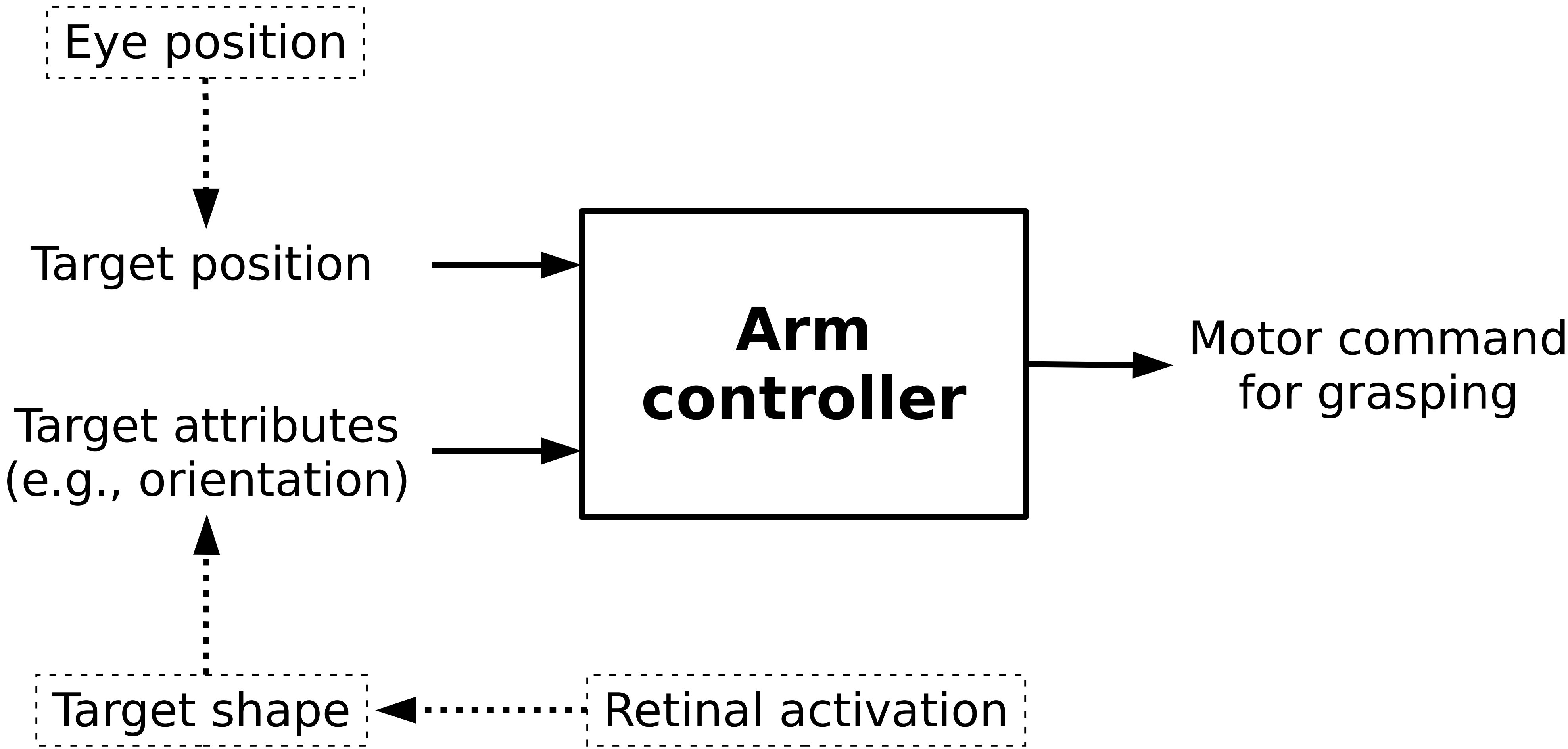


Schenck, Hoffmann, & Möller (2009)

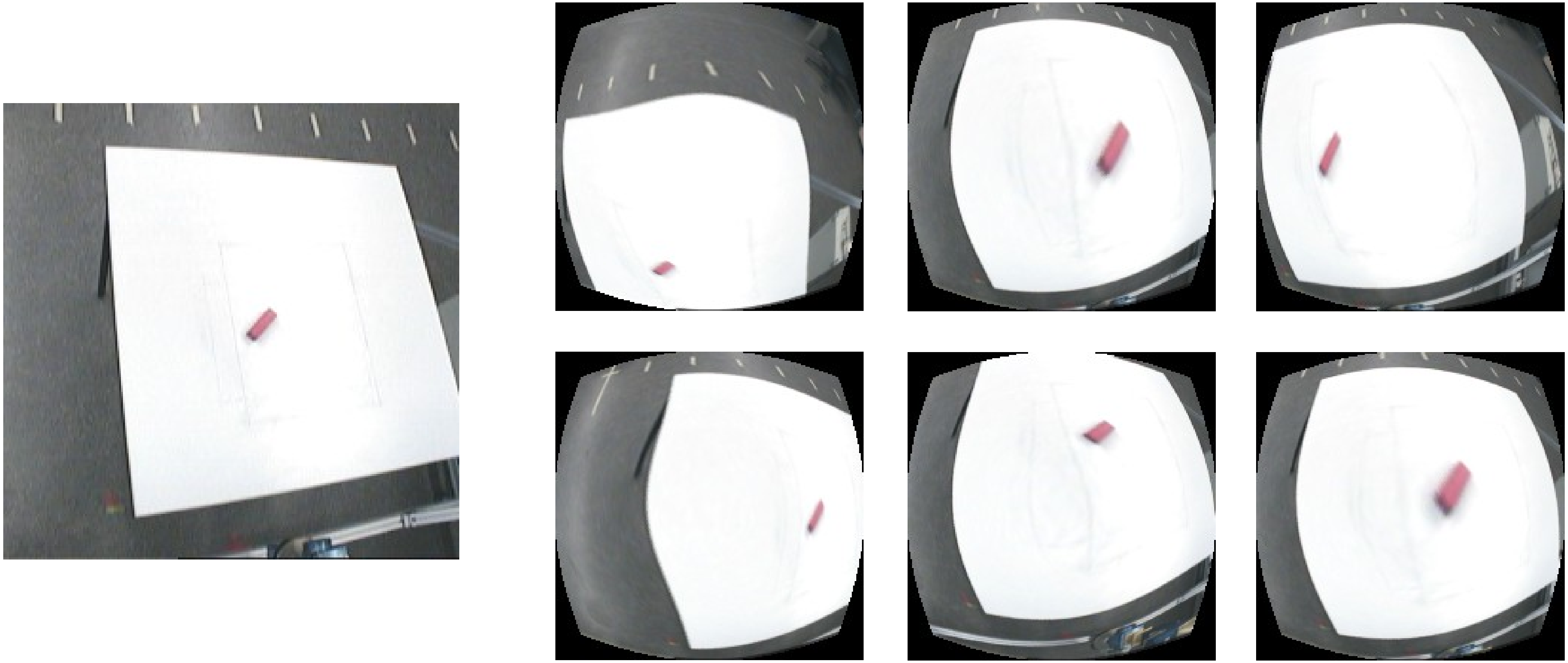
Grasping to Extrafoveal Targets

- Usually: Saccades precede arm movements for reaching and grasping
  - Target objects are projected onto the fovea
- Arm movements towards extrafoveal target objects are possible, but with less precision (e.g., Vercher et al., 1994)

Arm Control Scheme

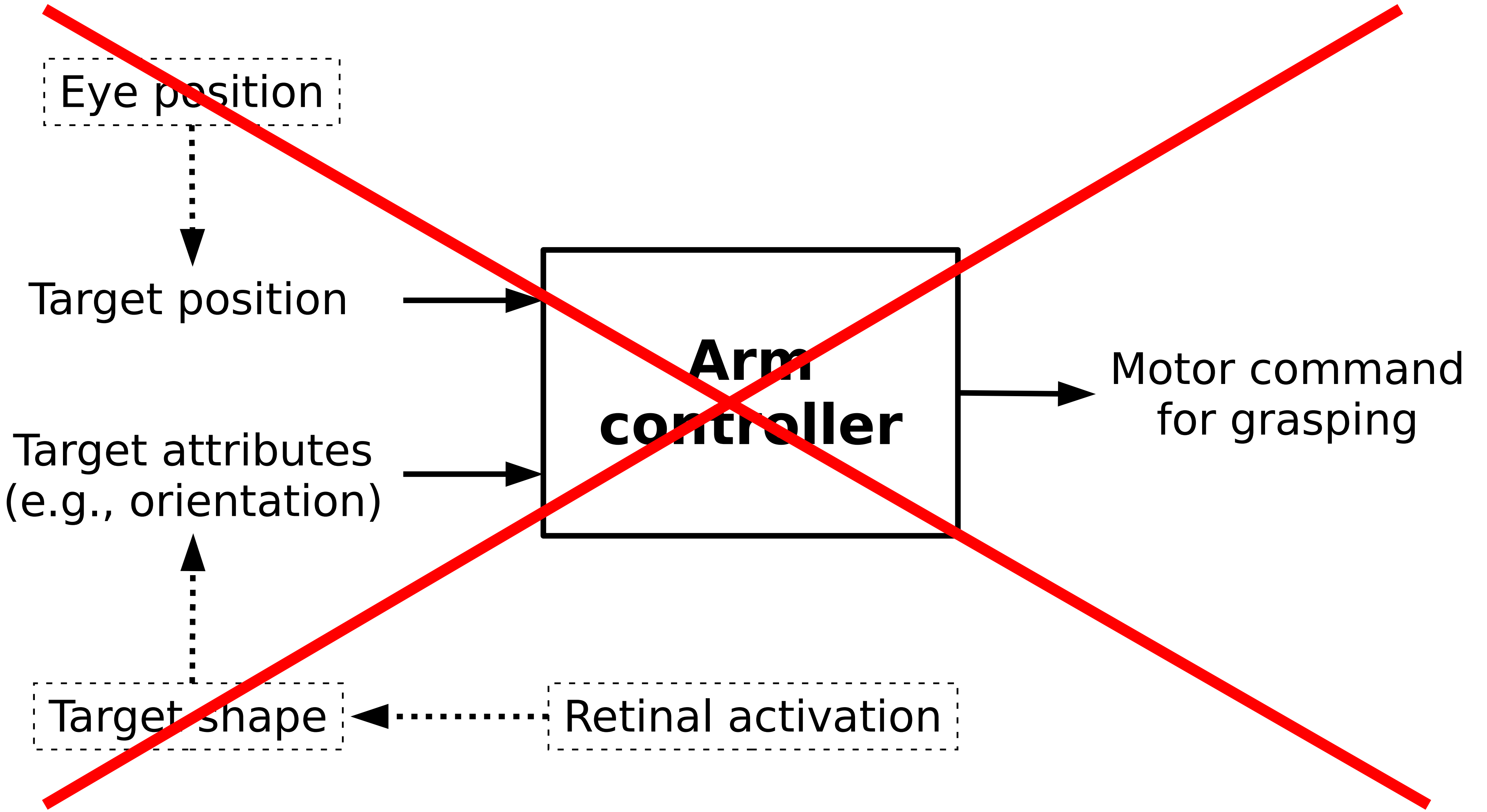


Retinal Variance



➔ Depending on retinal position, sensor activation differs considerably!

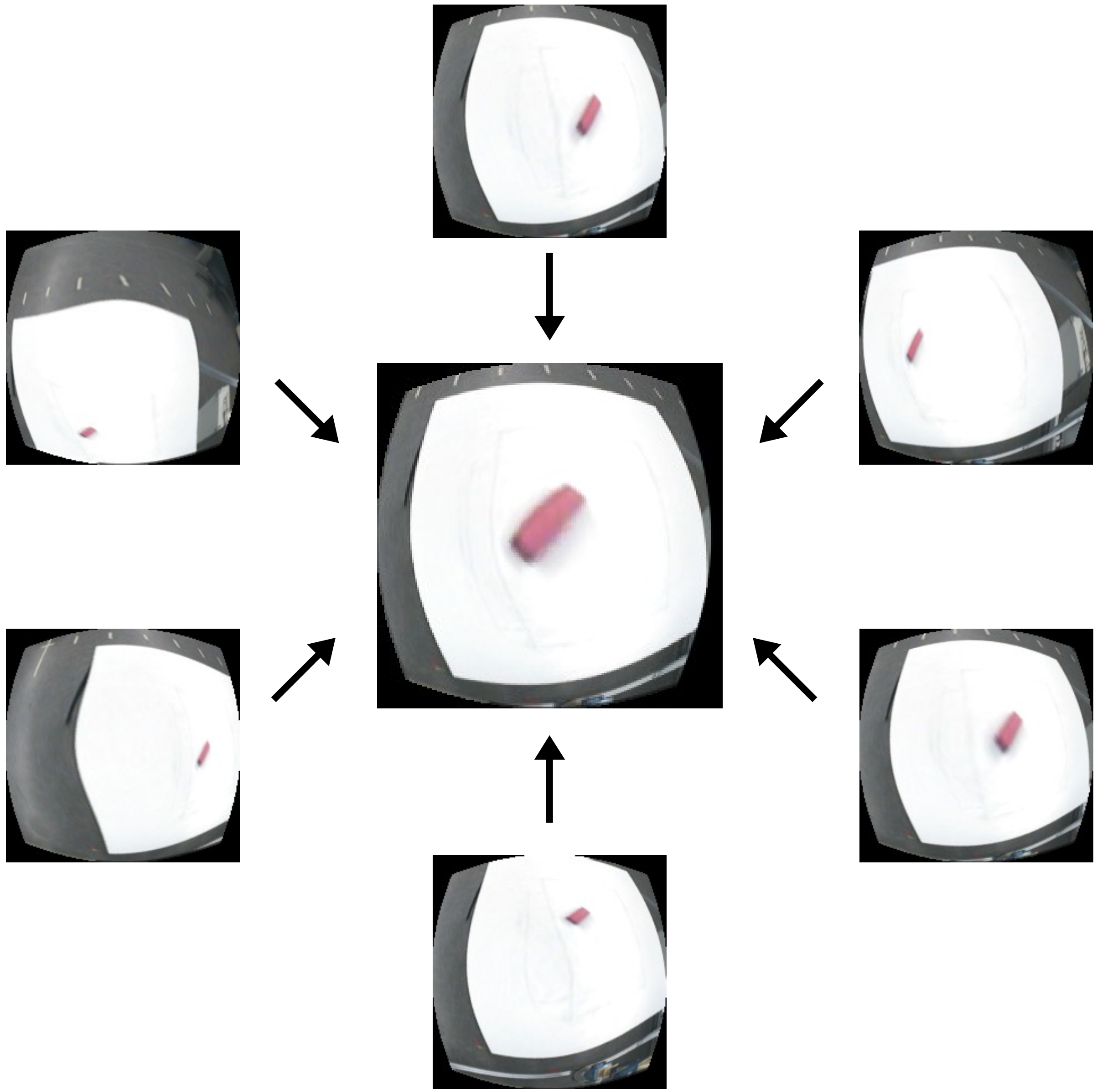
Arm Control Scheme



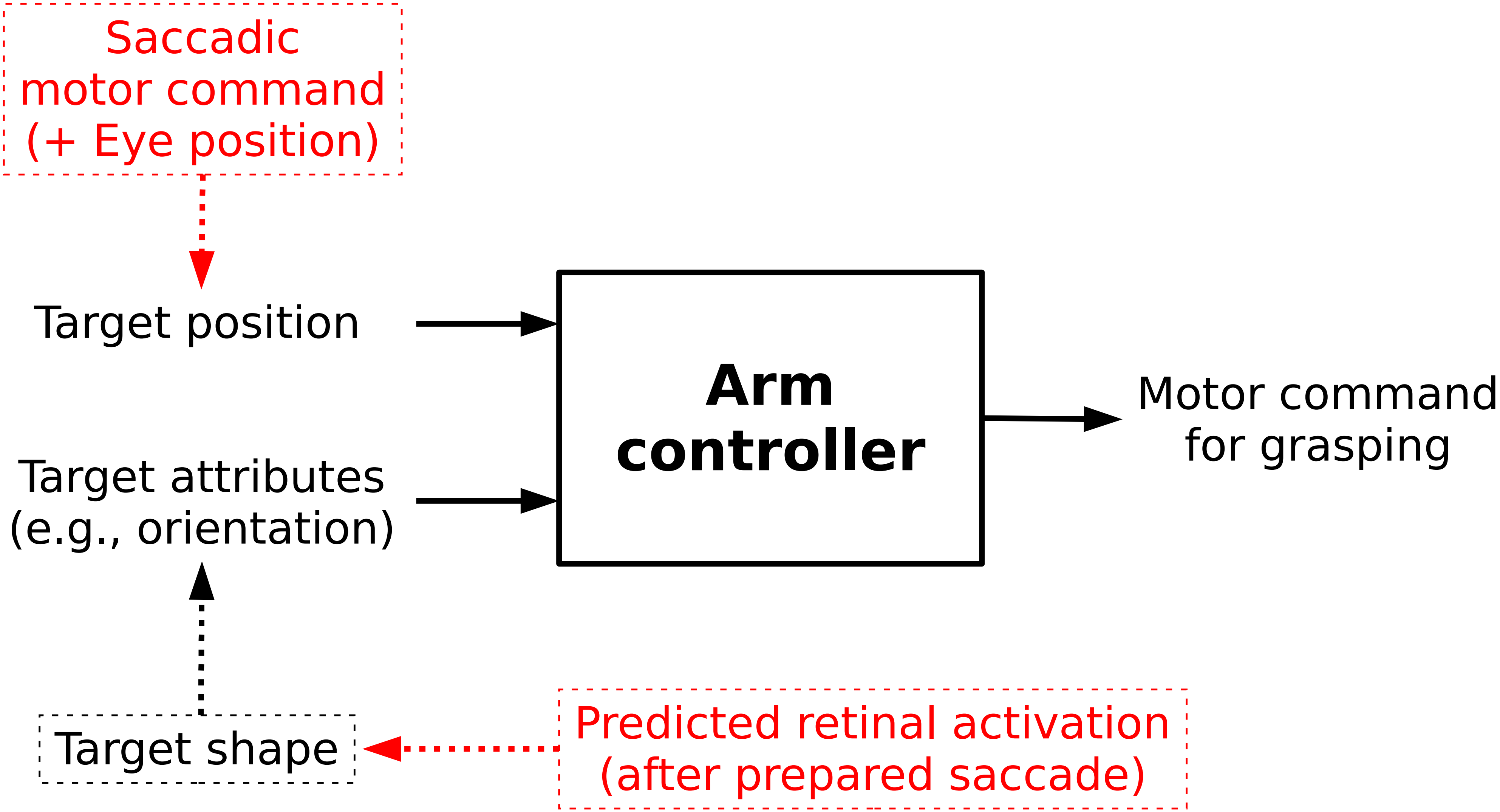
Premotor Theory

- Spatial attention: Consequence of *preparation* of goal-directed movements (Rizzolatti et al, 1994)
  - Attention shifts are accompanied by the preparation of eye movements
- Additional hypothesis:
  - The preparation of eye movements triggers a prediction of the retinal images after the movement

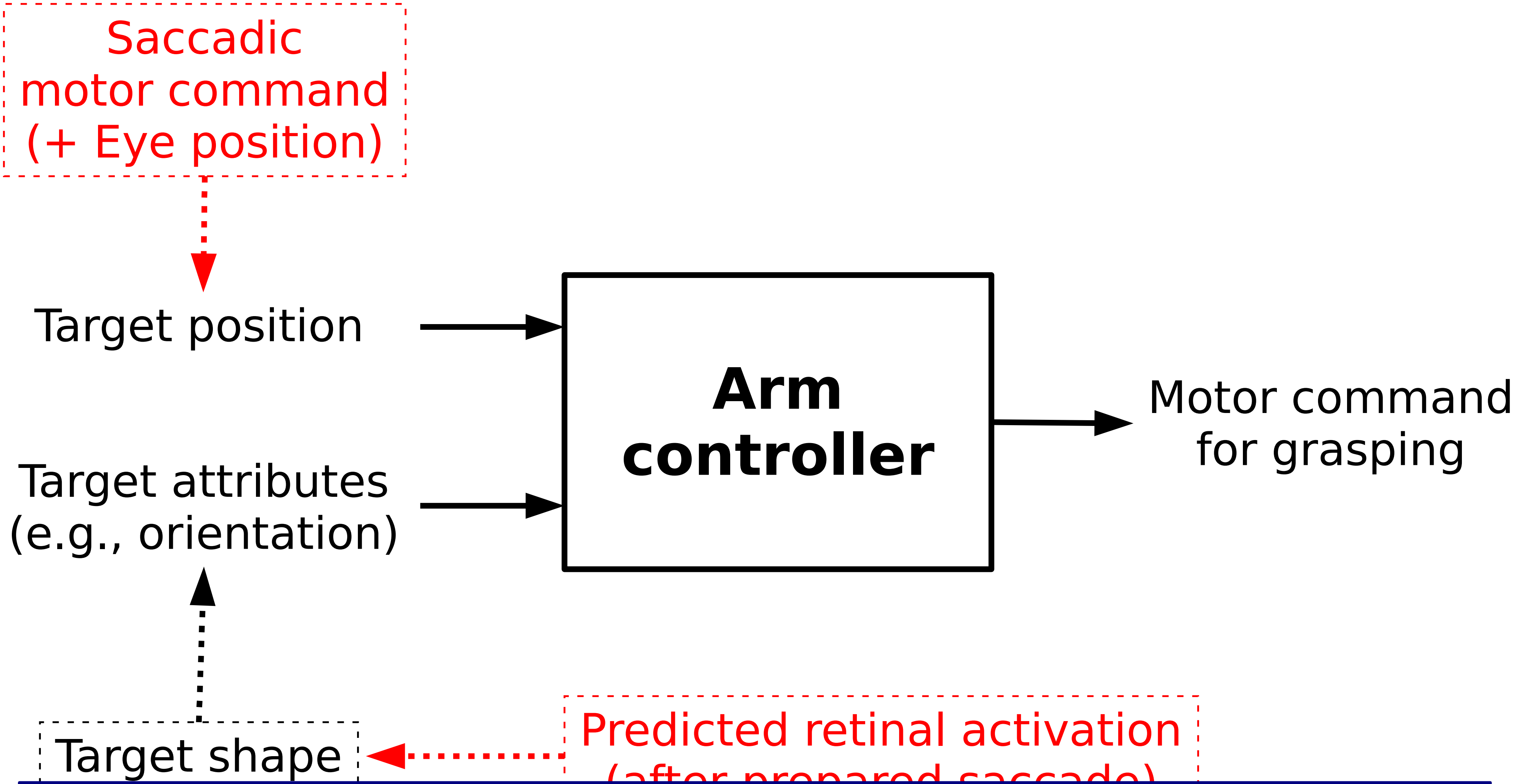
Retinal Invariance Through Visual Pred.



Revised Arm Control Scheme



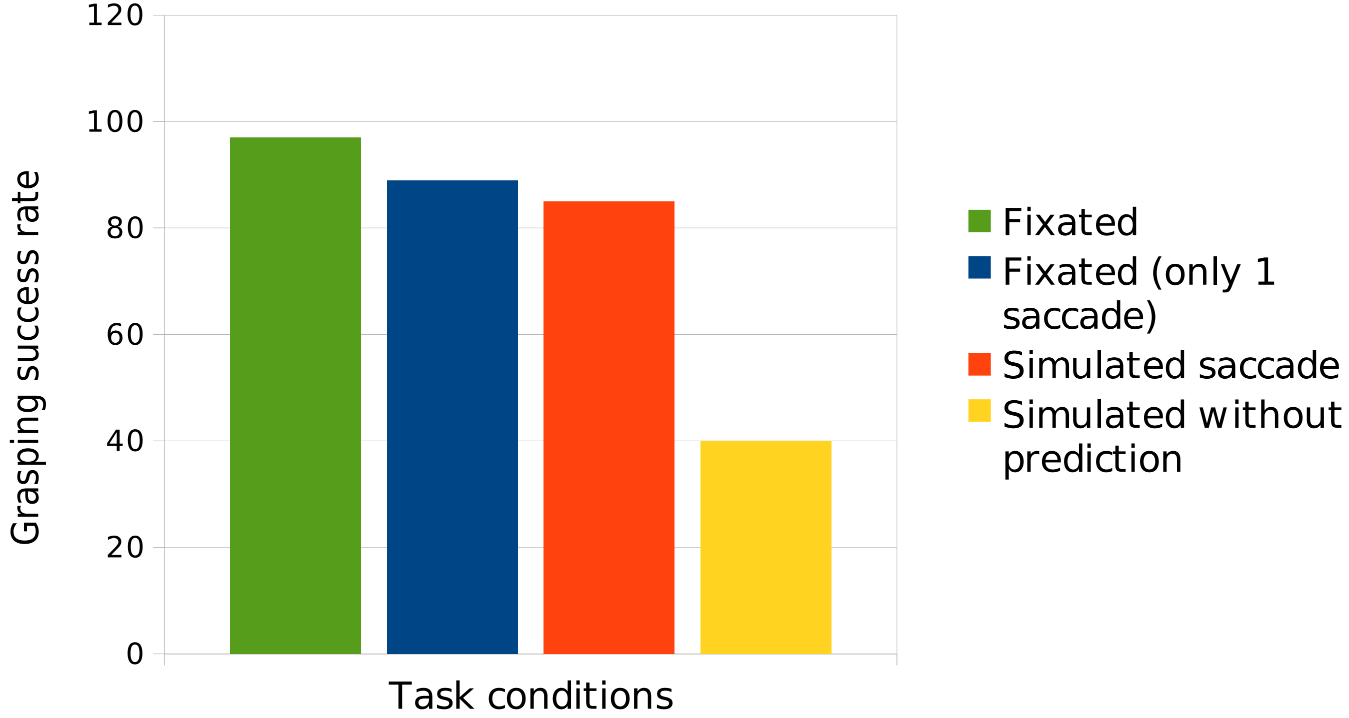
Revised Arm Control Scheme



➔ Single arm controller for both fixated and non-fixated target objects!

Experimental Results

- Grasping performance over 100 trials in four different experimental conditions

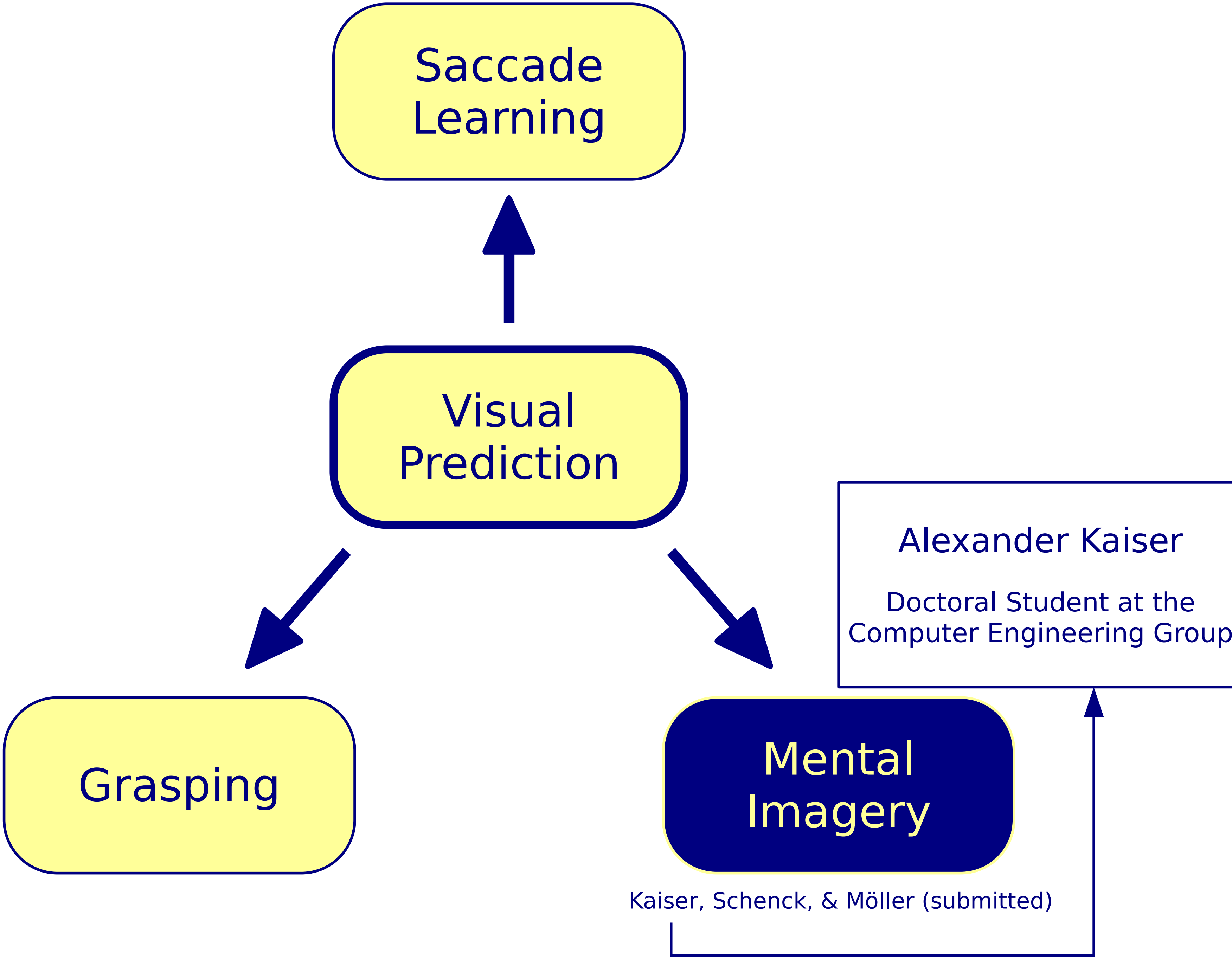


Intermediate Discussion

- Model successful in grasping to extrafoveal targets
  - Real-world robotic test
- Visual prediction might be an important component of visuomotor coordination in this task domain

Link to “spatial representations and dynamic interactions”:

Visual prediction (in combination with a saccade controller) enables (kind of) invariance of the retinal representation with respect to the gaze direction


Saccade Learning
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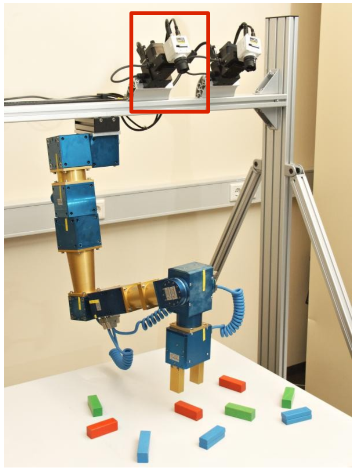
Alexander Kaiser
Doctoral Student at the Computer Engineering Group
Kaiser, Schenck, & Möller (submitted)

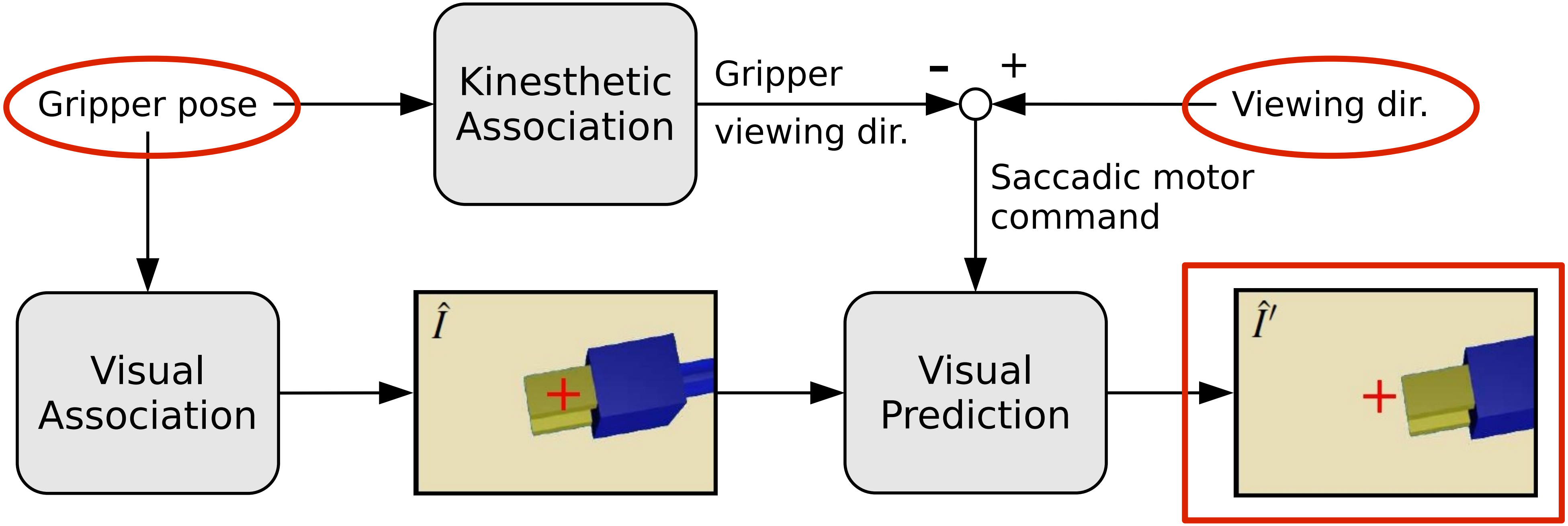
Mental Imagery for Motor Simulation

- Simulation theories: Simulation of action sequences and their accompanying sensory or system states as basis for perception and cognition (e.g., Hesslow, 2002; Möller, 1999; Ziemke at al., 2005)
- Covert (simulated) sensory and motor states: “Mental images”
- **Here:** Mental images of visual gripper states (to be used in forthcoming cognitive architectures)

Overall Model

- Input: Gripper pose, viewing direction
- Output: Image of the gripper
  (simulated "mental" image)





Sorry, further slides...

- … on this topic removed since this work has been recently submitted for publication (decision pending)

Intermediate Discussion

- Model successful in generating “mental images” of visual gripper states
- Holistic approach: The image is generated as a whole in its original “raw” format, not on the basis of single features
- Need for visual prediction results from the decomposition of the overall problem in a visual association and a prediction part

Link to “spatial representations and dynamic interactions”:

Visual prediction allows to generalize from a purely foveal representation (target fixated) to other gaze directions

Summary and Open Questions

Summary: Three Studies

- Visual prediction in the context of saccade learning
  - Purpose: Facilitates target re-identification
- Visual prediction in the context of grasping
  - Purpose: Transforms extrafoveal visual representations of target objects into foveal representations
- Visual prediction in the context of mental imagery
  - Purpose: Facilitates the generation of “mental images” by simplifying the visual association task

Open Questions

- Algorithms to learn visual prediction for motor tasks with many degrees of freedom?
- Visual prediction for movements where depth information is relevant?
- Multi-step visual prediction – stability, precision?

Thank you for your attention!