ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

BIWI Computer Vision

Learning for Tracking and Lessons Learned from it

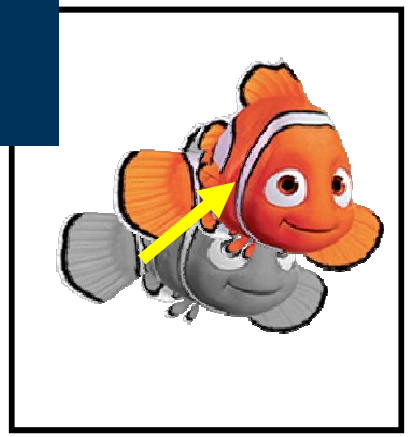
Helmut Grabner

Outline

ON-LINE

Machine learning

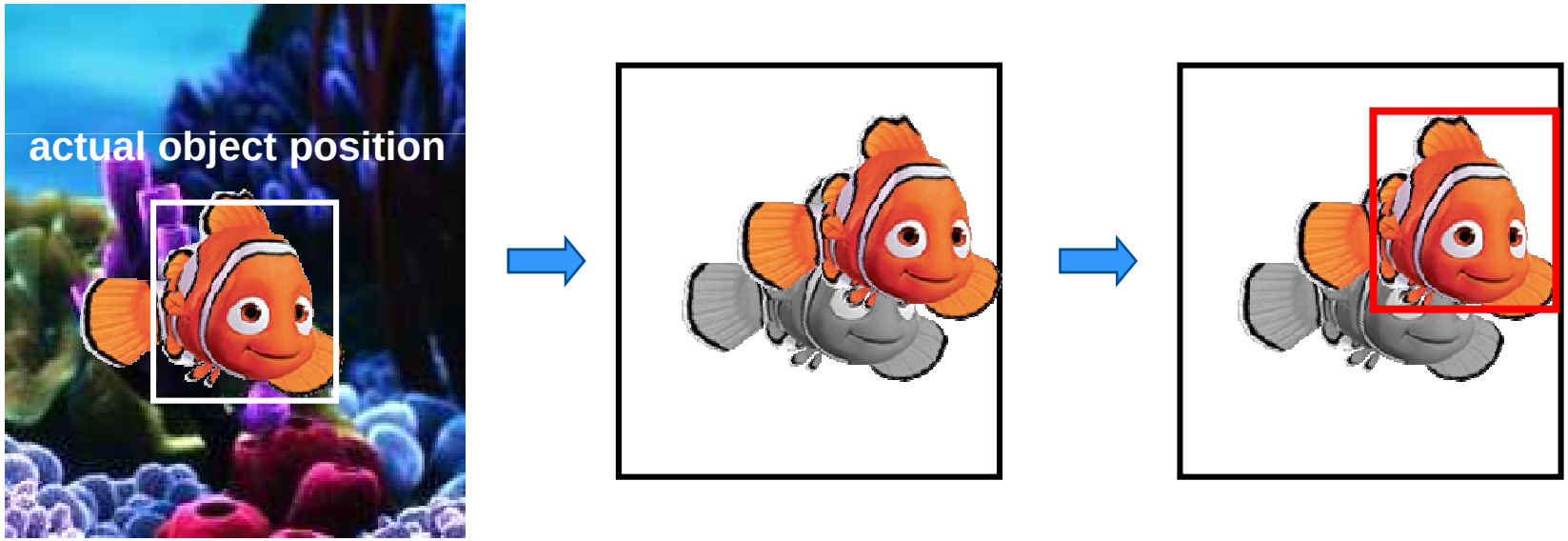
Computer Vision: Tracking



Lessons Learned

Tracking by fast (re-) detection

Time t **from time t to t+1** **„find“ again**



Tracking Cues

- Object Appearance
- Background

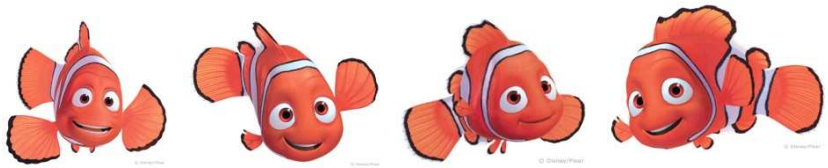
} **Object/Background discrimination**

- Object Boundary
- Motion

[Grabner et al. VideoProc.CVPR 2006]

Tracking Requirements

- Adaptive



- Robustness

- Generality

PART I

On-line Boosting based Tracking

2006

Boosting and Vision

- Boosting

  [Freund and Schapire, JCSC, 1997]

- Boosting for Feature Selection

  [Tieu and Viola. CVPR 2000], [Viola and Jones, CVPR 2001]

- On-line boosting

  [Oza and Russel, AIS, 2001]

- **On-line Boosting for Feature Selection**

  [Grabner and Bischof, CVPR 2006]

- Several Improvements:
  - E.g., on-line WaldBoost, Asymetric on-line Boosting,…

Off-line learning

On-line learning

Learning Algorithm

Labeled Information

Teacher

Off-line boosting

Strong classifier **Weak classifier**

$$H(\mathbf{x}) = \text{sign}\left(\sum_{n=1}^{N} \alpha_n \cdot h_n(\mathbf{x})\right)$$

Reweighting the training examples

On-line Boosting

$$H_t^{on} \leftarrow \text{update}\left(H_{t-1}^{on}, (\mathbf{x_t}, y_t)\right)$$

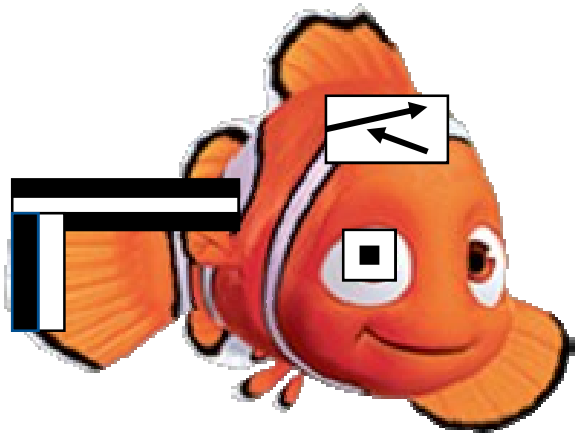
On-line Boosting

Converges to the off-line result!

Boosting for Feature Selection (1)

Combination of Simple Image Features

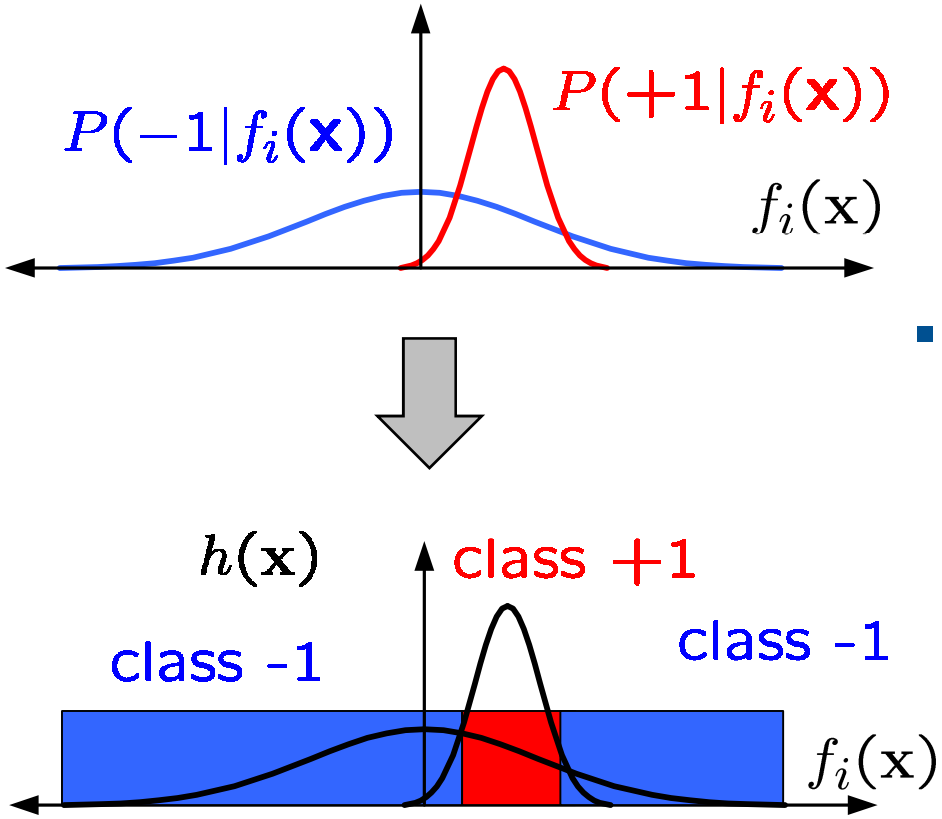
for distinguishing two classes



$$\text{sign}(\alpha_1 \cdot \boxed{} + \alpha_2 \cdot \boxed{} + \alpha_3 \cdot \boxed{} + \ldots)$$

Boosting for Feature Selection (2)

- Each feature corresponds to a weak classifier

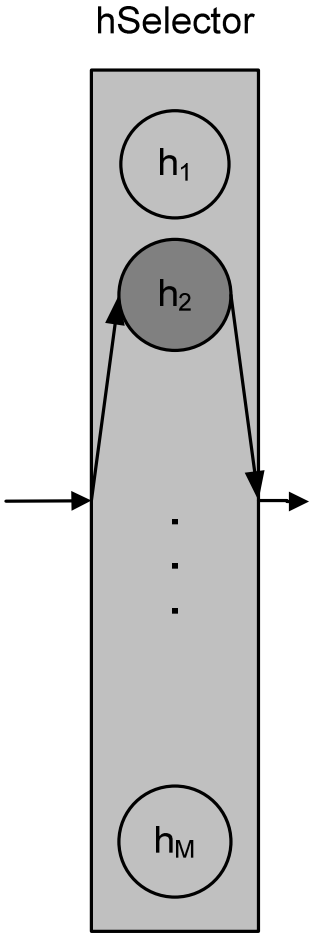


- Features
  - Haar-like wavelets
  - Orientation histograms
  - Locally binary patterns (LBP)
  - Color Features
- Fast computation using efficient data structures
  - integral images
  - integral histograms

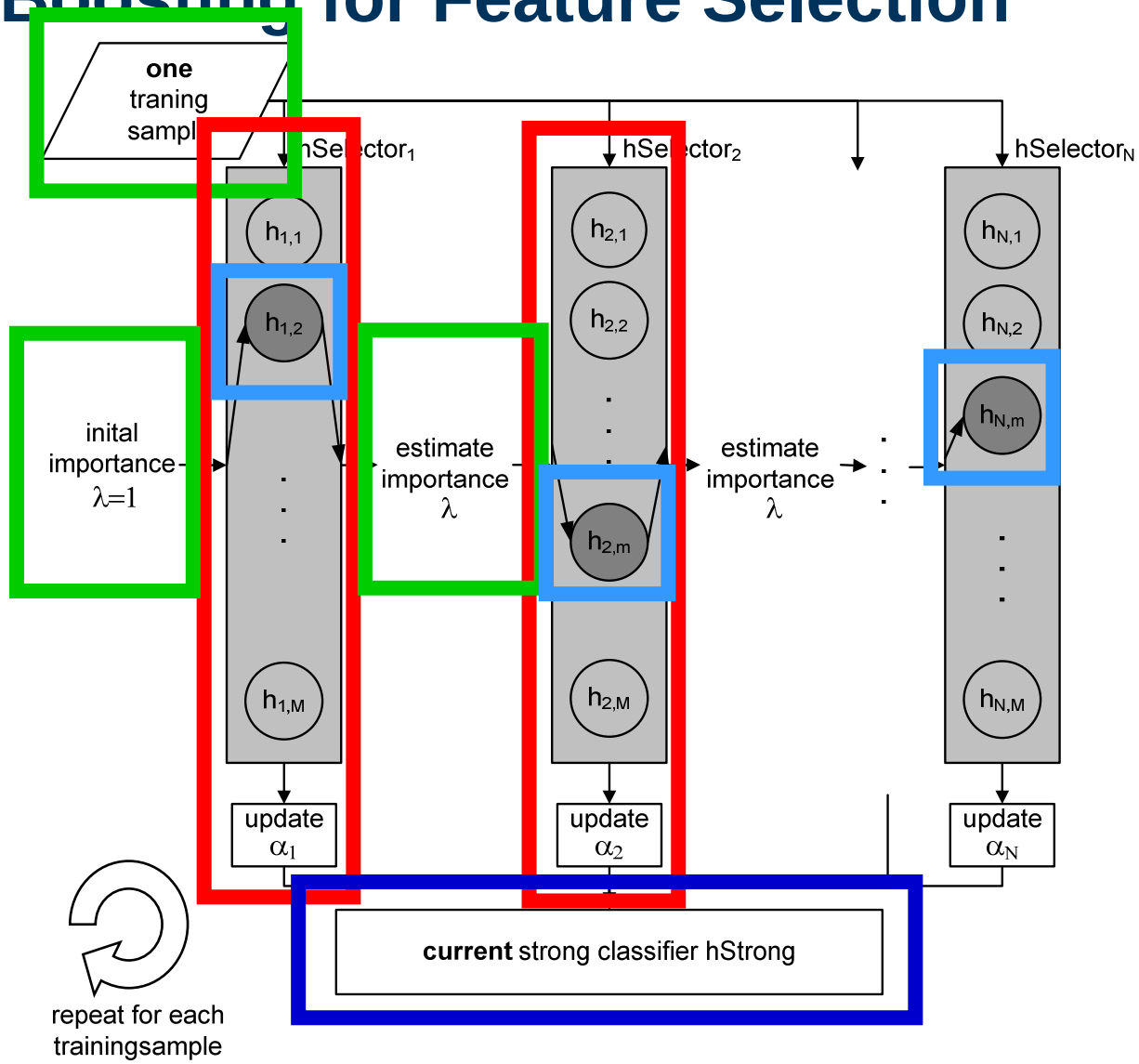
The concept of Selectors

selects one feature from its local feature pool

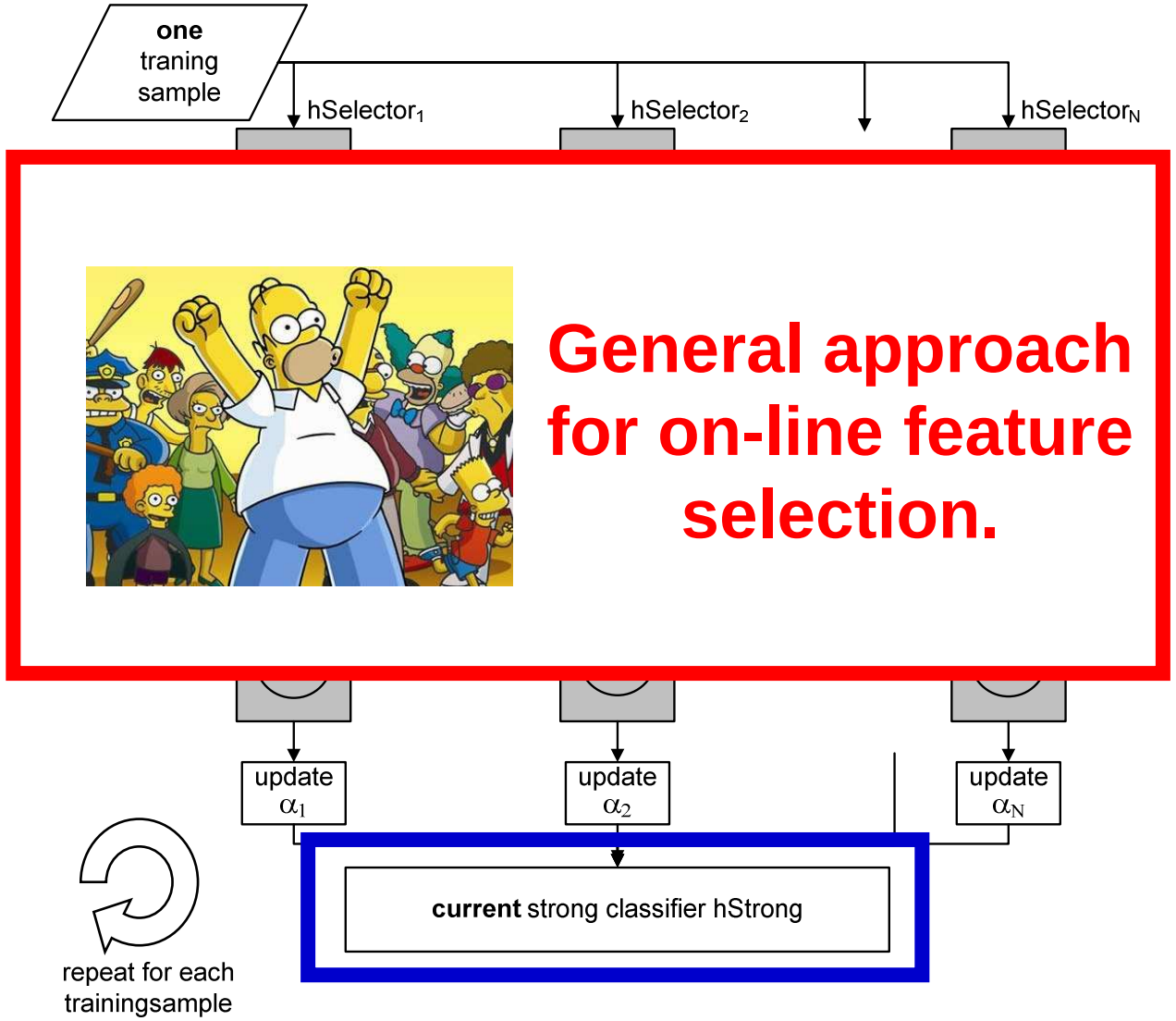
Boosting is performed on the Selectors and not on the weak classifiers directly.



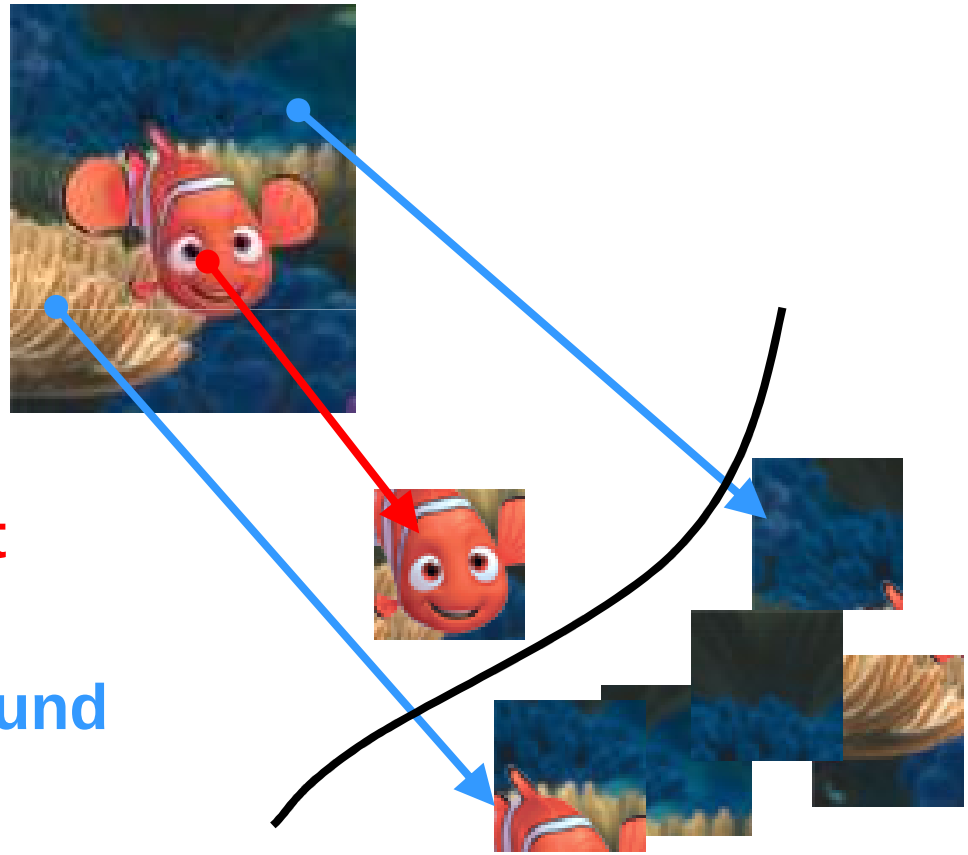
On-line Boosting for Feature Selection



On-line Boosting for Feature Selection



Tracking as Classification

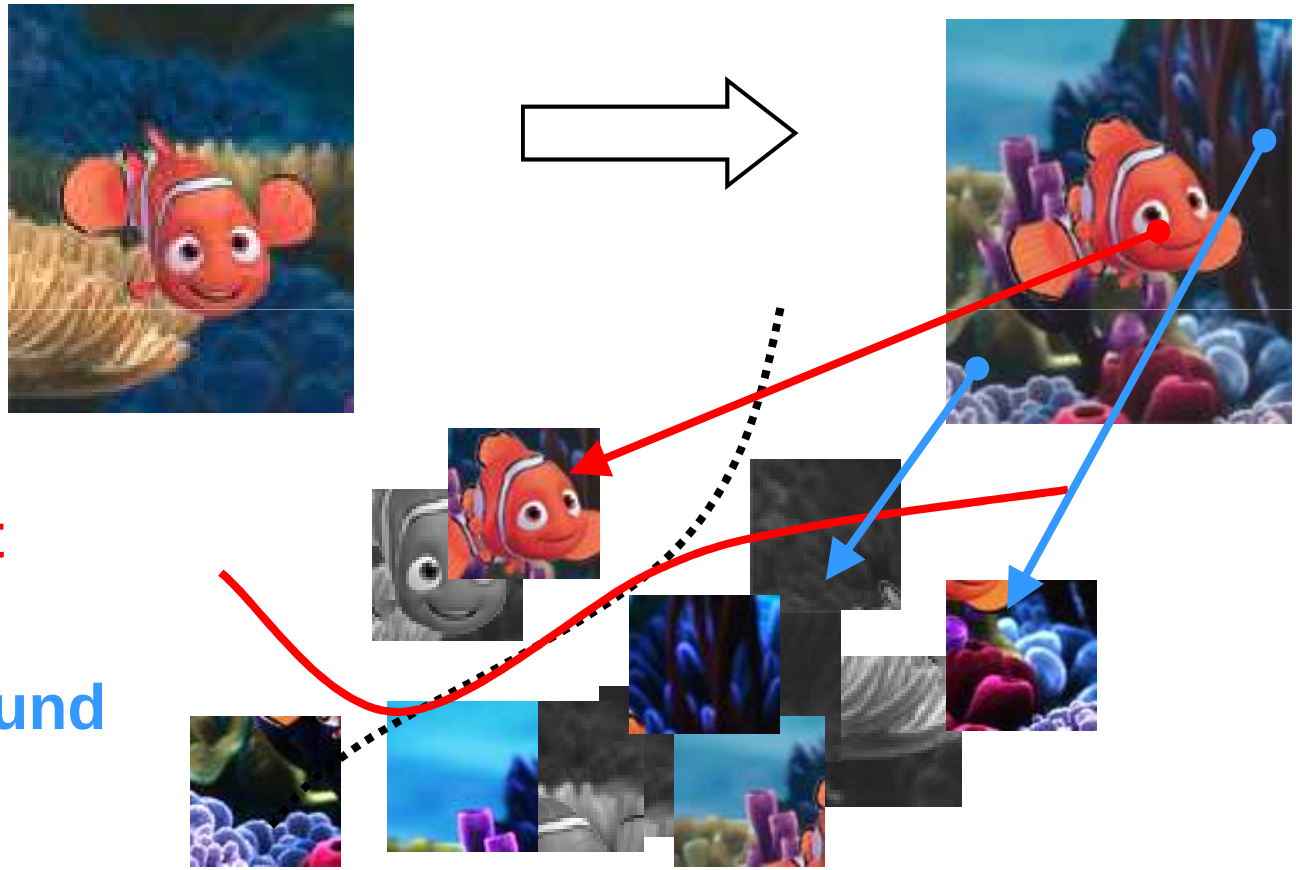


object

vs.

background

Tracking as Classification



object

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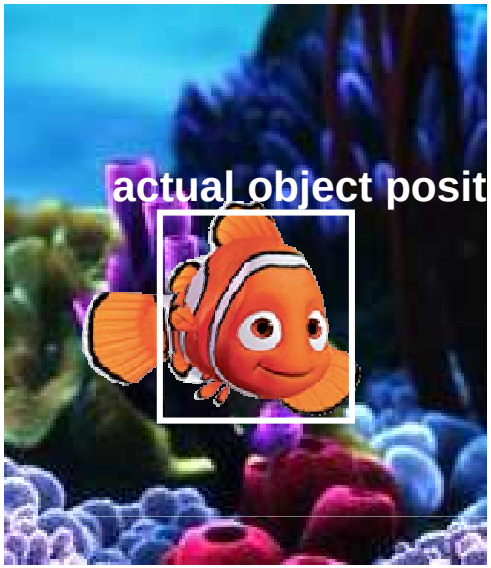
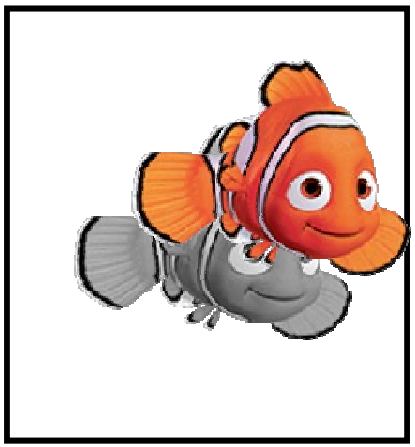
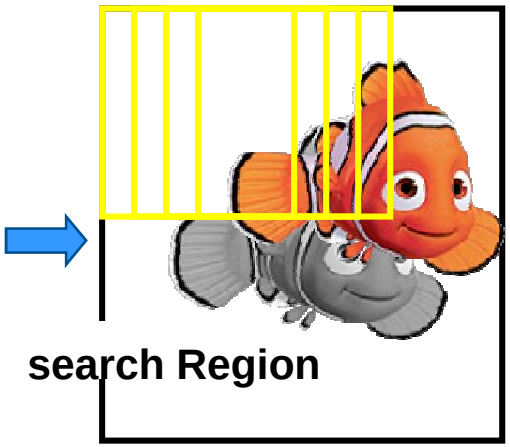


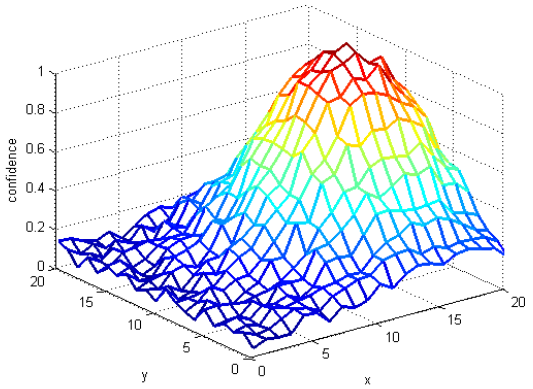
from time t to t+1



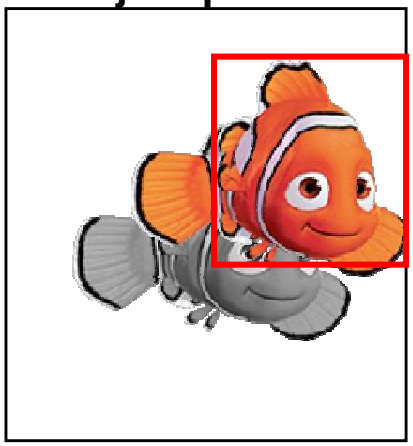
evaluate classifier on sub-patches



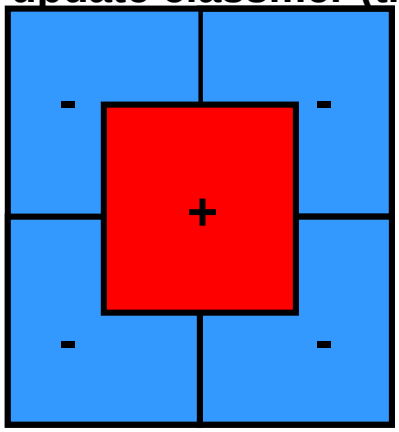
create confidence map



analyze map and set new object position



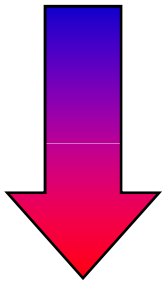
update classifier (tracker)



Object Detector

Fixed Training set
General object detector

Off-line Boosting for Feature Selection



Object Tracker

On-line update
Object vs. Background

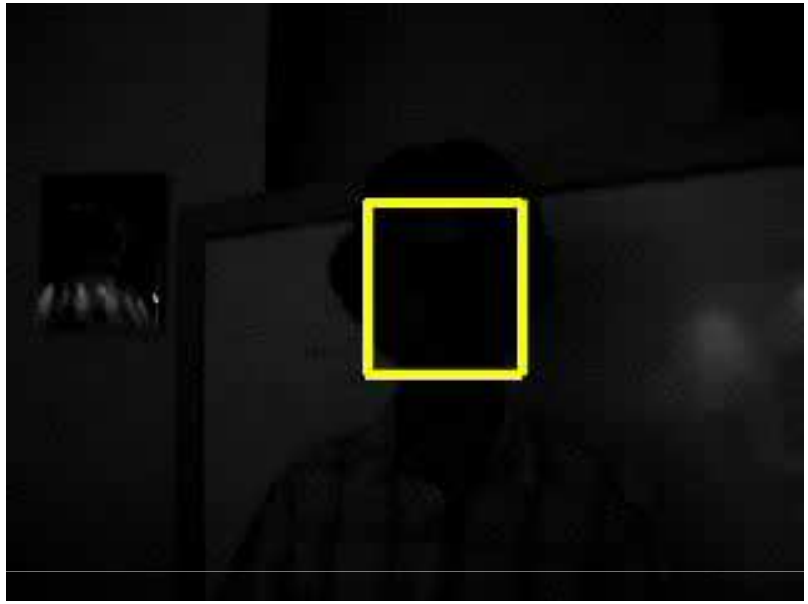
On-Line Boosting for Feature Selection

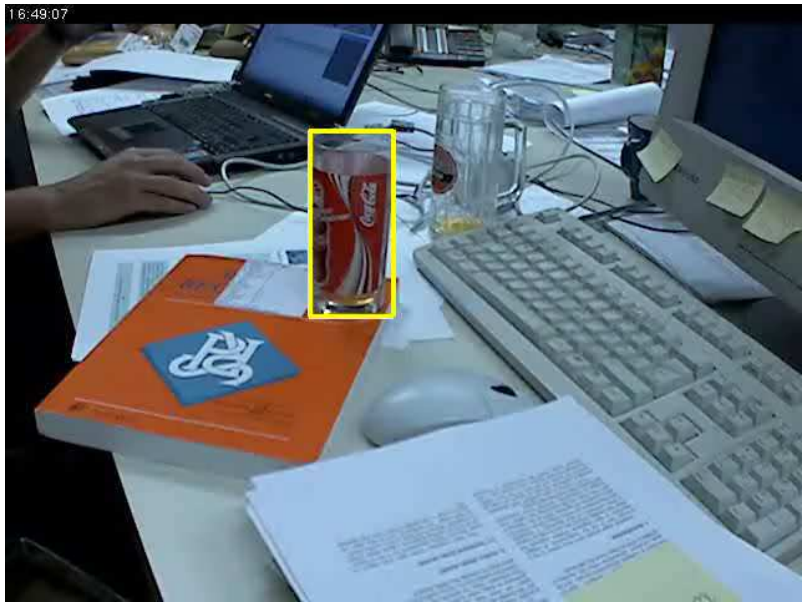
[Grabner et al, CVPR 2006, BMVC 2006,]

Lesson learned 1

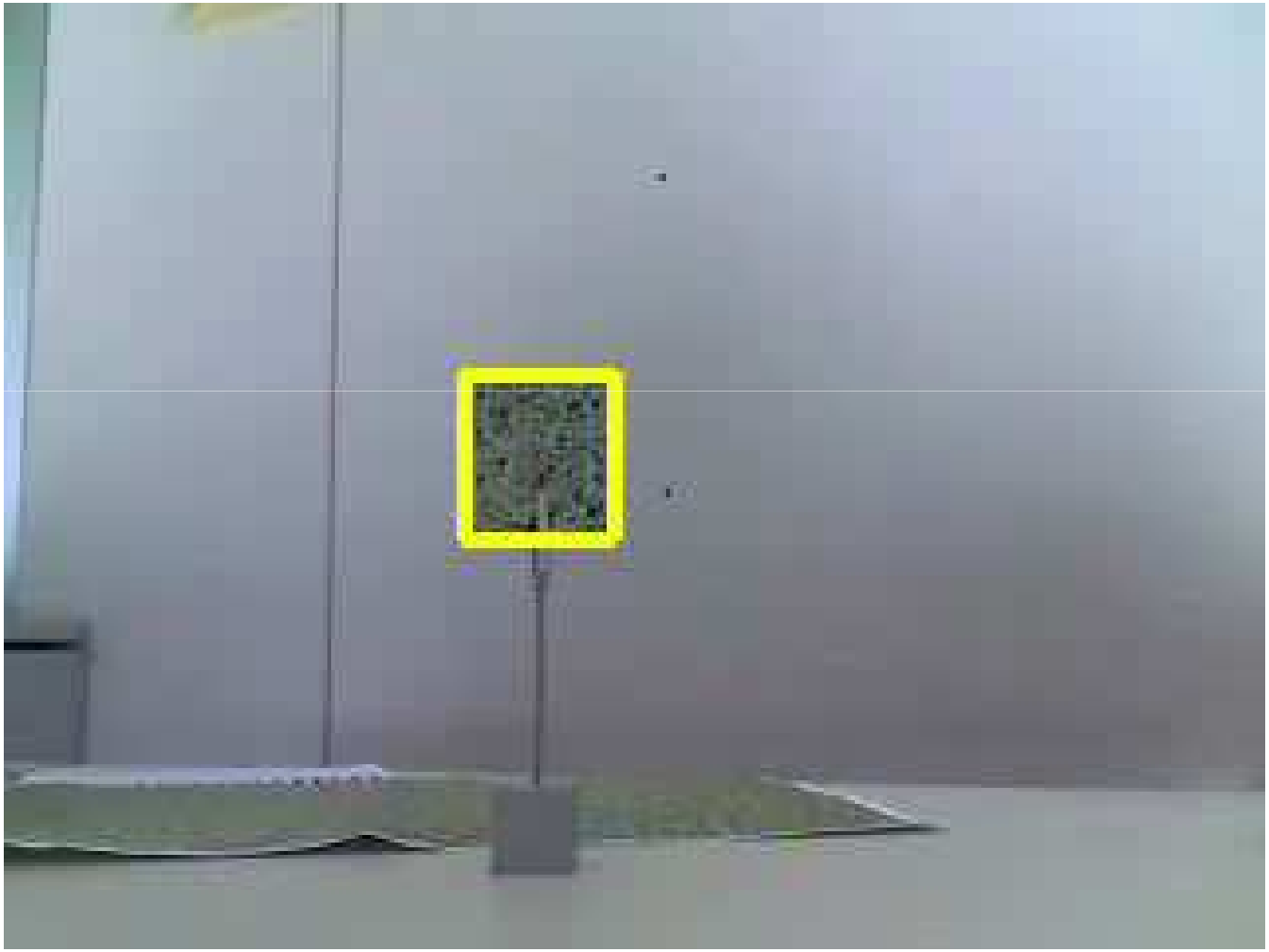
Tracking is a simple task!

(When formulating it properly)

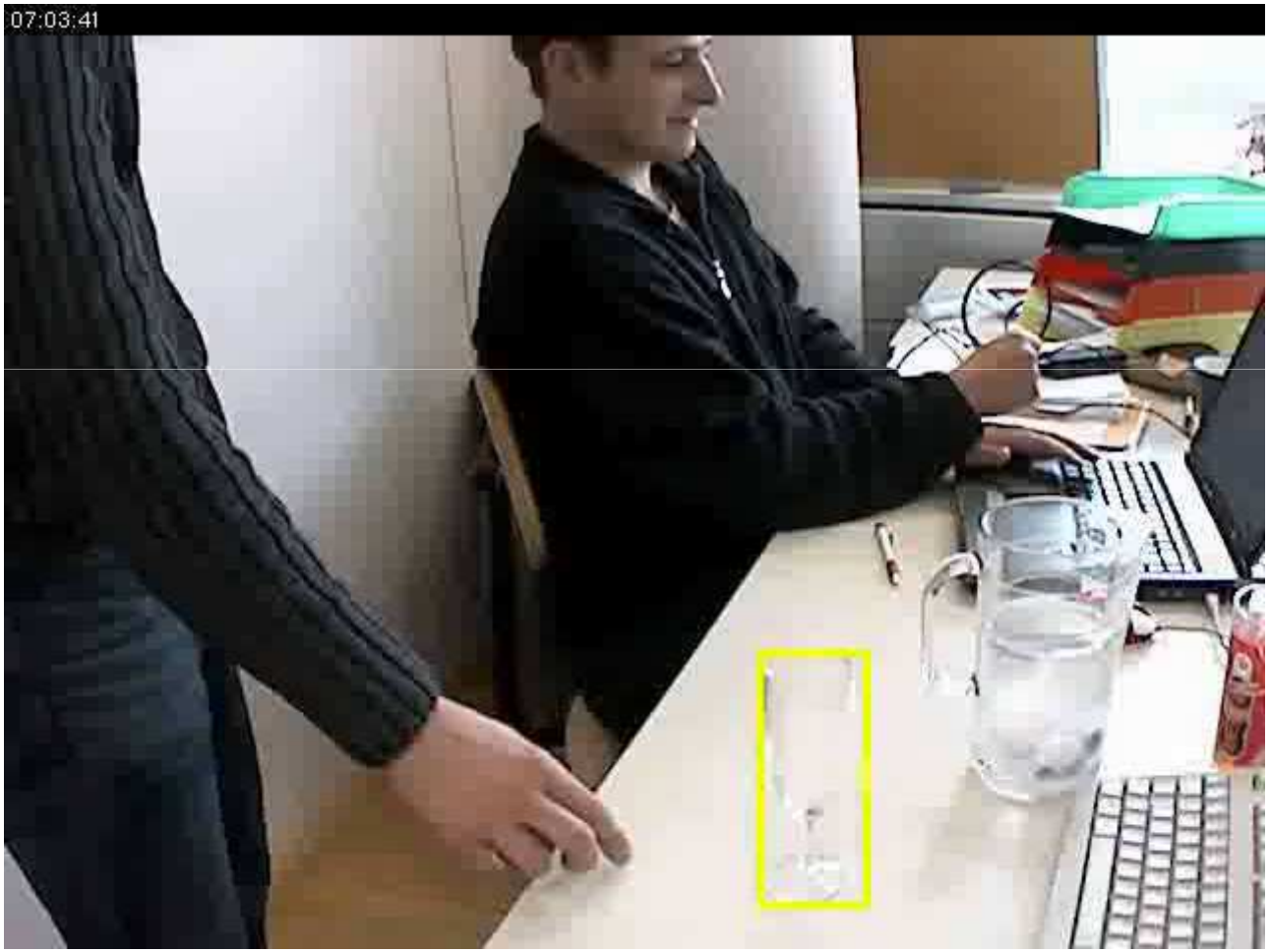



16:49:07

“Simple tracking”



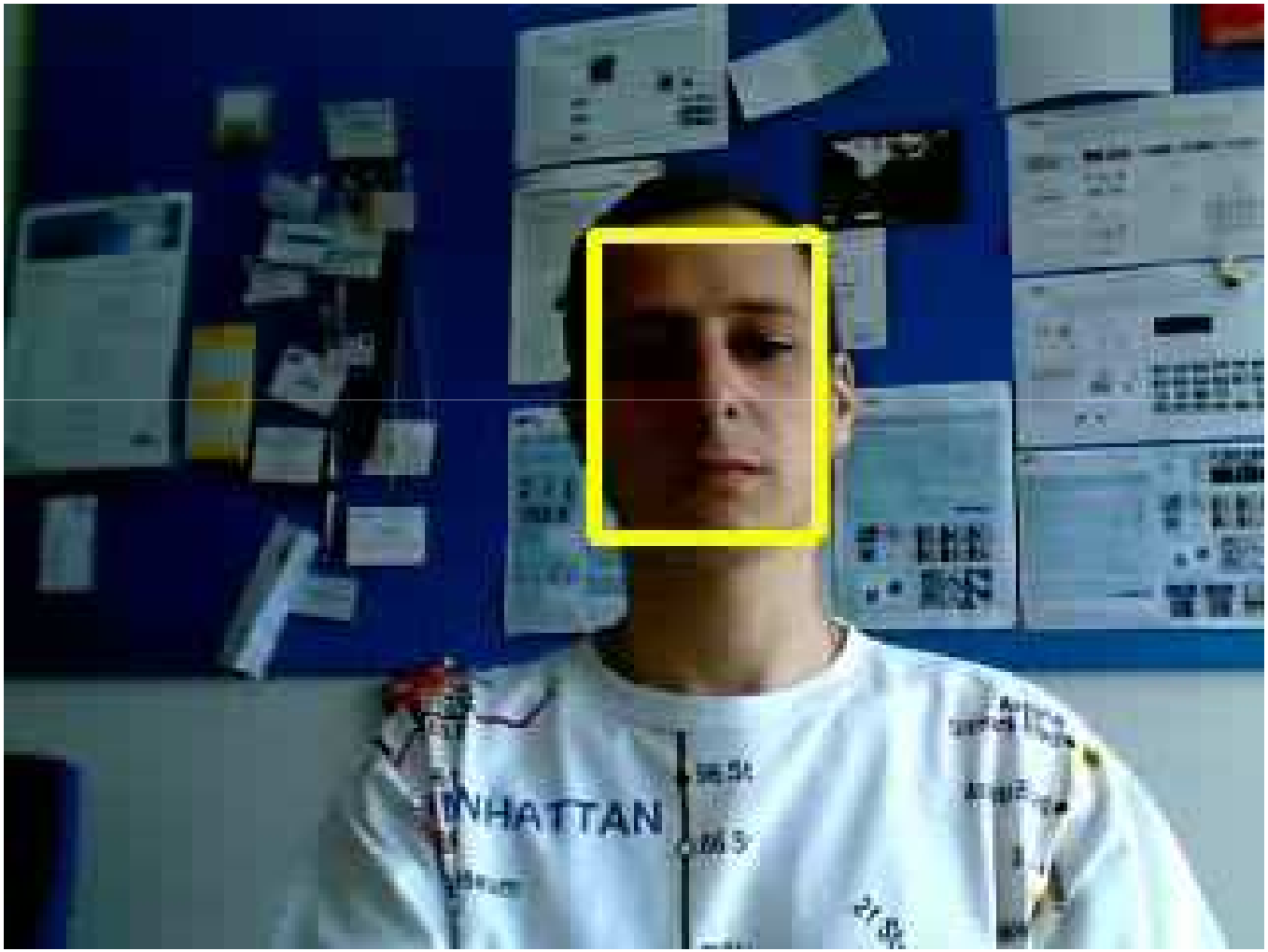
“Tracking the Invisible”



Tracking Solved ☺

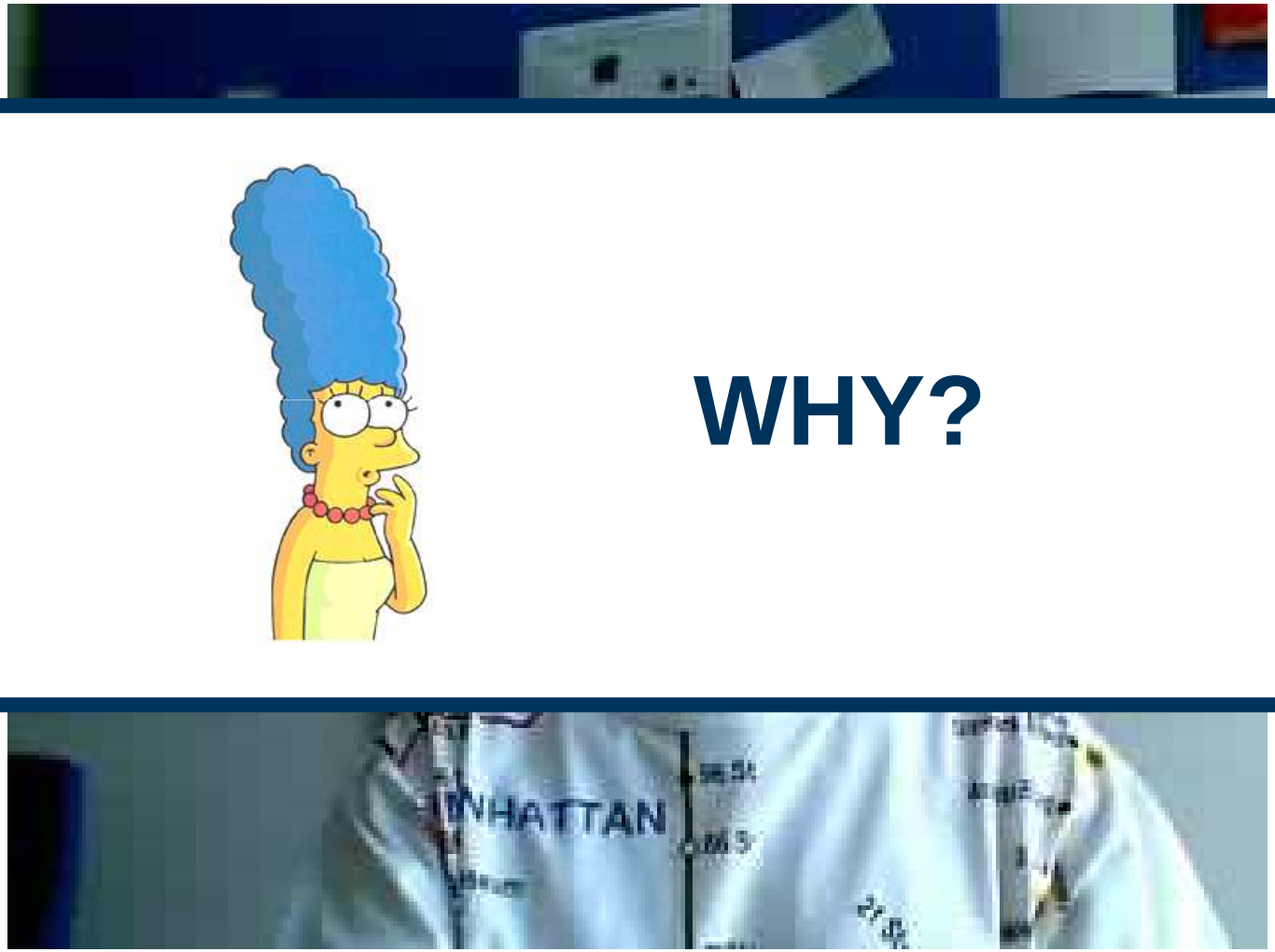
Does it fail?
If yes, when?

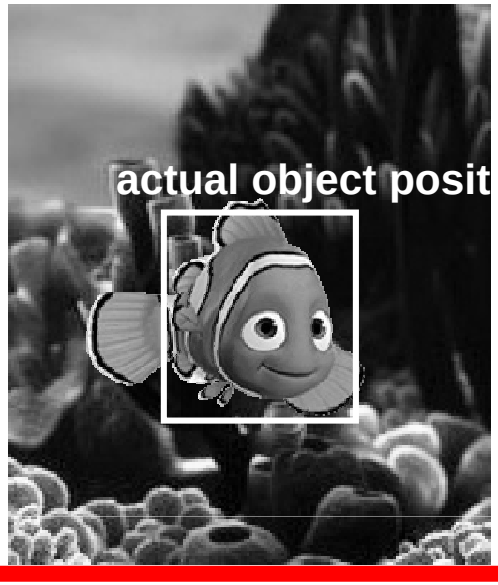
When does it fail…



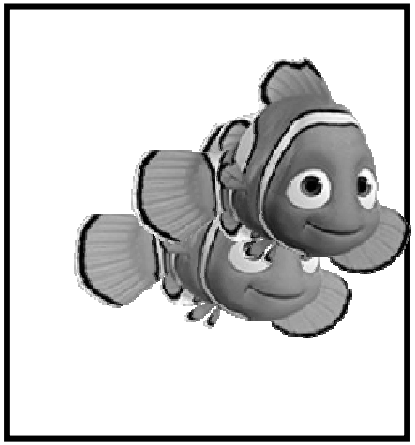
When does it fail…

When does it fail…

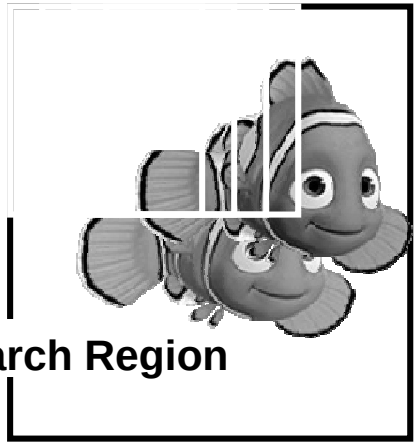




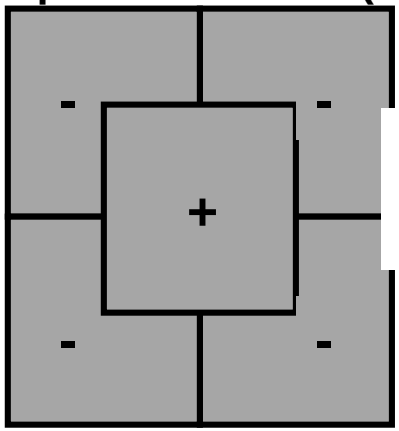
from time t to t+1



evaluate classifier on sub-patches



update classifier (tracker)



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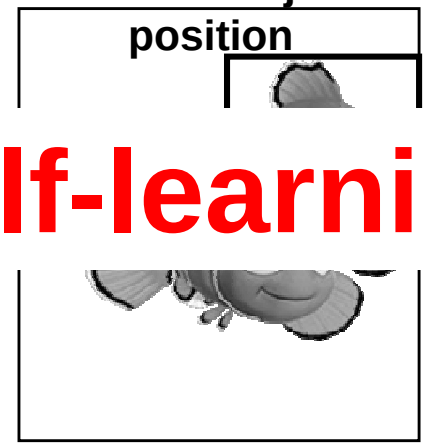
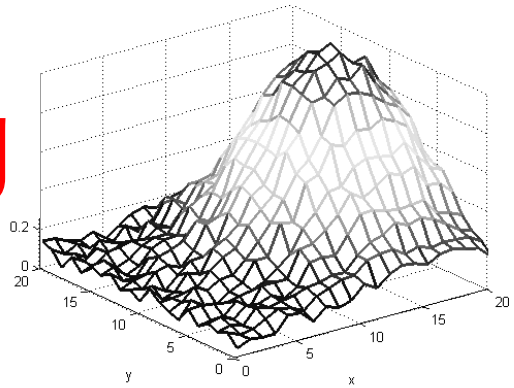


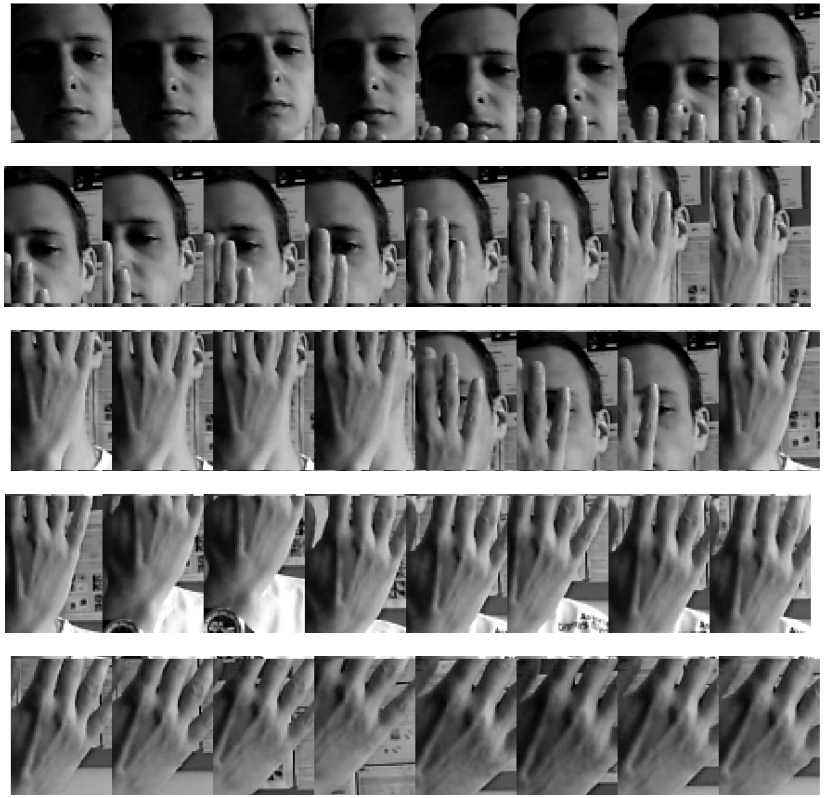
create confidence map



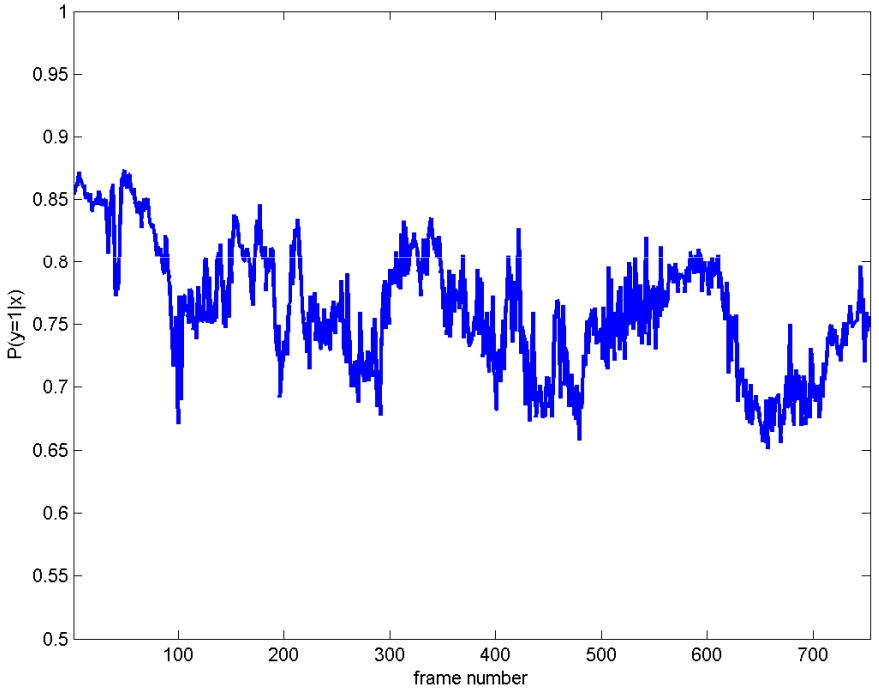
Self-learning

Drifting due to self-learning policy

Tracked Patches



Confidence



Lesson learned 2

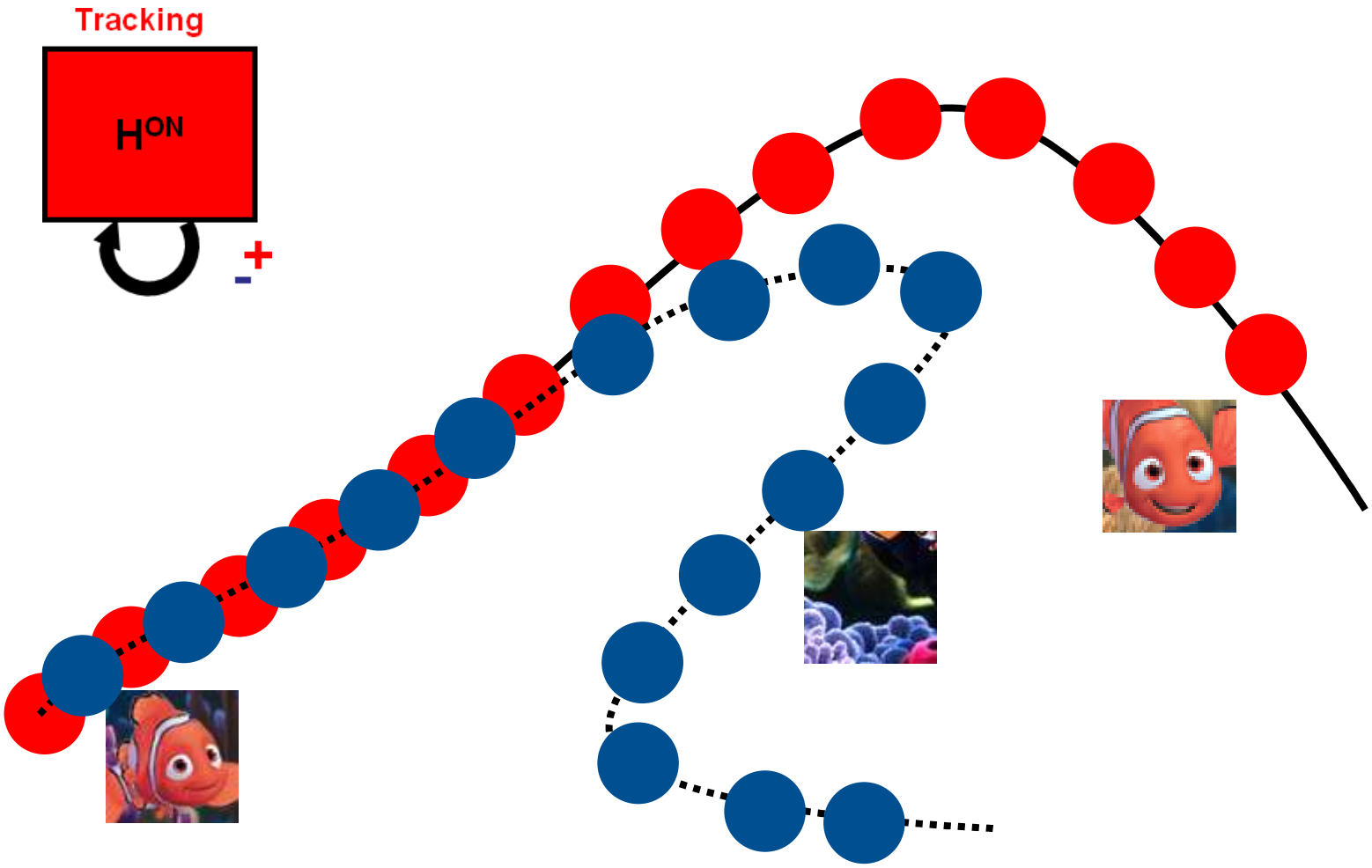
Self-learning → drifting!

PART II

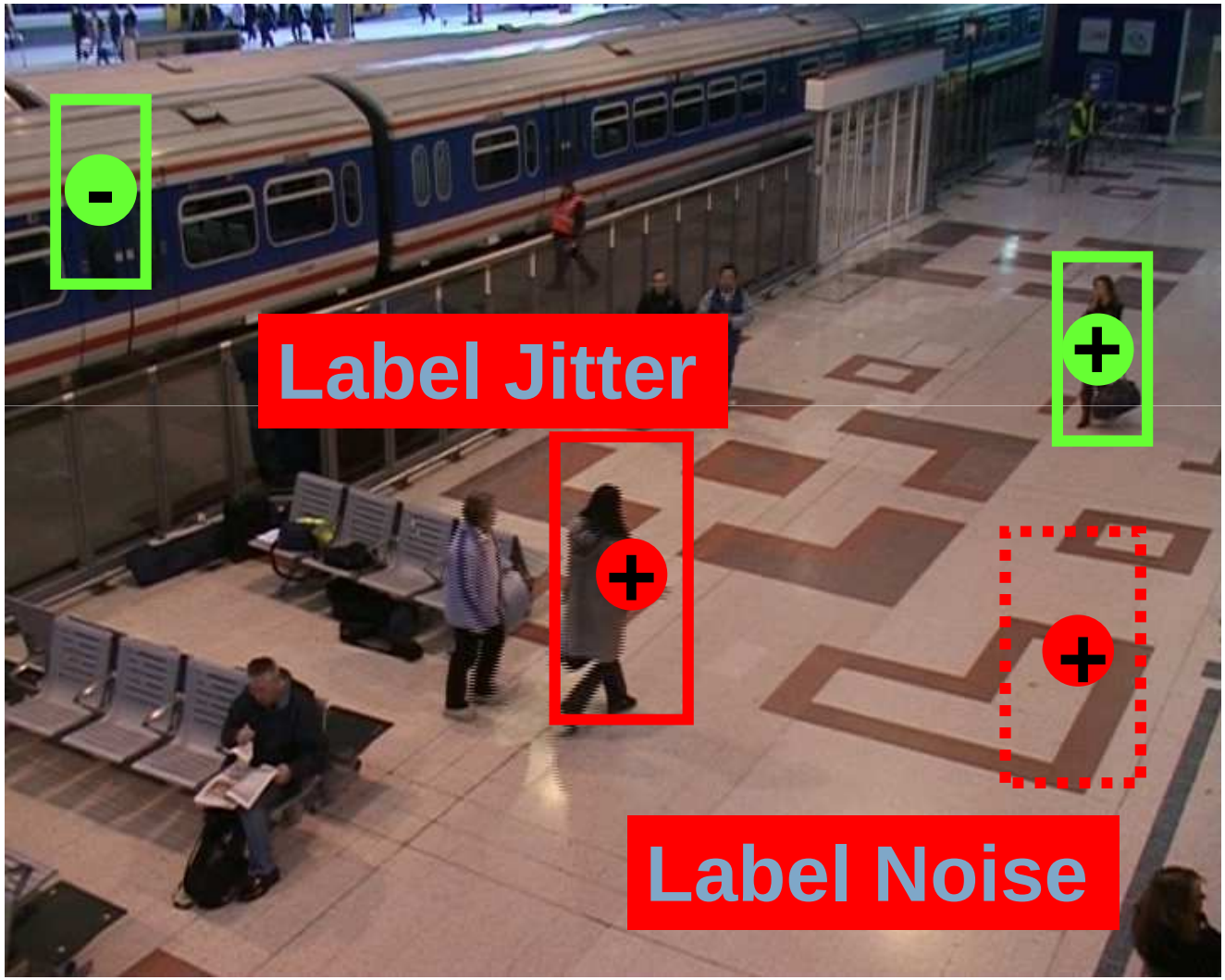
Semi-Supervised On-line Boosting for Tracking

2008

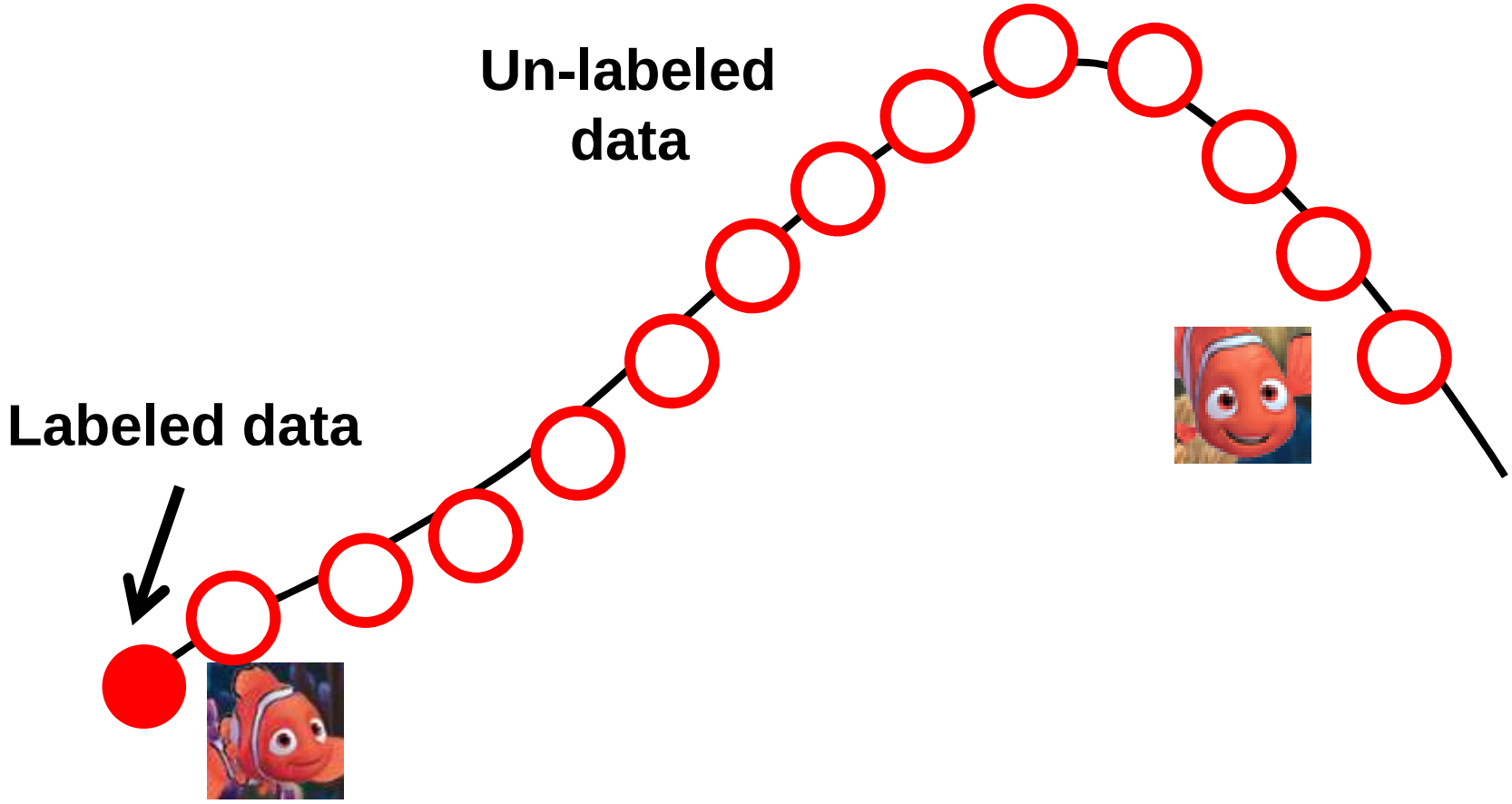
Review: Supervised Tracking



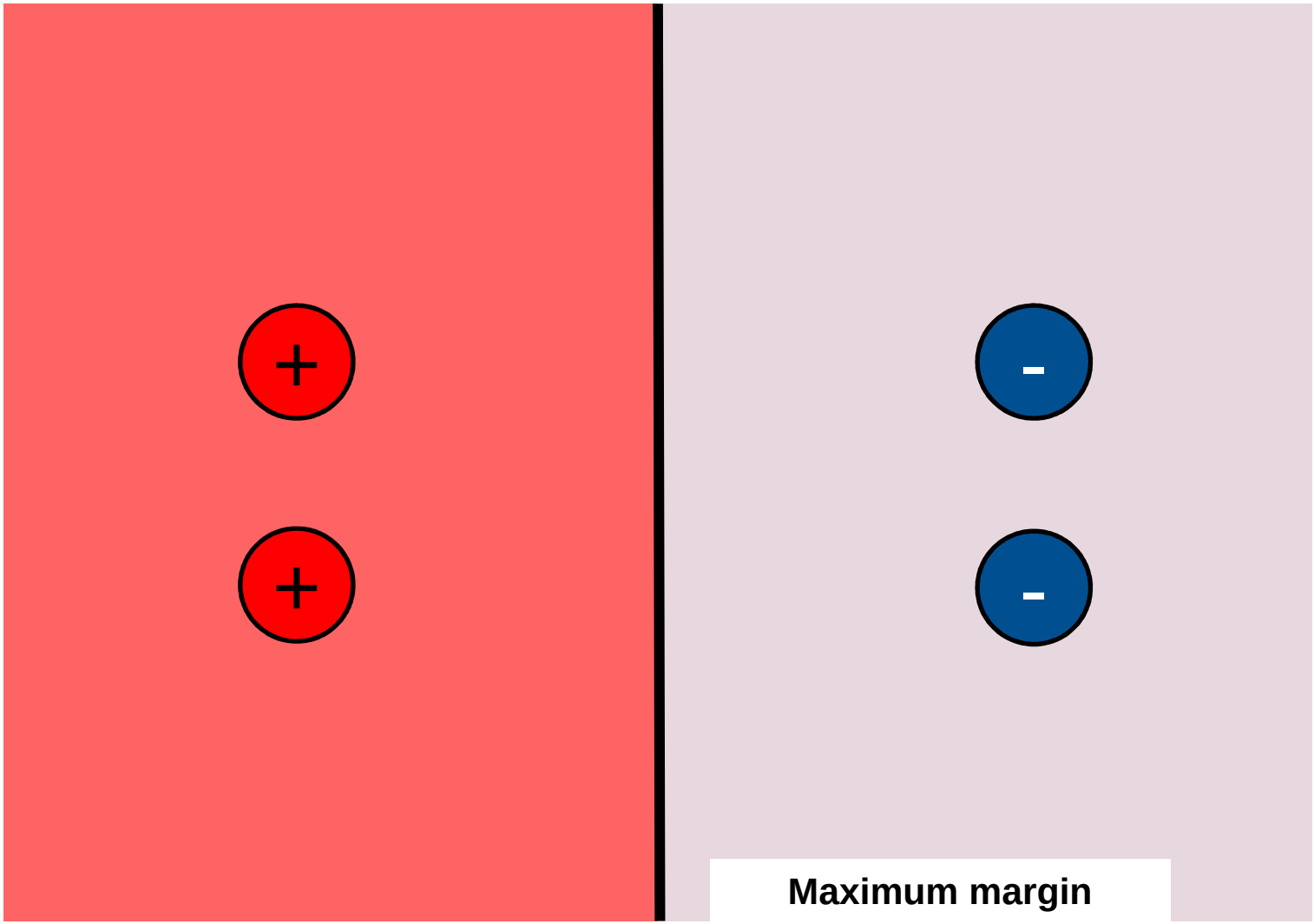
Problems of...



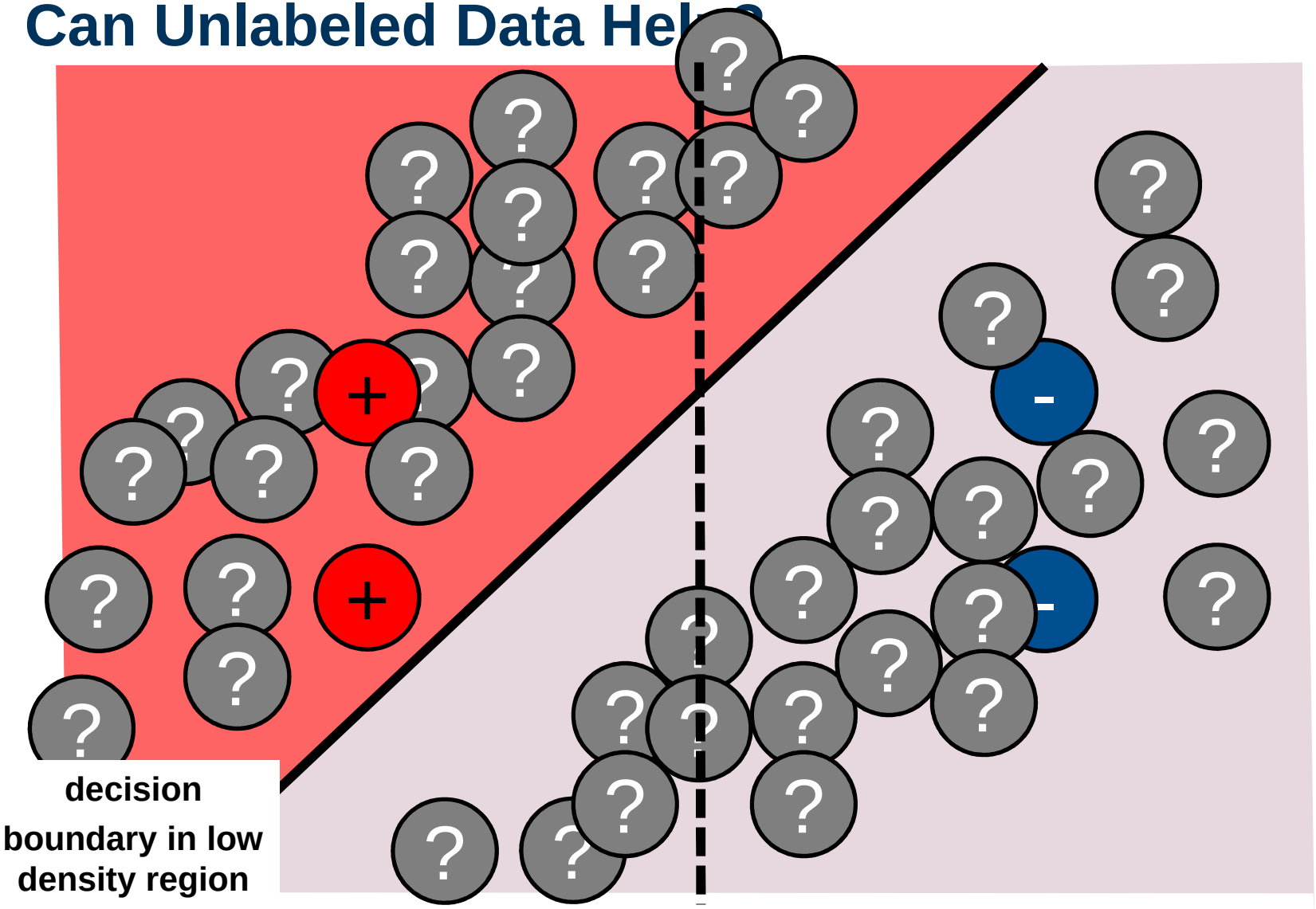
Semi-Supervised Tracking



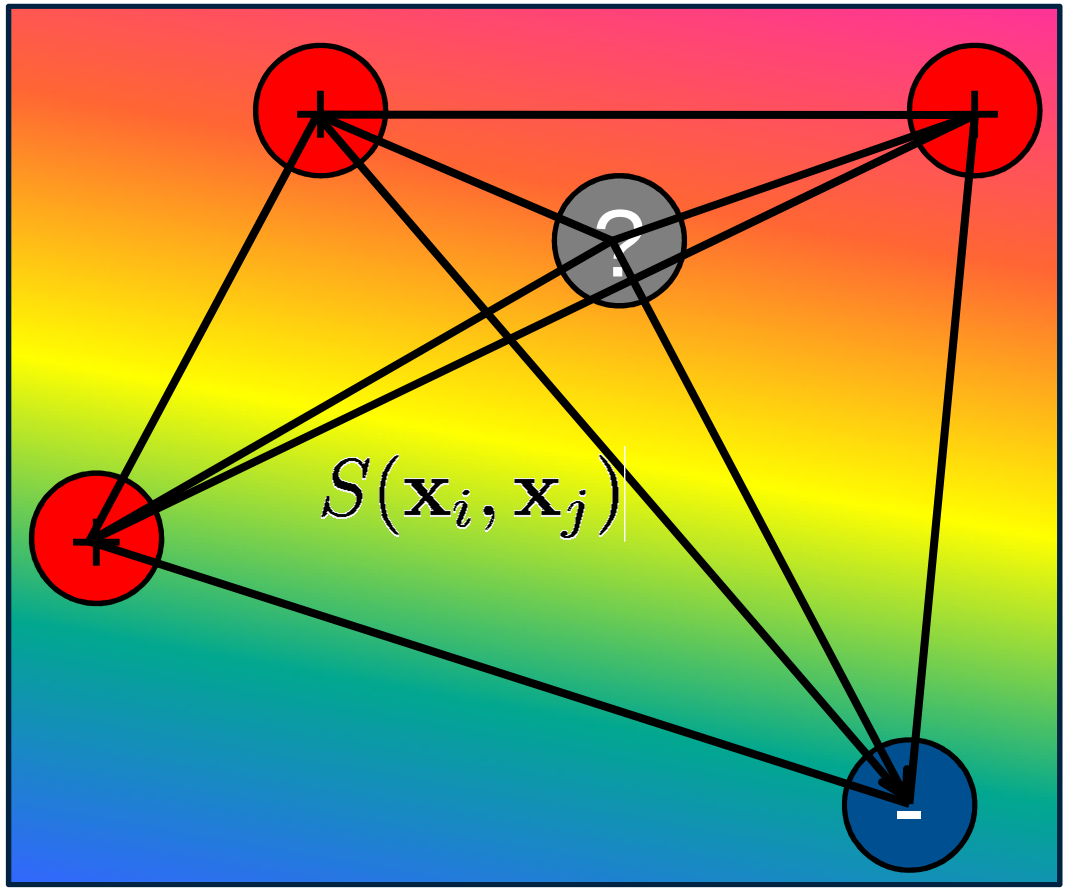
Supervised learning



Can Unlabeled Data Help?

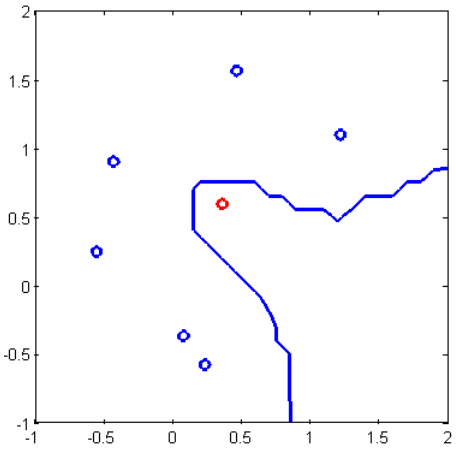


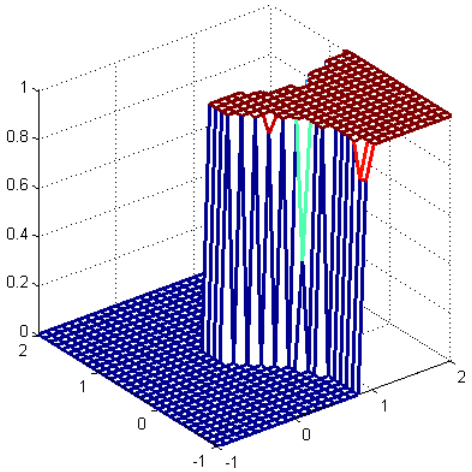
Semi-Boosting



“Boosting with a graph inspired regularization”

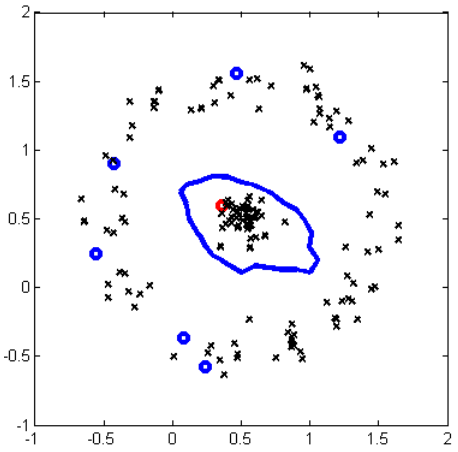
[Leistner, Grabner, Bischof, CVPR 2008]

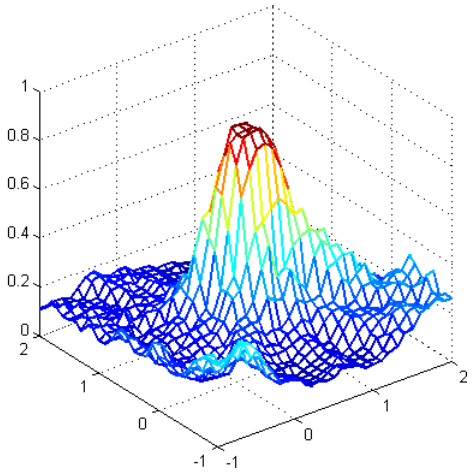




Boosting

SemiBoost



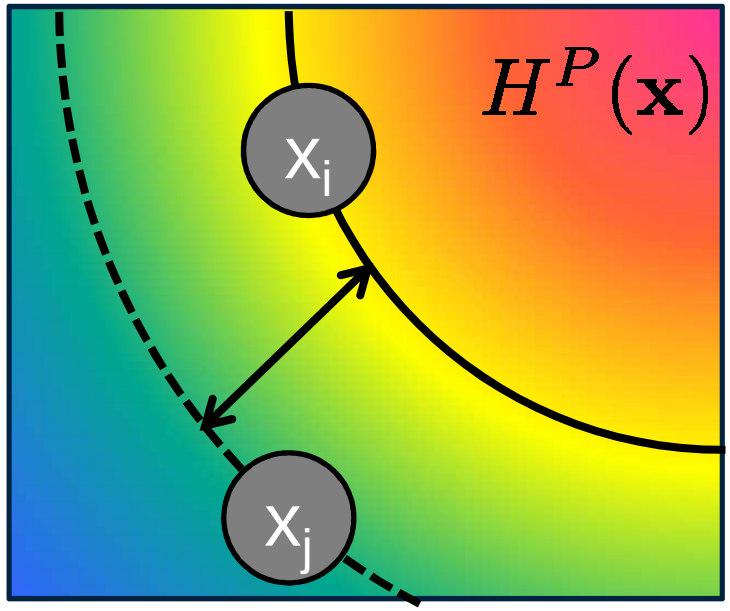


Similarities as Prior Classifier

$$S(\mathbf{x}_i, \mathbf{x}_j)$$

$$\Downarrow$$

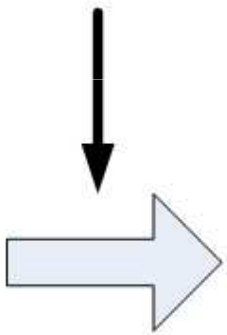
$$|H^P(\mathbf{x}_i) - H^P(\mathbf{x}_j)|$$

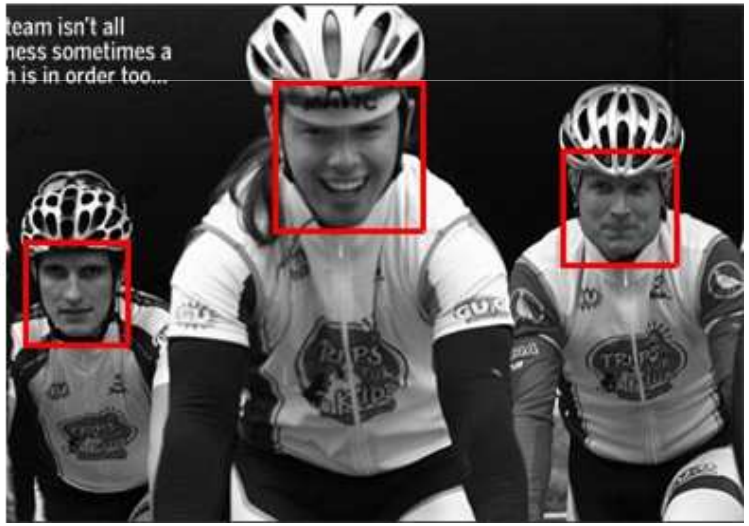


Classifier Improvement

Note, this is NOT a simple sum-rule, since training of H(x) depends on $H^P(x)$!

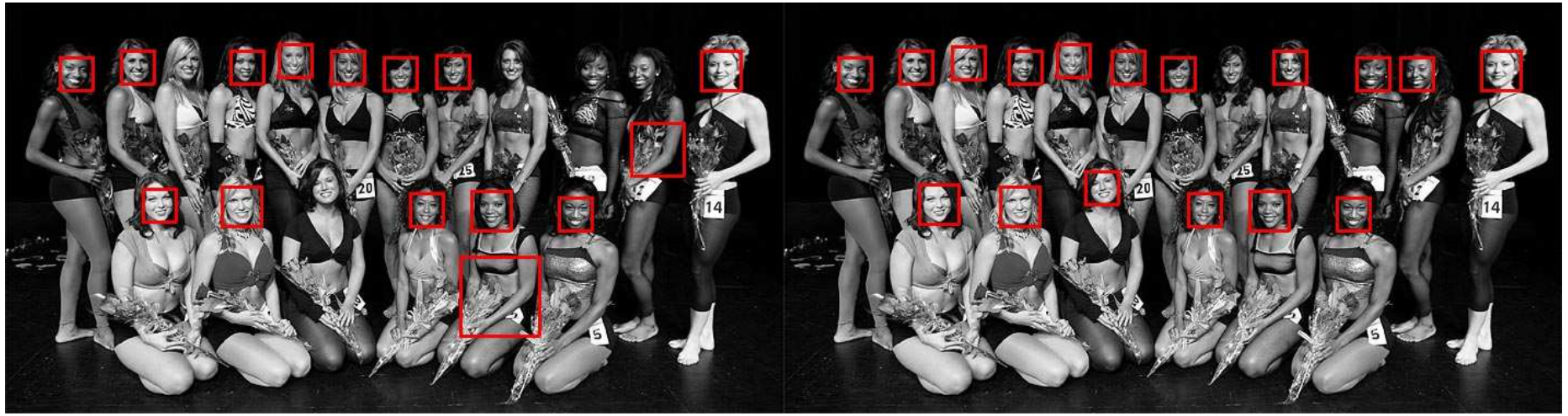
Unlabeled Data

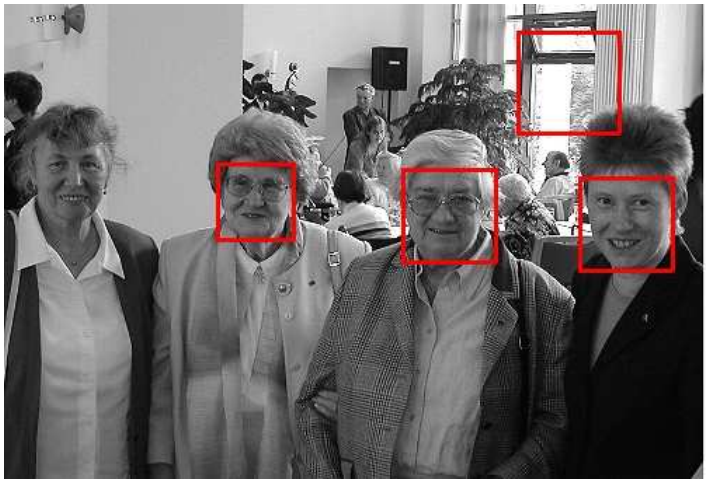


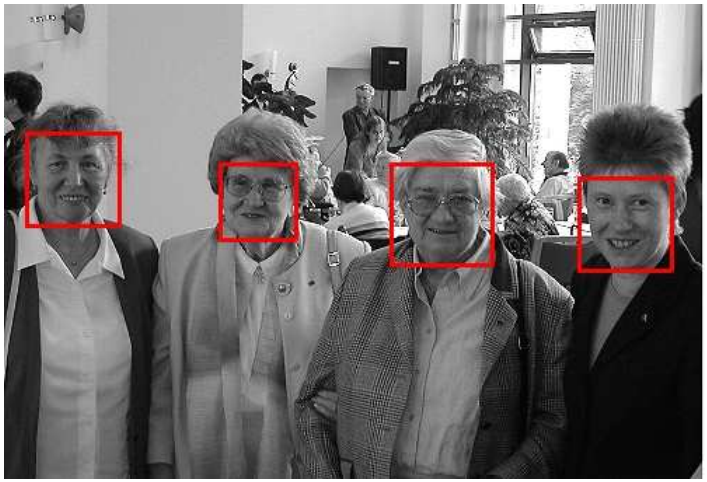


Face Detector

Improved Results







Going on-line…

- Off-line classifier serves as prior (similarity measure)

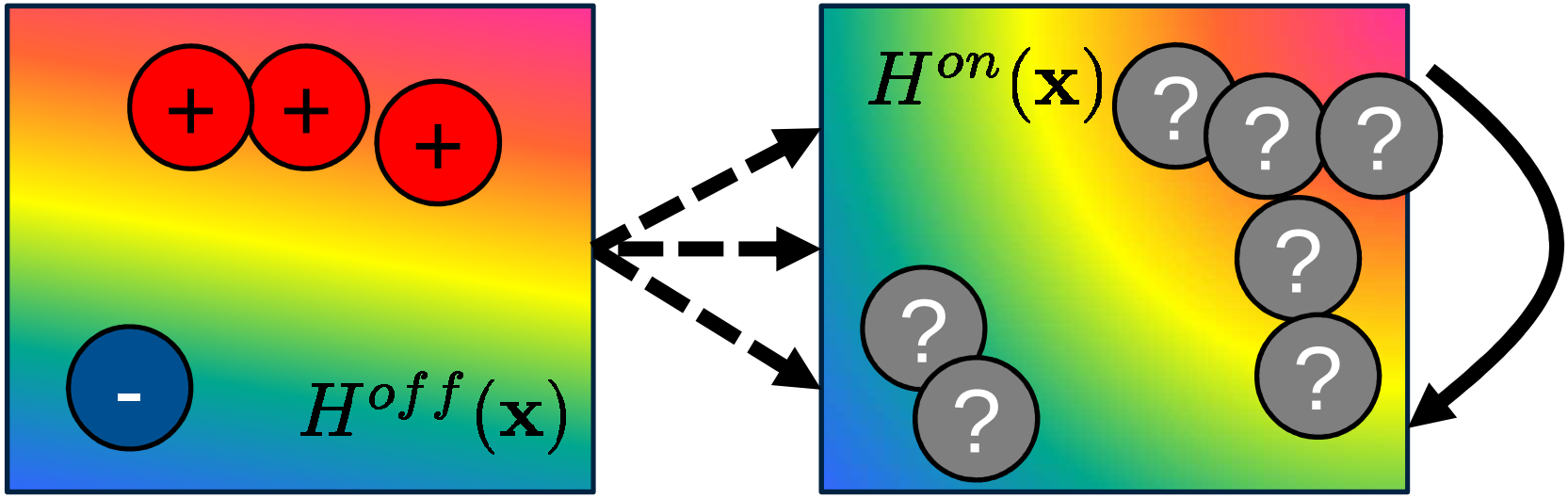
$$H^P(\mathbf{x}) = H^{off}(\mathbf{x})$$

- Both, **label** and **importance** of the example are adjusted during training for each selector n

$$z_n(\mathbf{x}) = \text{sign}\left(\tanh(H^{off}(\mathbf{x})) - \tanh(H_n^{on}(\mathbf{x}))\right)$$

$$\text{conf}_n(\mathbf{x}) = \left|\tanh(H^{off}(\mathbf{x})) - \tanh(H_n^{on}(\mathbf{x}))\right|$$

Semi-Supervised On-line Boosting



Semi-Supervised On-line Boosting

fix

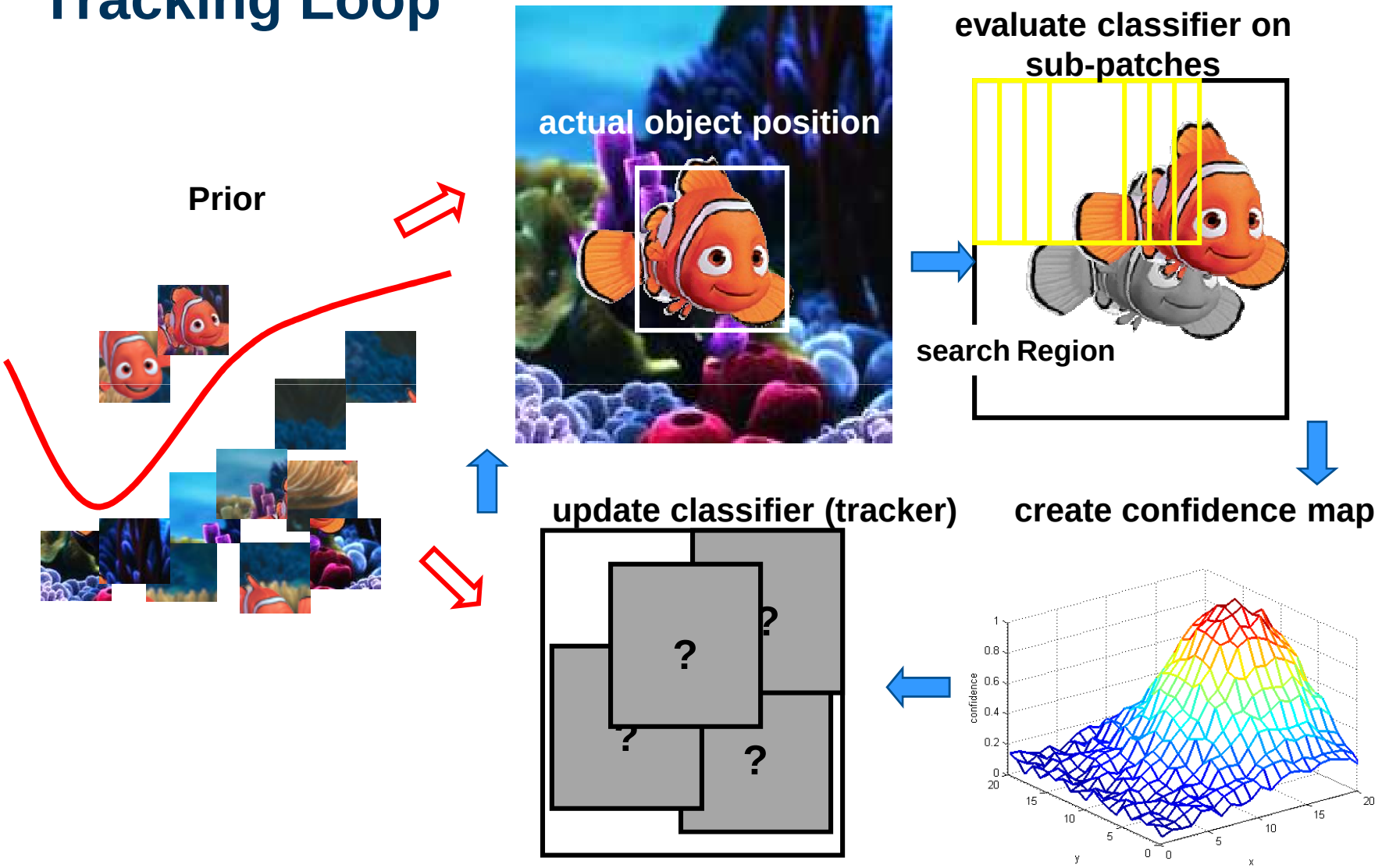
"stable"

dynamic

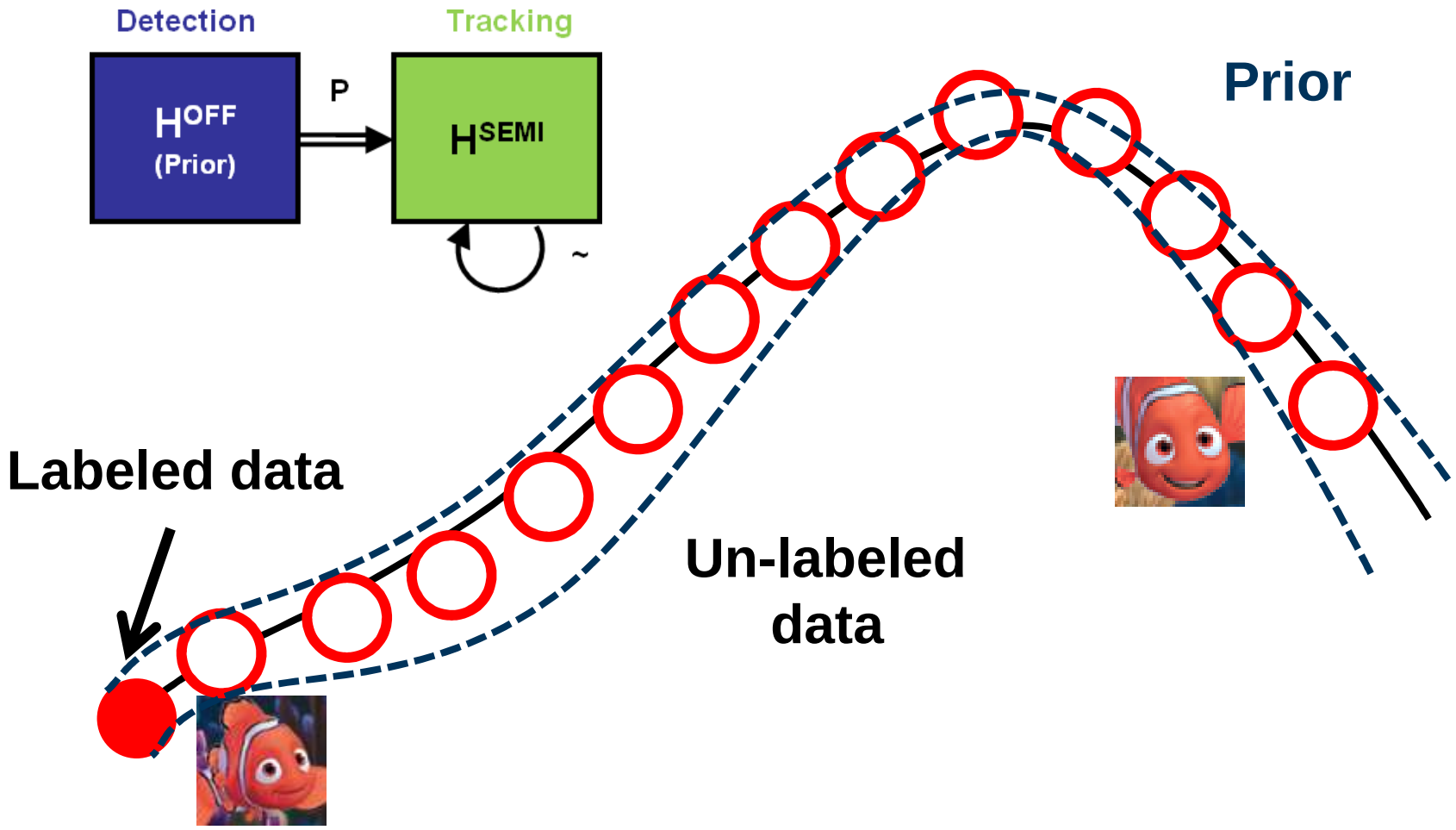
Nobody is perfect!
But, be a honest Teacher!

H^{off} can be wrong with low confidence.

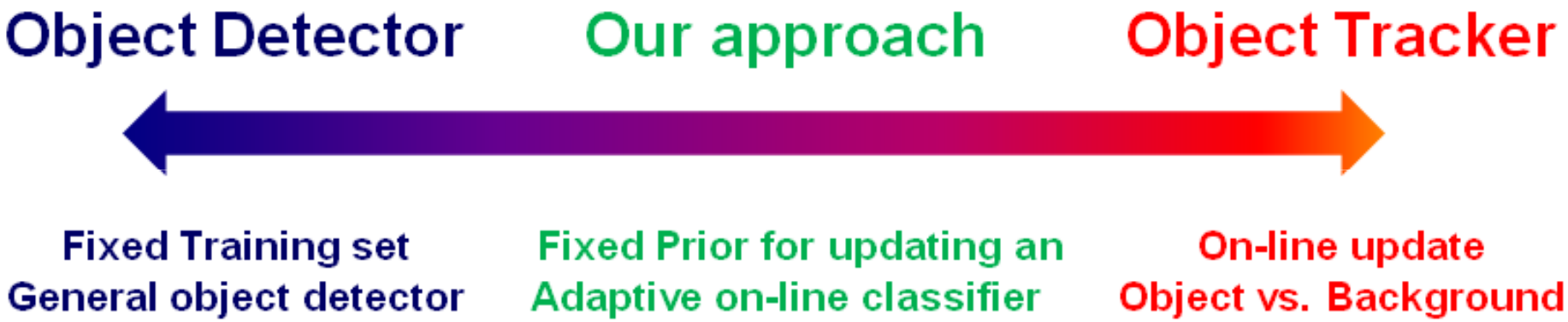
Tracking Loop



Semi-Supervised Tracking



Robust Semi-supervised Tracking



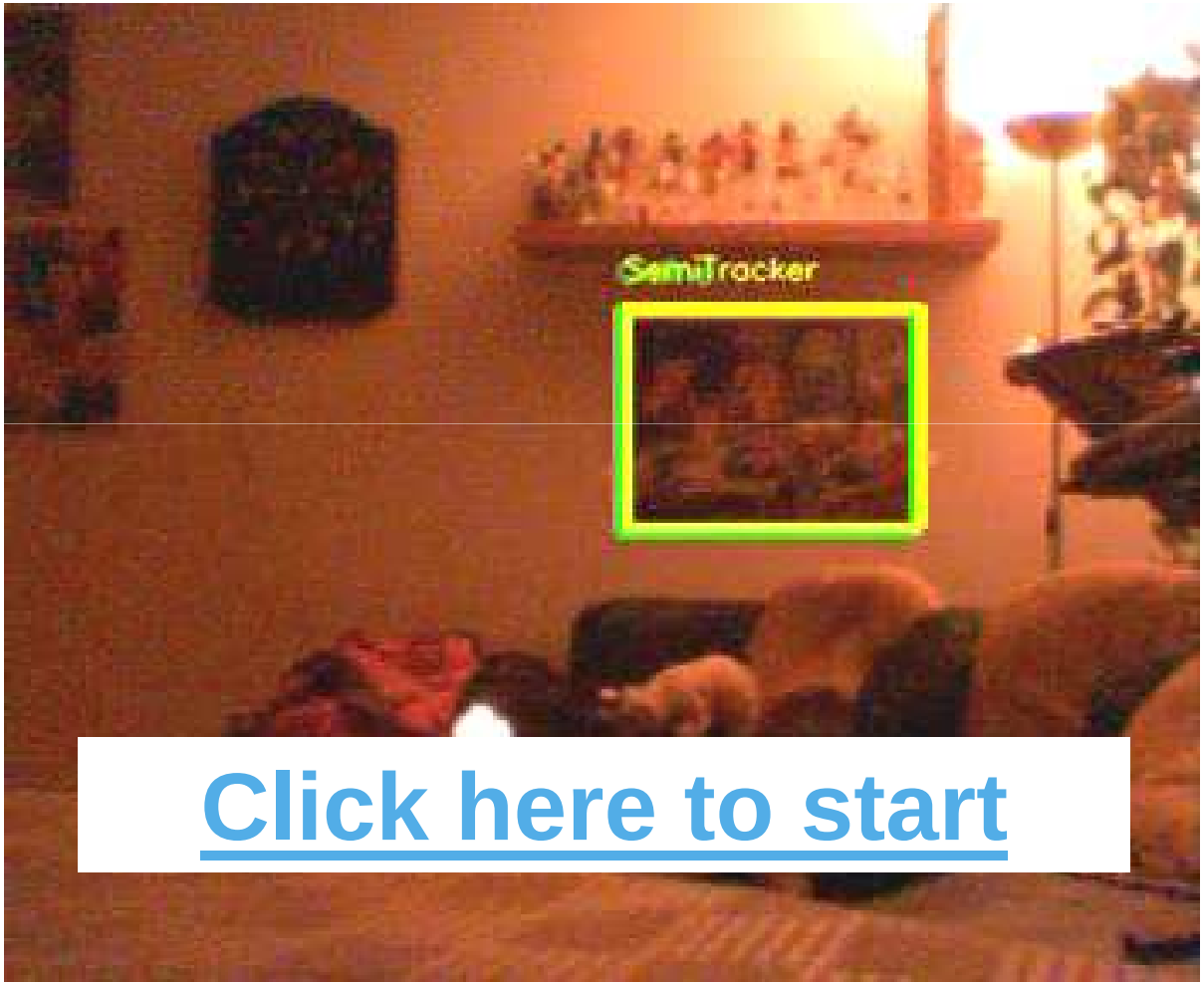
Lesson learned 3

On-line Semi-supervised learninig → limited drifting.

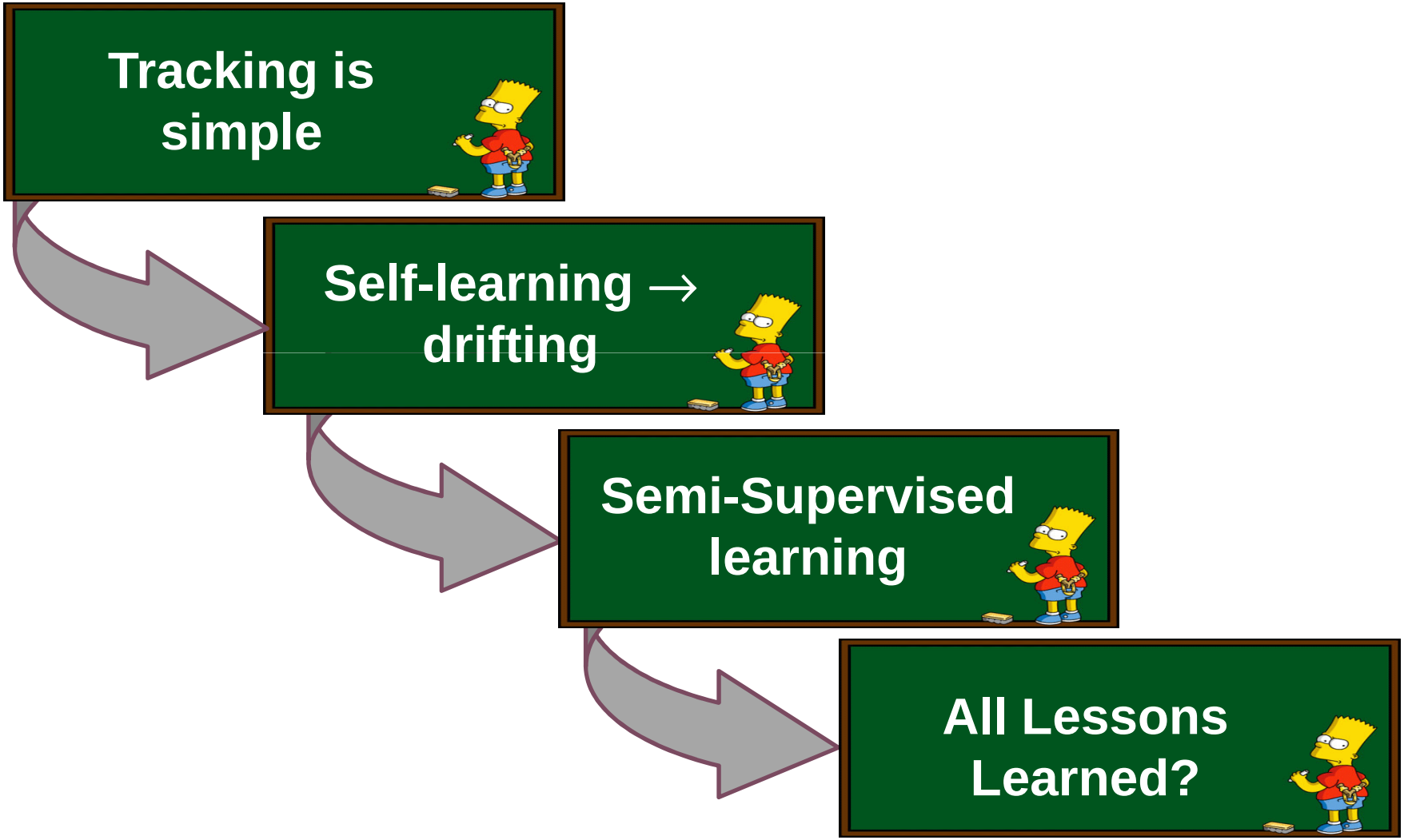

PATTERN
RECOGNITION
SemiTracker
ScienceDirect

Robust Tracking

Long term tracking (1h)



Conclusion


Tracking is simple
Self-learning → drifting
Semi-Supervised learning
All Lessons Learned?

Your choice…

Thank you for your attention

1 further:
“lesson learned”

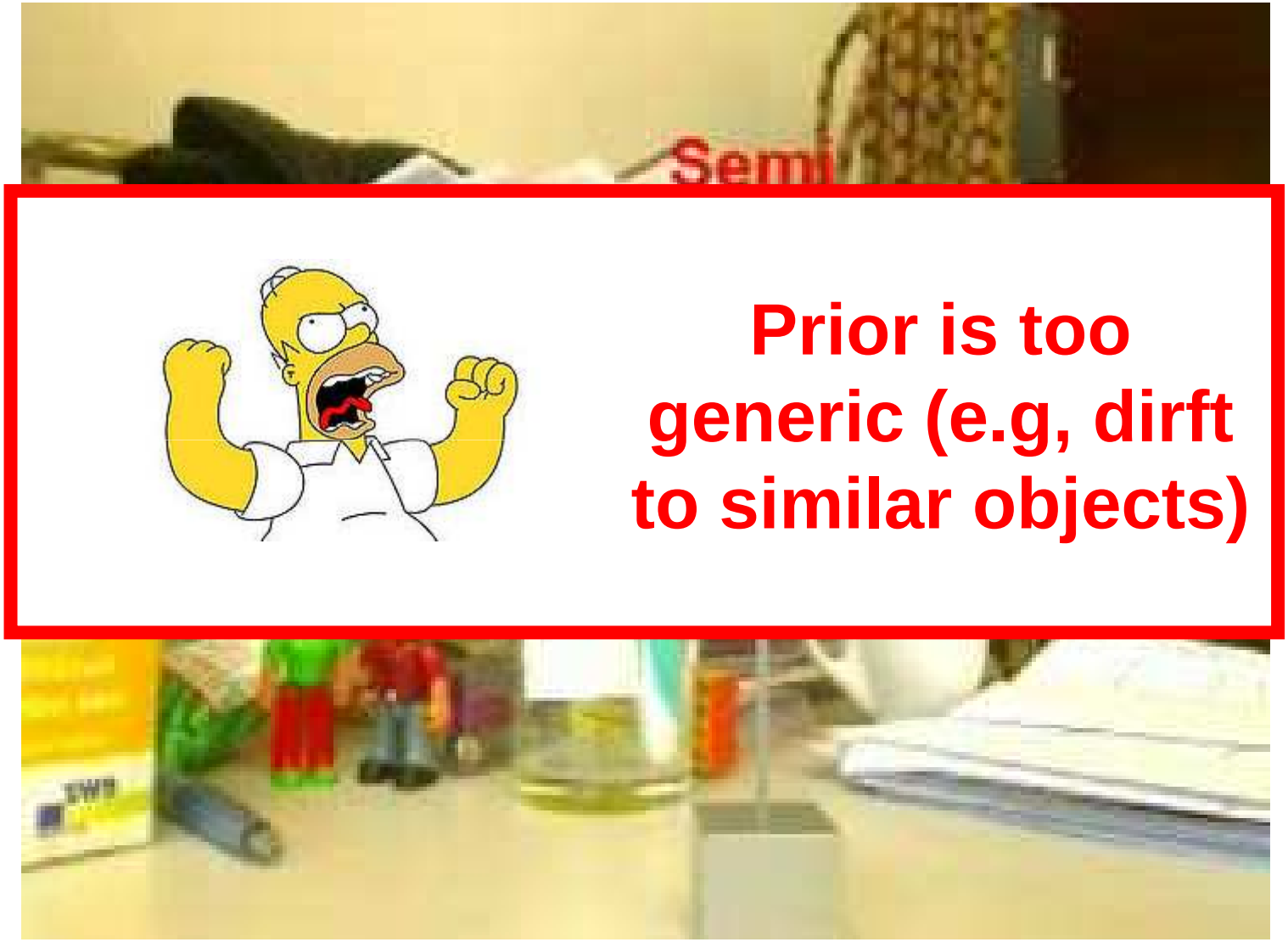
PART III

Beyond Learning, Learning Everywhere now

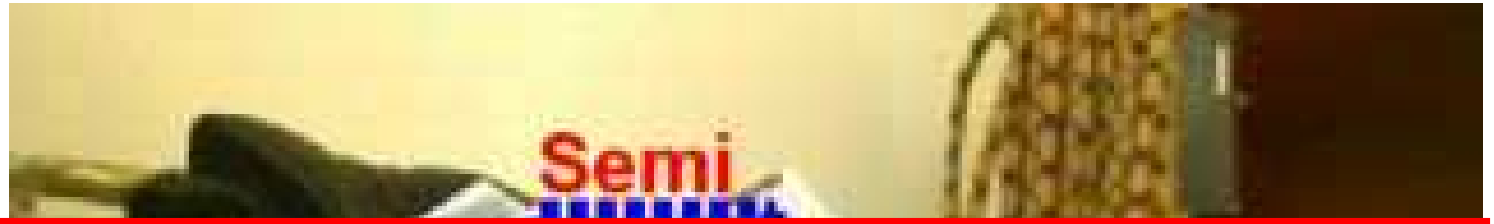
Tracking Solved ☺

Does it fail?
If yes, when?

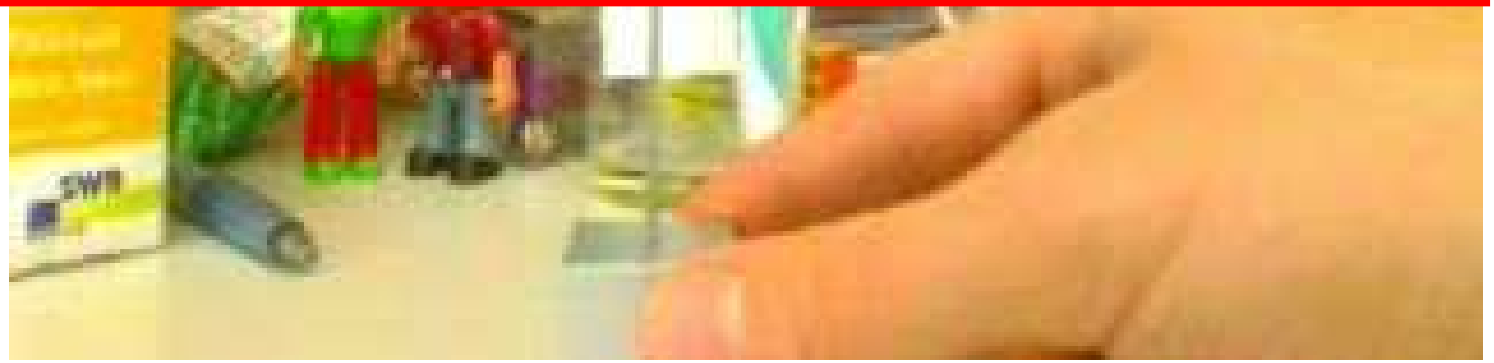

Semi
On


Semi
Prior is too generic (e.g, dirft to similar objects)


Semi
On



Prior restricts too much (e.g., partial occlusions)



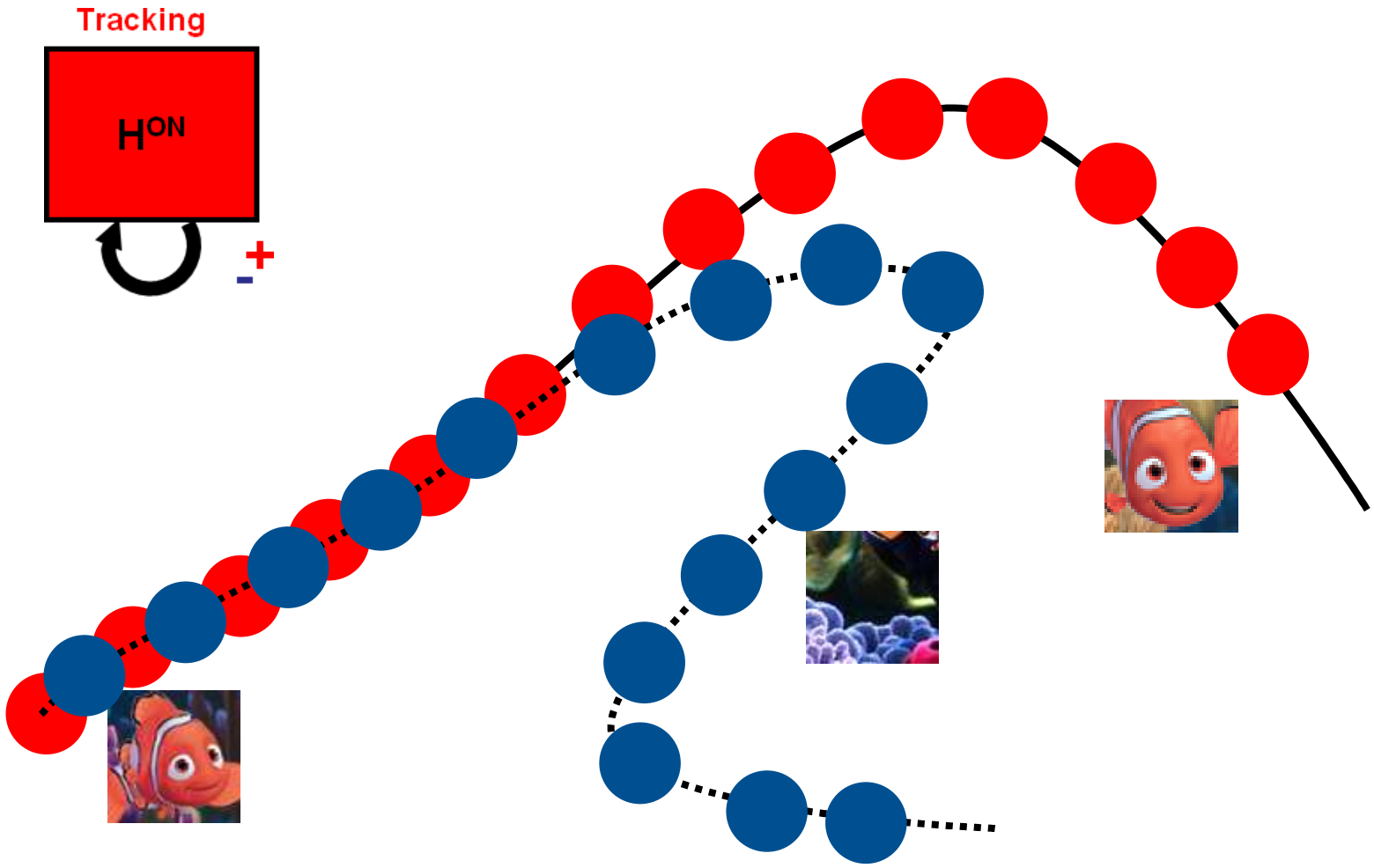
Lesson learned 4

Prior is essential in semi-supervised learning.

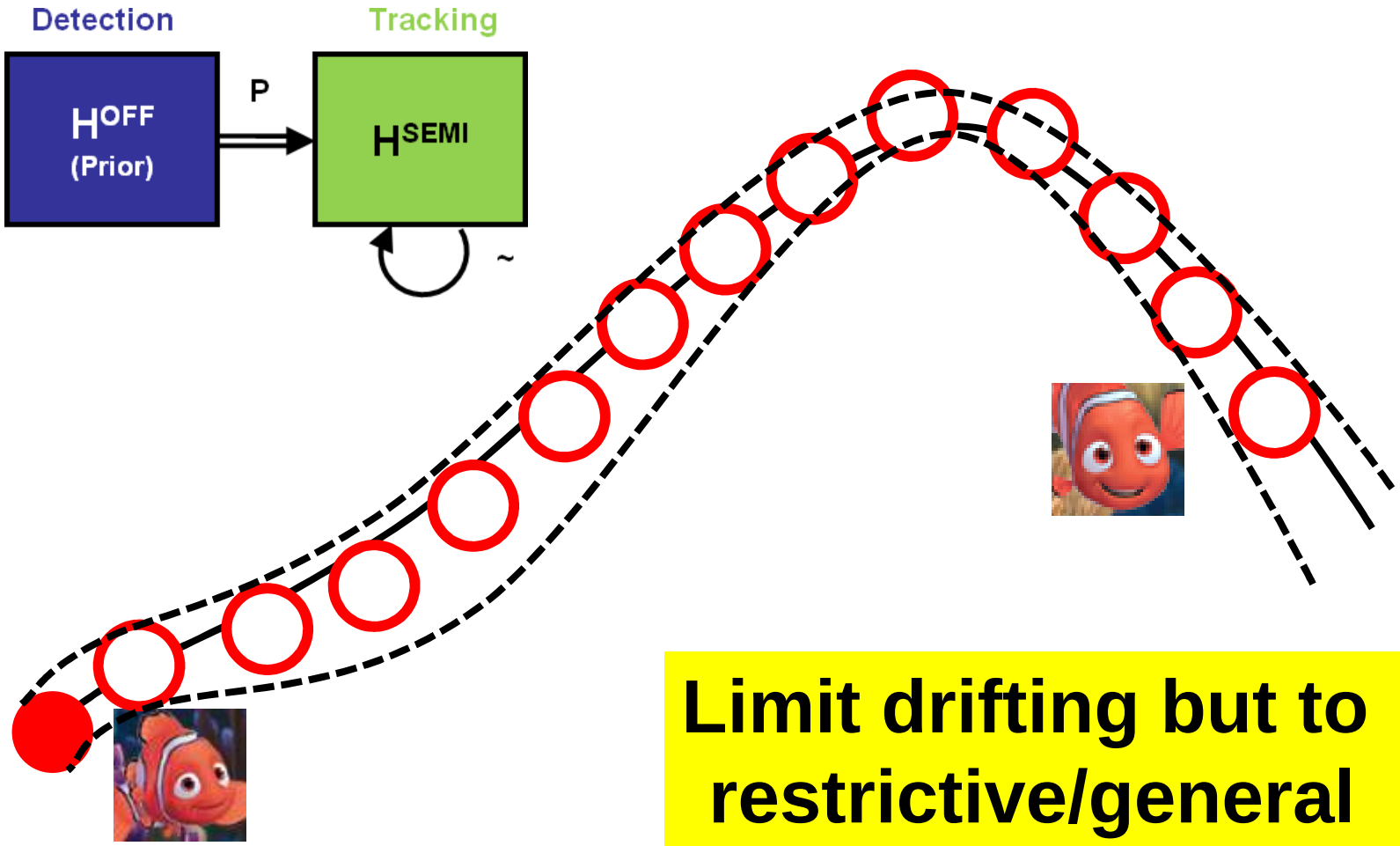
(c.f., Stability Plasticy Dilemma)

Review: Supervised Tracking

To adaptive



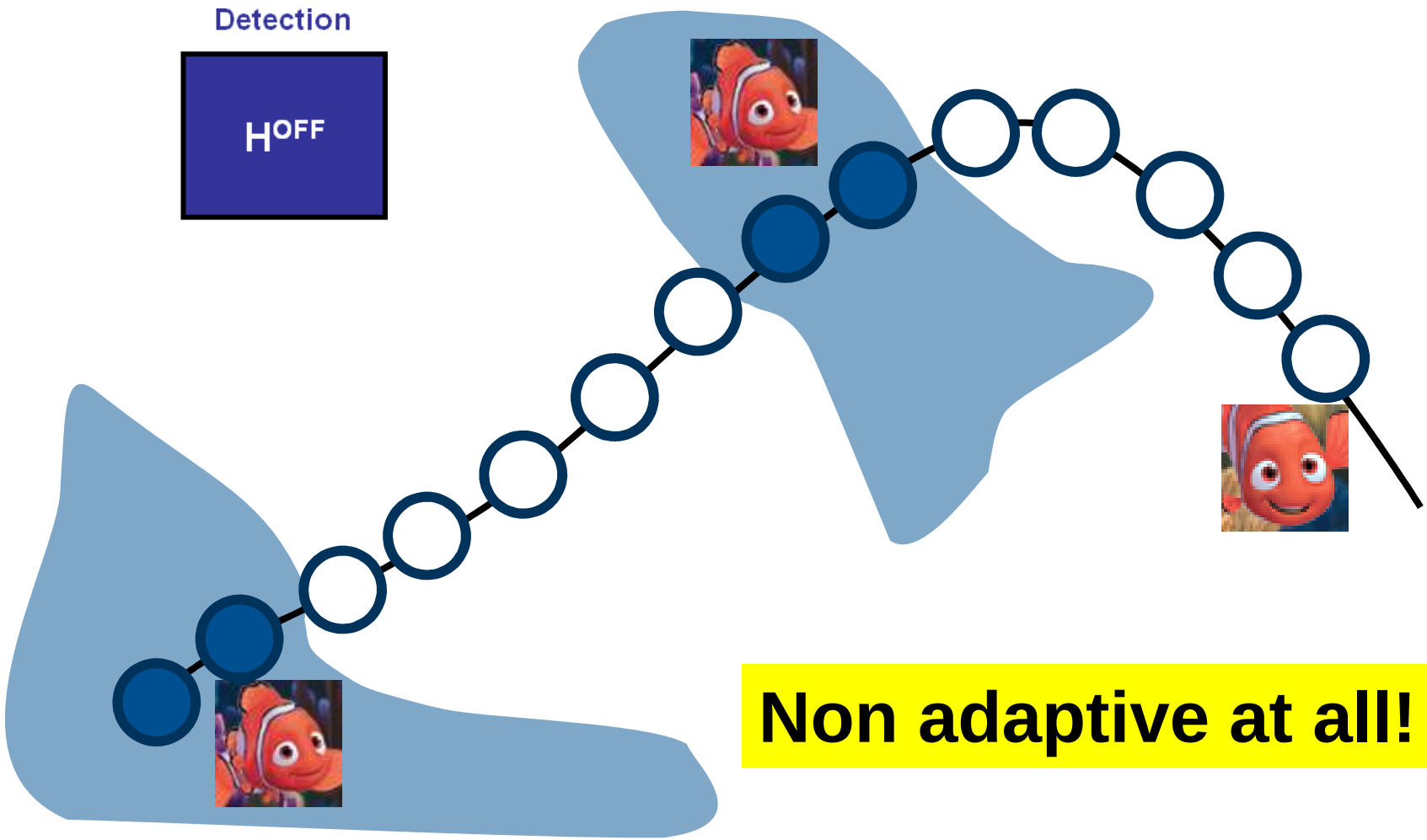
Review: Semi-Supervised Tracking



Limit drifting but to restrictive/general

Detection

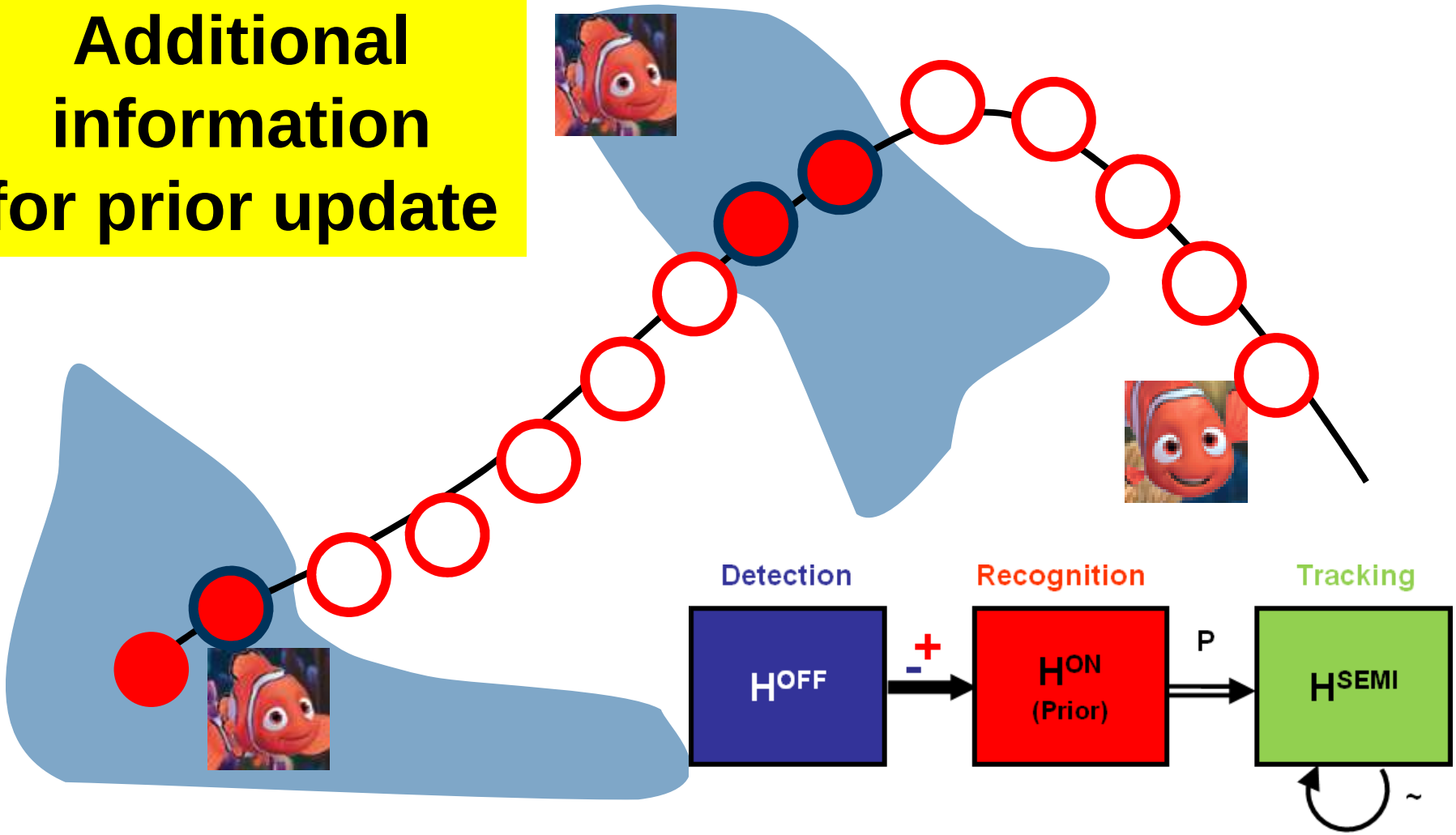
Add information!

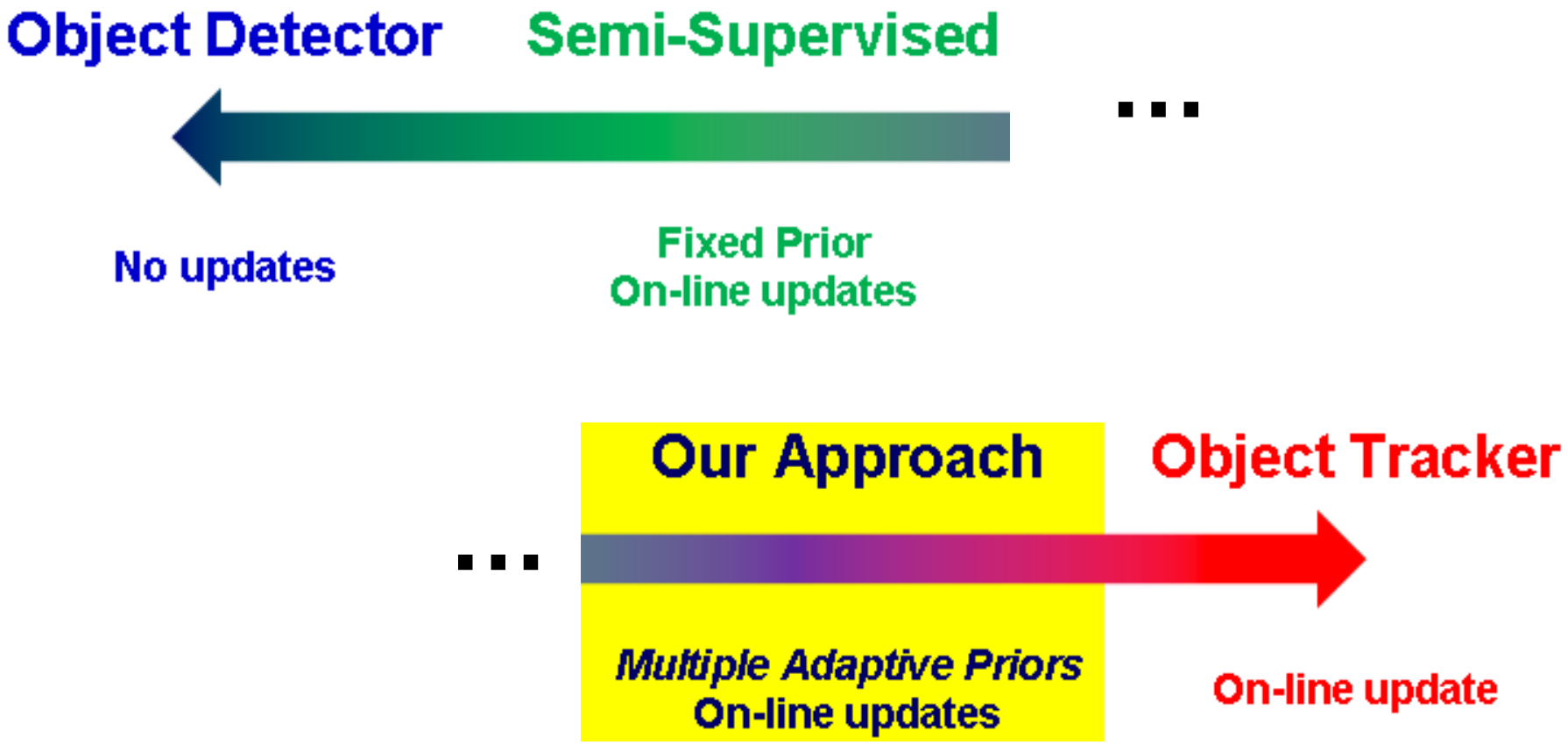


Non adaptive at all!

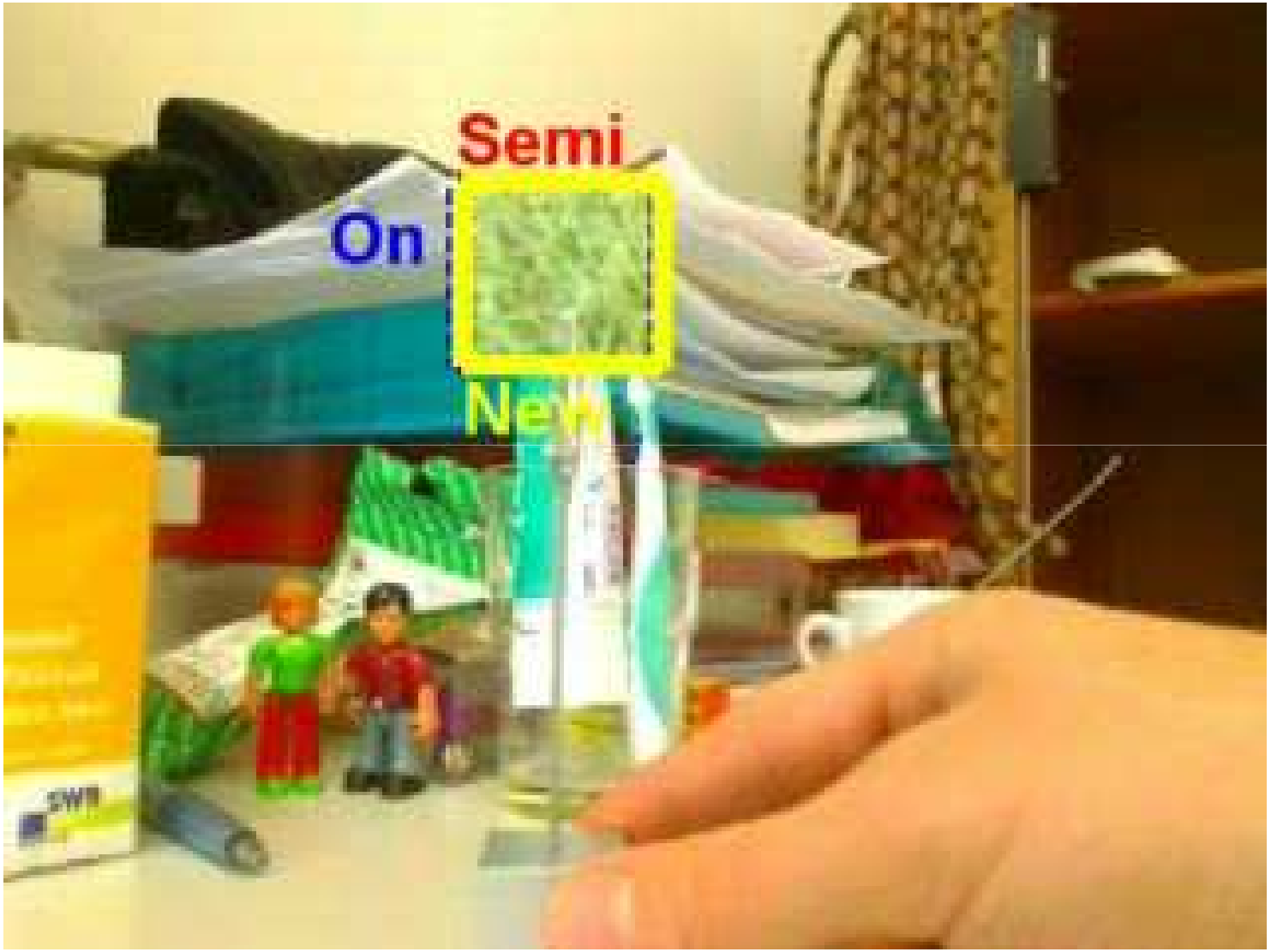
Adaptive Prior

Additional information for prior update

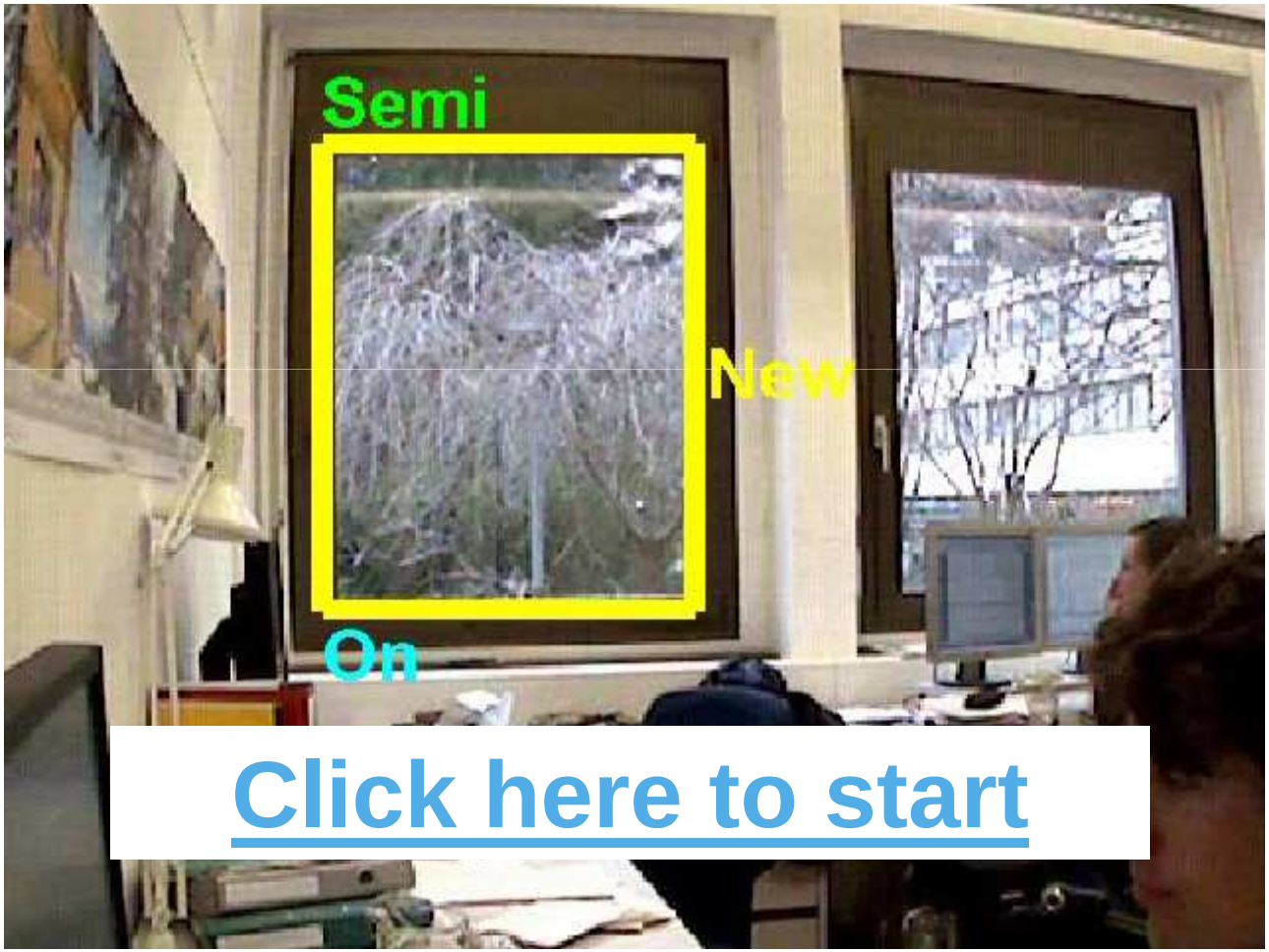



Object Detector
Semi-Supervised
No updates
Fixed Prior
On-line updates
Our Approach
Object Tracker
Multiple Adaptive Priors
On-line updates
On-line update


Semi
On
New


Semi
On
NeH

Long term tracking (24h)



Lesson learned 5

Vision is more then pure Machine Learning!

(keep problems simple)

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Christian Leistner

Jiri Matas

Jan Sochamn

In conjunction with ICCV 2009

3rd On-line Learning for Computer Vision Workshop 2009

Kyoto, Japan, October 3, 2009

CALL FOR PAPER

SUBMISSION DEADLINE: June 19, 2009

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Suter, Oncel Tuzel, Lior Wolf

We invite you to participate in the *3rd On-line Learning for Computer Vision Workshop* (OLCV'09) which will be held in junction with ICCV in Kyoto, Japan. The workshop will bring together computer vision rese ested in providing solid foundations to this promising and challe

Topics:
The topics of inte ot limited to:

- On- ject detection and tracking,
- g for object identification and recognition,
- mental fusion of multi-modal data,
- Applications using on-line classification methods, and
- Theoretical characterizations.
- Work towards a solid framework for benchmarking on-line learning algorithms

Important Dates:

Submission of full papers	June 19, 2009
Notification of acceptance	July 20, 2009
Submission of camera ready papers	August 31, 2009
Workshop	October 3, 2009