



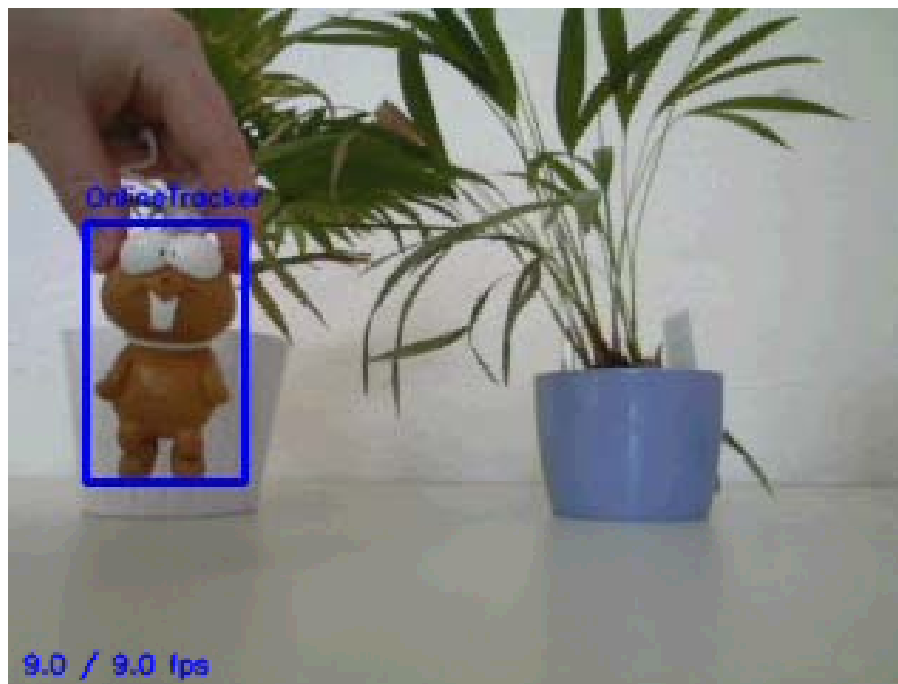
Speeding up Semi-supervised On-line Boosting for Tracking

Martin Godec
Helmut Grabner
Christian Leistner
Horst Bischof

{ godec, leistner, bischof }@icg.tugraz.at
grabner@vision.ee.ethz.ch



On-line Boosting for Tracking



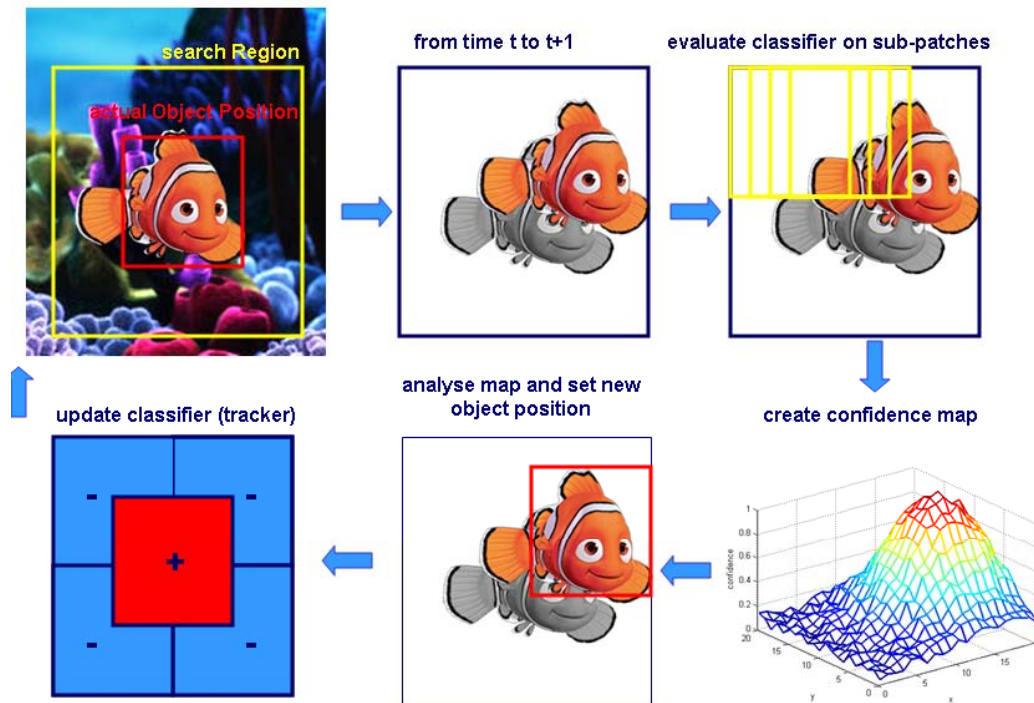


On-line Boosting for Tracking





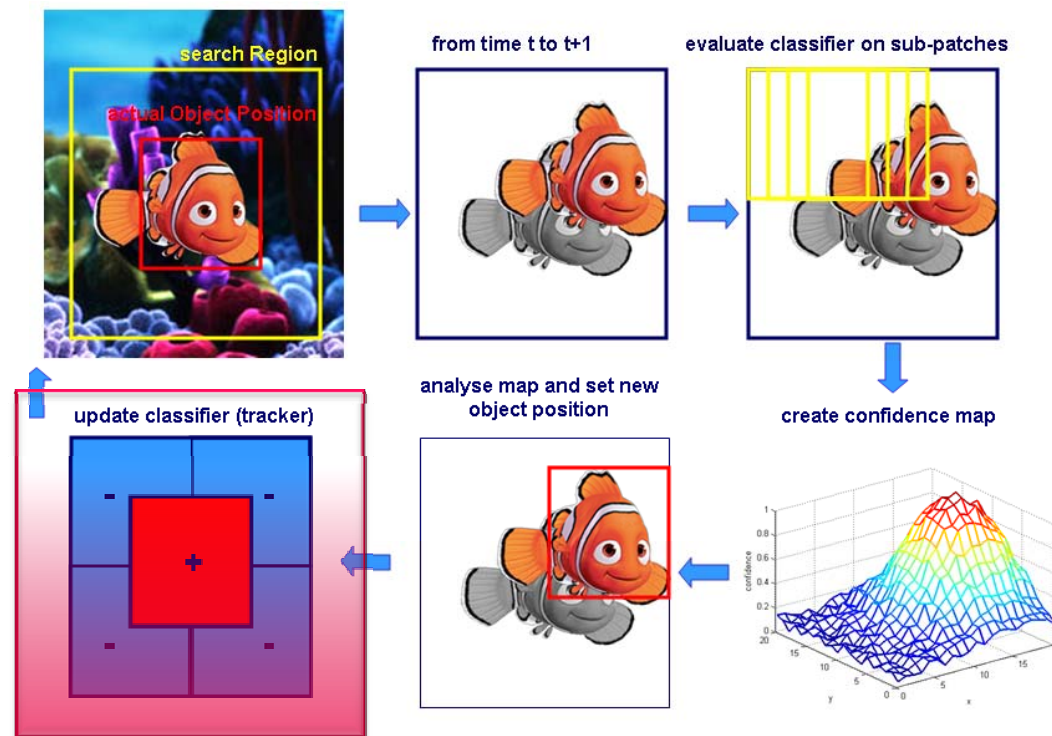
Why does it fail?



From: Grabner, H., Grabner, M., and Bischof, H. (2006). **Real-time tracking via on-line boosting**. In Proc. British Machine Vision Conf.



Why does it fail?



Supervised Learning Algorithm for Unsupervised Problem?

From: Grabner, H., Grabner, M., and Bischof, H. (2006). **Real-time tracking via on-line boosting**. In Proc. British Machine Vision Conf.



Changing the Learning Strategy

- We have...
 - one reliably marked object position
 - unreliable object positions during tracking

 - We want to...
 - track arbitrary/unknown objects
 - be adaptive to appearance changes
 - limit the risk of drifting
- ▶ *One-shot* Semi-Supervised On-line Learning

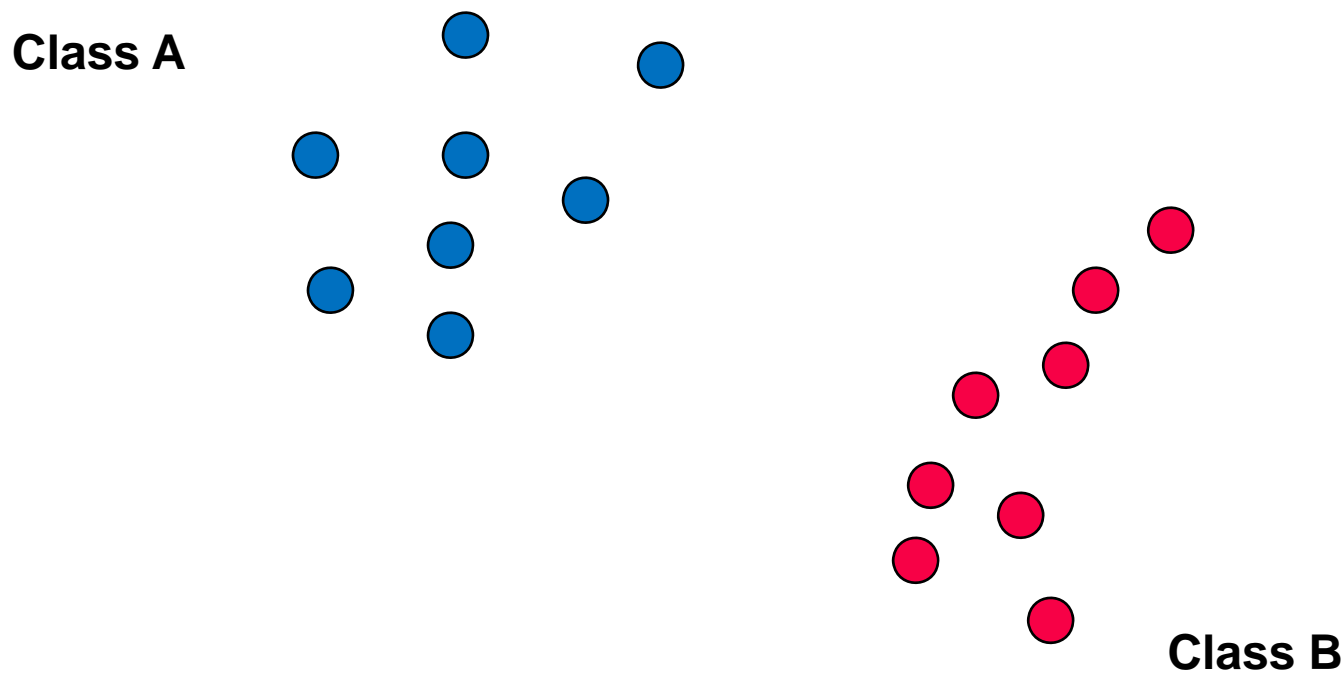


Outline

- Motivation
- **Review of Semi-Supervised On-line Boosting**
- Speeding up with Particle Filtering
- Evaluations and Results
- Conclusion & Outlook

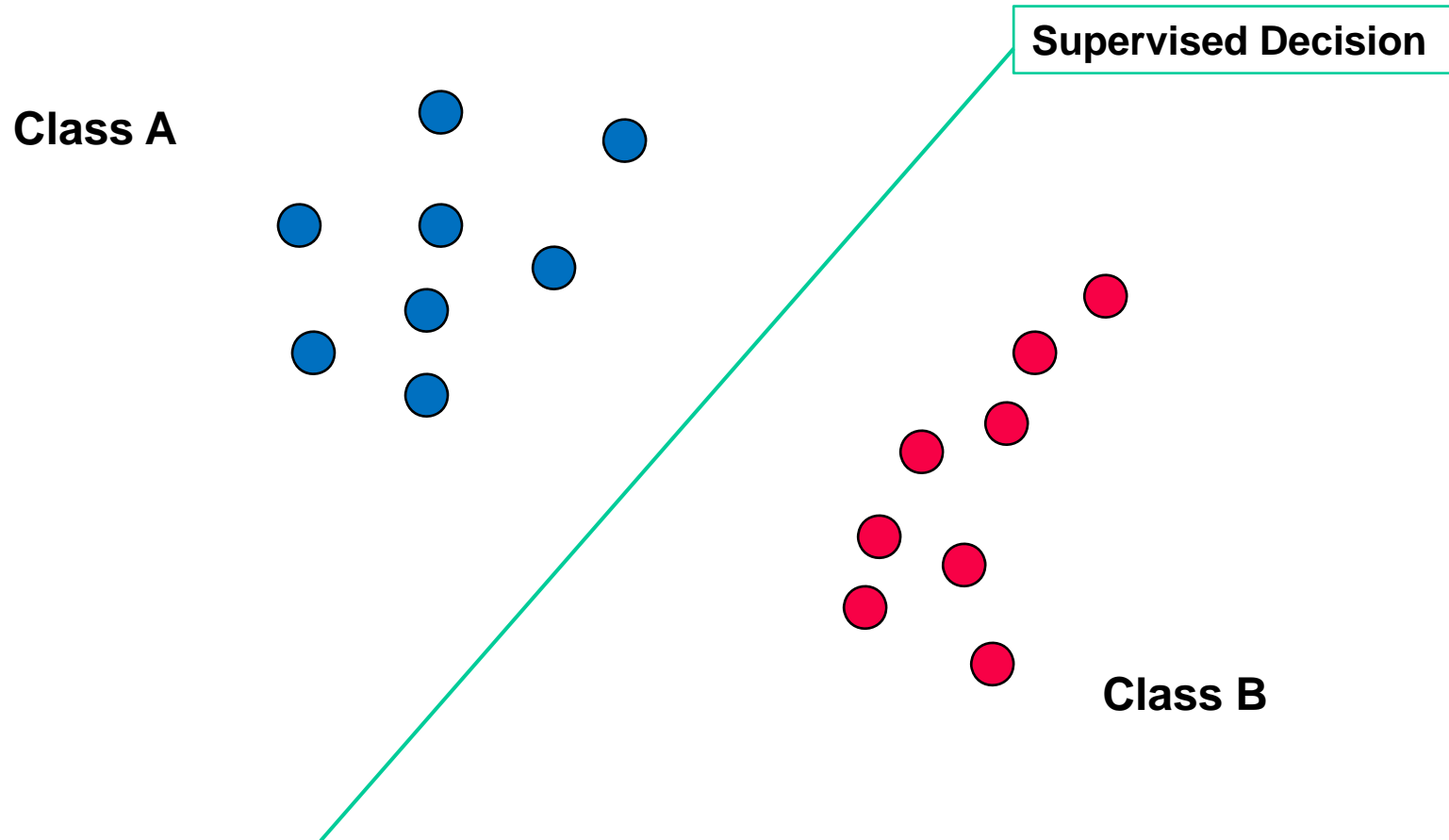


Semi-Supervised Learning



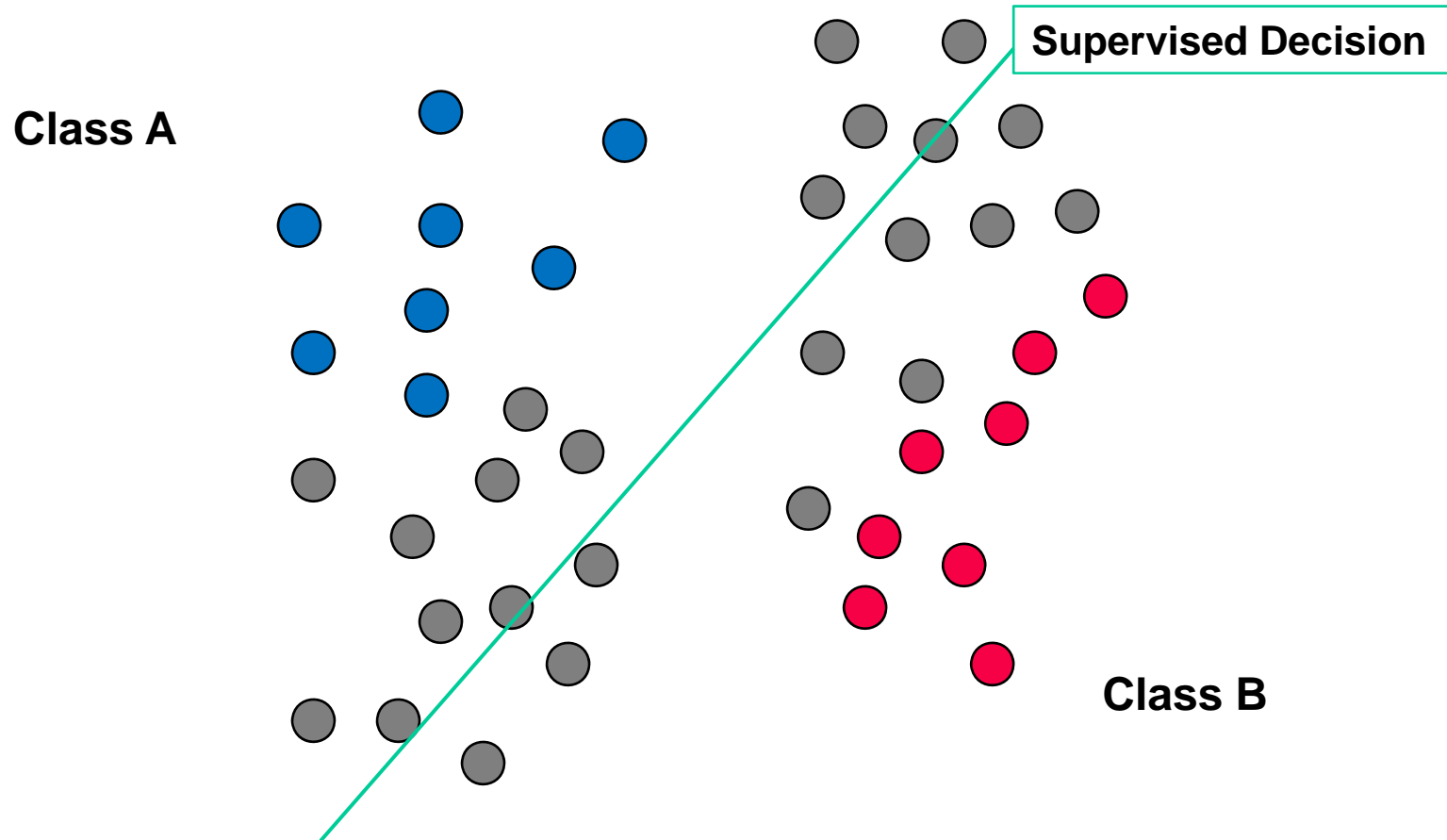


Semi-Supervised Learning



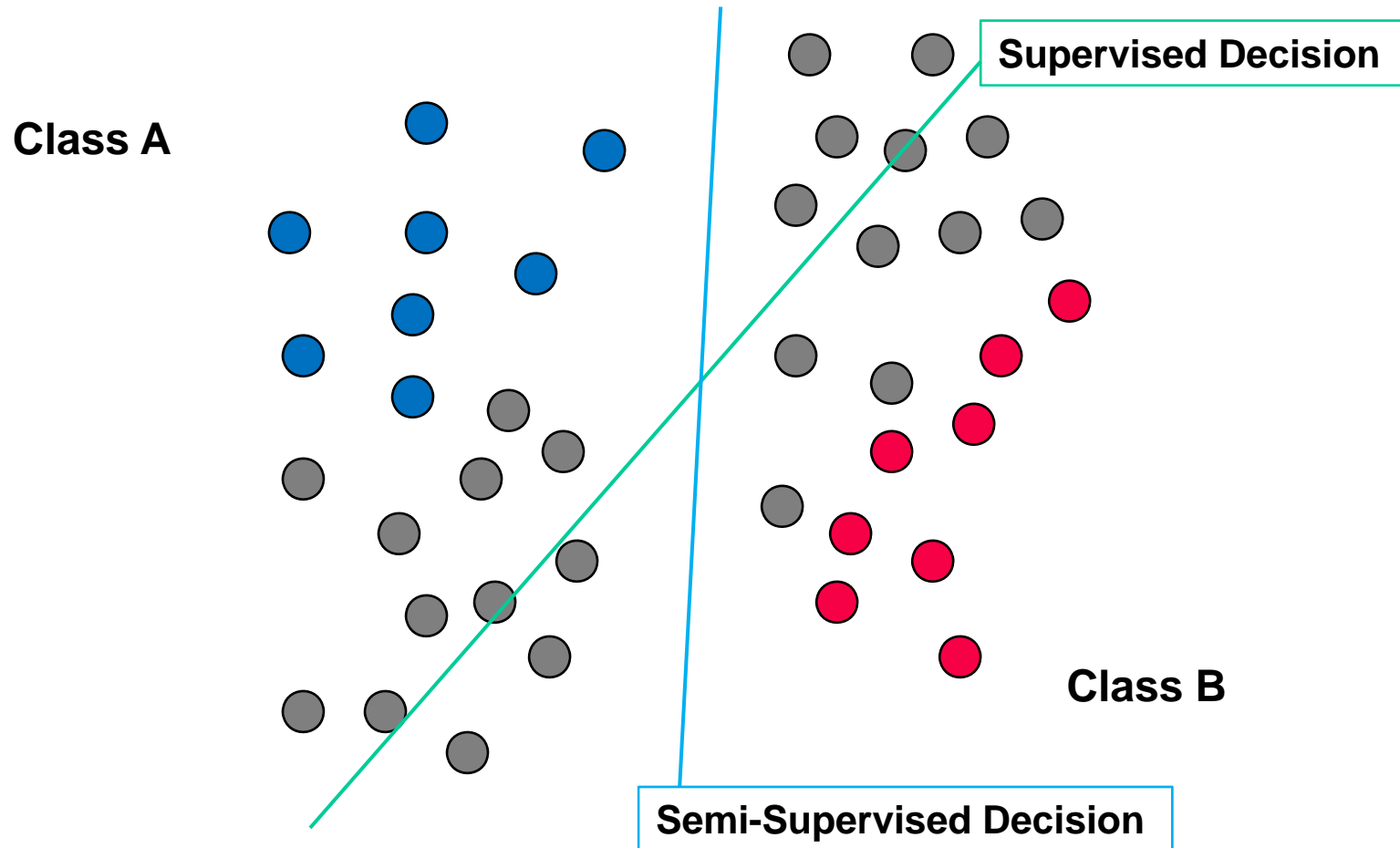


Semi-Supervised Learning





Semi-Supervised Learning





Semi-Supervised Off-line Boosting

- Off-line Boosting incrementally selects the best classifier out of a pool based on a loss function



Semi-Supervised Off-line Boosting

- Off-line Boosting incrementally selects the best classifier out of a pool based on a loss function

Loss for Labeled Data



Semi-Supervised Off-line Boosting

- Off-line Boosting incrementally selects the best classifier out of a pool based on a loss function

Loss for Labeled Data + Loss for Unlabeled Data



Semi-Supervised Off-line Boosting

- Off-line Boosting incrementally selects the best classifier out of a pool based on a loss function

$$h_n = \arg \min_{h_n} \left(\frac{1}{|\mathcal{X}^L|} \sum_{\substack{\mathbf{x} \in \mathcal{X}^L \\ h_n(\mathbf{x}) \neq y}} w_n(\mathbf{x}, y) + \frac{1}{|\mathcal{X}^U|} \sum_{\mathbf{x} \in \mathcal{X}^U} (p_n(\mathbf{x}) - q_n(\mathbf{x})) \alpha_n h_n(\mathbf{x}) \right)$$

Loss for Labeled Data + Loss for Unlabeled Data



Semi-Supervised Off-line Boosting

- Off-line Boosting incrementally selects the best classifier out of a pool based on a loss function

$$h_n = \arg \min_{h_n} \left(\frac{1}{|\mathcal{X}^L|} \sum_{x \in \mathcal{X}^L} w_n(x) \ell(h_n(x), y(x)) + \sum_{x \in \mathcal{X}^U} (p_n(\mathbf{x}) - q_n(\mathbf{x})) \alpha_n h_n(\mathbf{x}) \right)$$

How does this work for On-line Boosting?

Loss for Labeled Data + Loss for Unlabeled Data



Semi-supervised On-line Boosting (SSOB)



Semi-supervised On-line Boosting (SSOB)

Loss for Unlabeled Data



Semi-supervised On-line Boosting (SSOB)

$$p_n(\mathbf{x}) = w_n(\mathbf{x}, 1) \frac{1}{|\mathcal{X}^L|} \sum_{\mathbf{x}_i \in \mathcal{X}^+} S(\mathbf{x}, \mathbf{x}_i) + \frac{1}{|\mathcal{X}^U|} \sum_{\mathbf{x}_i \in \mathcal{X}^U} S(\mathbf{x}, \mathbf{x}_i) e^{H_{n-1}(\mathbf{x}_i) - H_{n-1}(\mathbf{x})}$$

Labeled/Unlabeled Pairs

Unlabeled Pairs



Semi-supervised On-line Boosting (SSOB)

$$p_n(\mathbf{x}) = w_n(\mathbf{x}, 1) \frac{1}{|\mathcal{X}^L|} \sum_{\mathbf{x}_i \in \mathcal{X}^+} S(\mathbf{x}, \mathbf{x}_i) + \frac{1}{|\mathcal{X}^U|} \sum_{\mathbf{x}_i \in \mathcal{X}^U} S(\mathbf{x}, \mathbf{x}_i) - H_{n-1}(\mathbf{x})$$

Labeled/Unlabeled Pairs

Unlabeled Pairs



Semi-supervised On-line Boosting (SSOB)

$$p_n(\mathbf{x}) = w_n(\mathbf{x}, 1) \frac{1}{|\mathcal{X}^L|} \sum_{\mathbf{x}_i \in \mathcal{X}^+} S(\mathbf{x}, \mathbf{x}_i) + \frac{1}{|\mathcal{X}^U|} \sum_{\mathbf{x}_i \in \mathcal{X}^U} S(\mathbf{x}, \mathbf{x}_i) - H_{n-1}(\mathbf{x})$$

Labeled/Unlabeled Pairs
Unlabeled Pairs

$$\tilde{p}_n(\mathbf{x}) \approx e^{-2H_{n-1}(\mathbf{x})} \sum_{\mathbf{x}_i \in \mathcal{X}^+} S(\mathbf{x}, \mathbf{x}_i)$$

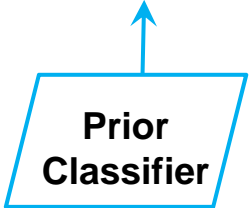


Semi-supervised On-line Boosting (SSOB)

$$p_n(\mathbf{x}) = w_n(\mathbf{x}, 1) \frac{1}{|\mathcal{X}^L|} \sum_{\mathbf{x}_i \in \mathcal{X}^+} S(\mathbf{x}, \mathbf{x}_i) + \frac{1}{|\mathcal{X}^U|} \sum_{\mathbf{x}_i \in \mathcal{X}^U} S(\mathbf{x}, \mathbf{x}_i) e^{-H_{n-1}(\mathbf{x}_i) - H_{n-1}(\mathbf{x})}$$

Labeled/Unlabeled Pairs
Unlabeled Pairs

$$\tilde{p}_n(\mathbf{x}) \approx e^{-2H_{n-1}(\mathbf{x})} \sum_{\mathbf{x}_i \in \mathcal{X}^+} S(\mathbf{x}, \mathbf{x}_i) \approx e^{-H_{n-1}(\mathbf{x})} H^+(\mathbf{x}) \approx \frac{e^{-H_{n-1}(\mathbf{x})} e^{H^P(\mathbf{x})}}{e^{H^P(\mathbf{x})} + e^{-H^P(\mathbf{x})}}$$



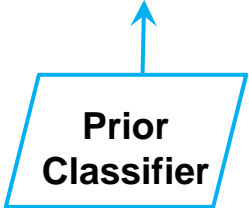


Semi-supervised On-line Boosting (SSOB)

$$p_n(\mathbf{x}) = w_n(\mathbf{x}, 1) \frac{1}{|\mathcal{X}^L|} \sum_{\mathbf{x}_i \in \mathcal{X}^+} S(\mathbf{x}, \mathbf{x}_i) + \frac{1}{|\mathcal{X}^U|} \sum_{\mathbf{x}_i \in \mathcal{X}^U} S(\mathbf{x}, \mathbf{x}_i) - H_{n-1}(\mathbf{x})$$

Labeled/Unlabeled Pairs
Unlabeled Pairs

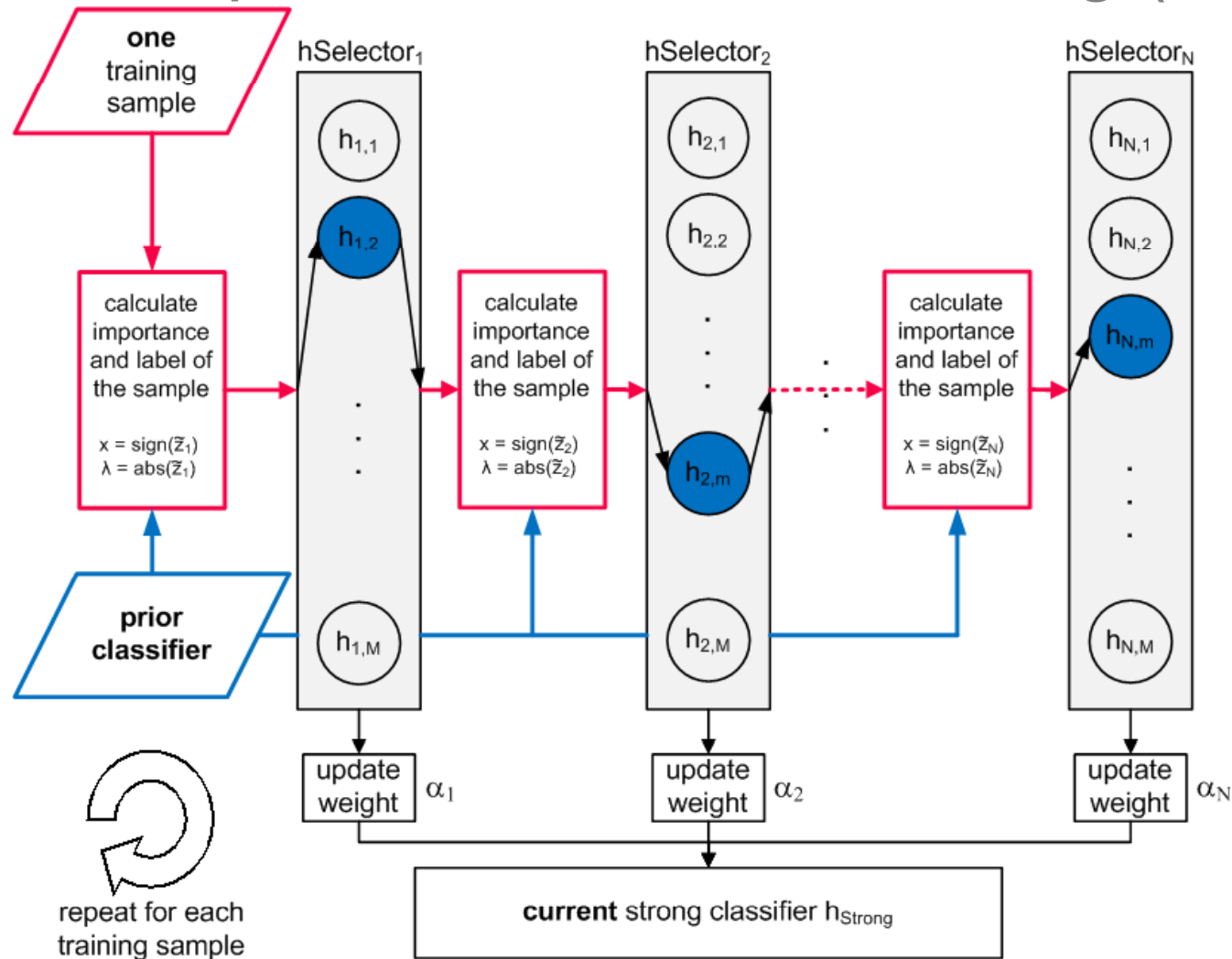
$$\tilde{p}_n(\mathbf{x}) \approx e^{-2H_{n-1}(\mathbf{x})} \sum_{\mathbf{x}_i \in \mathcal{X}^+} S(\mathbf{x}, \mathbf{x}_i) \approx e^{-H_{n-1}(\mathbf{x})} H^+(\mathbf{x}) \approx \frac{e^{-H_{n-1}(\mathbf{x})} e^{H^P(\mathbf{x})}}{e^{H^P(\mathbf{x})} + e^{-H^P(\mathbf{x})}}$$



$$\tilde{z}_n(\mathbf{x}) = \tilde{p}_n(\mathbf{x}) - \tilde{q}_n(\mathbf{x}) = \tanh(H^P(\mathbf{x})) - \tanh(H_{n-1}(\mathbf{x}))$$



Semi-supervised On-line Boosting (SSOB)







Open Issues?

- Speed
 - We have to evaluate two classifiers during update
 - What are the most time-consuming
- Prior Classifier
 - Can we create a strong classifier with only one sample?
- Update Strategies
 - Which patches should be presented to the classifier?

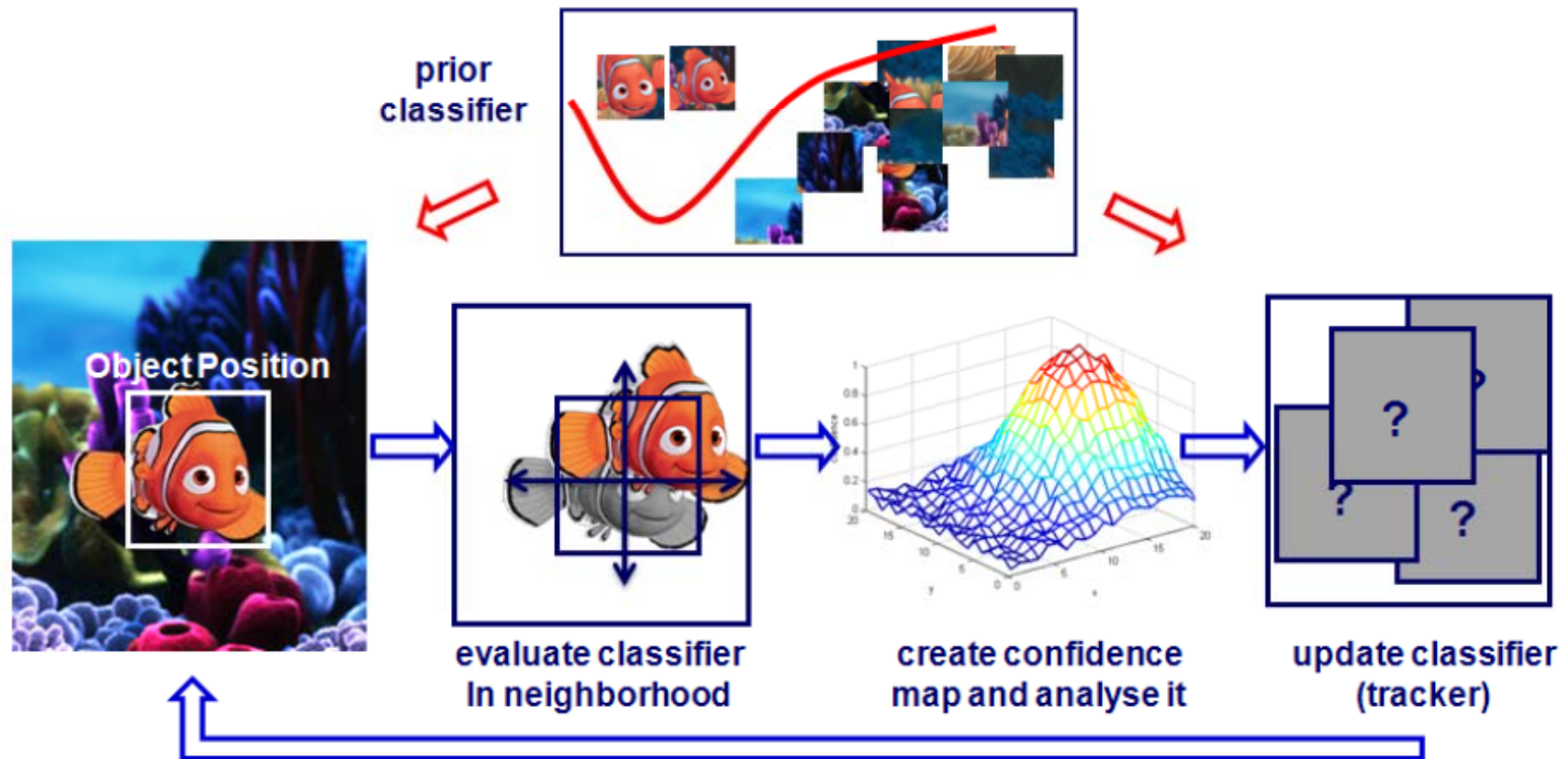


Outline

- Motivation
- Review of Semi-Supervised On-line Boosting
- **Speeding up with Particle Filtering**
- Evaluations and Results
- Conclusion & Outlook

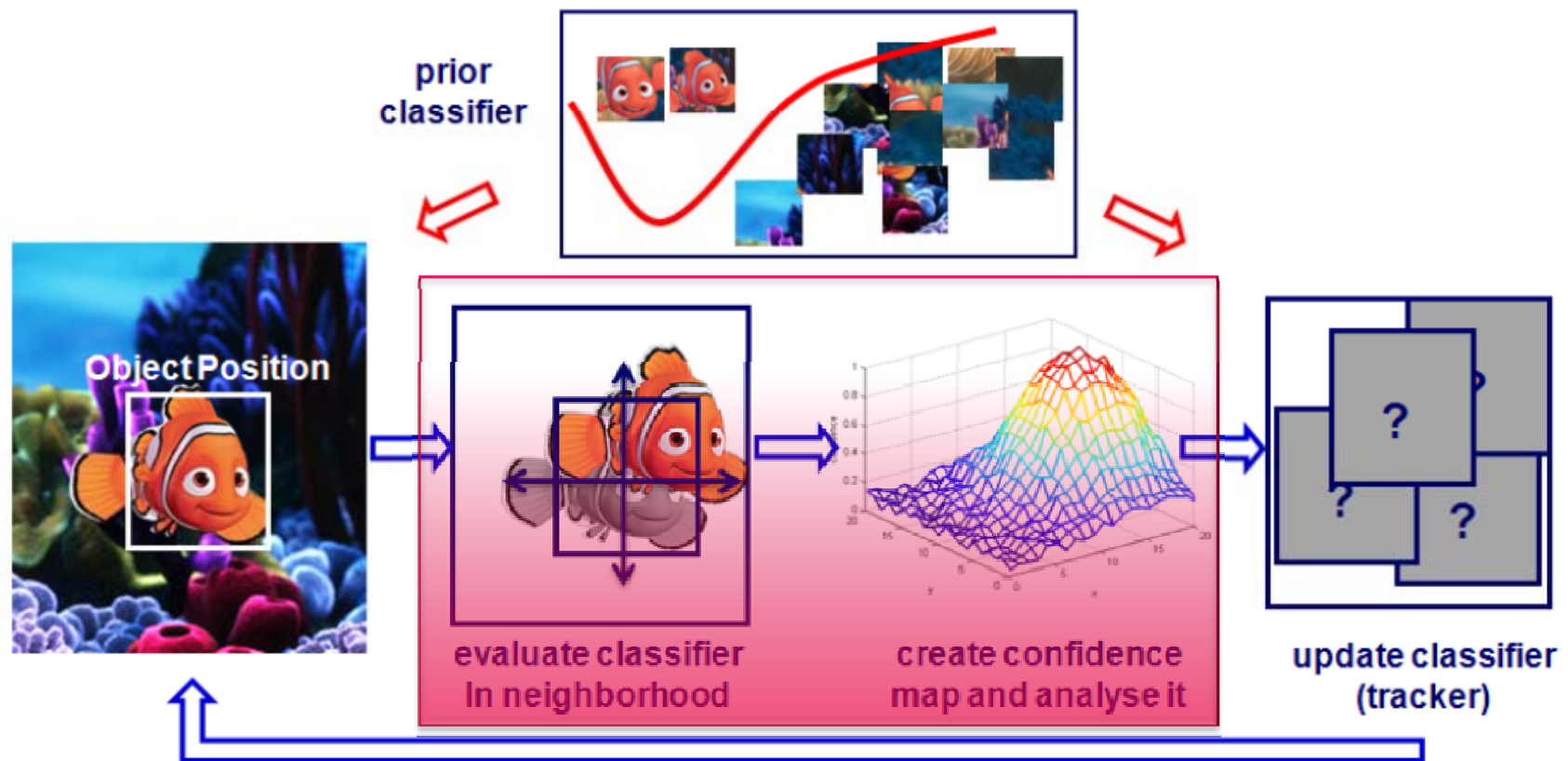


Tracking Loop





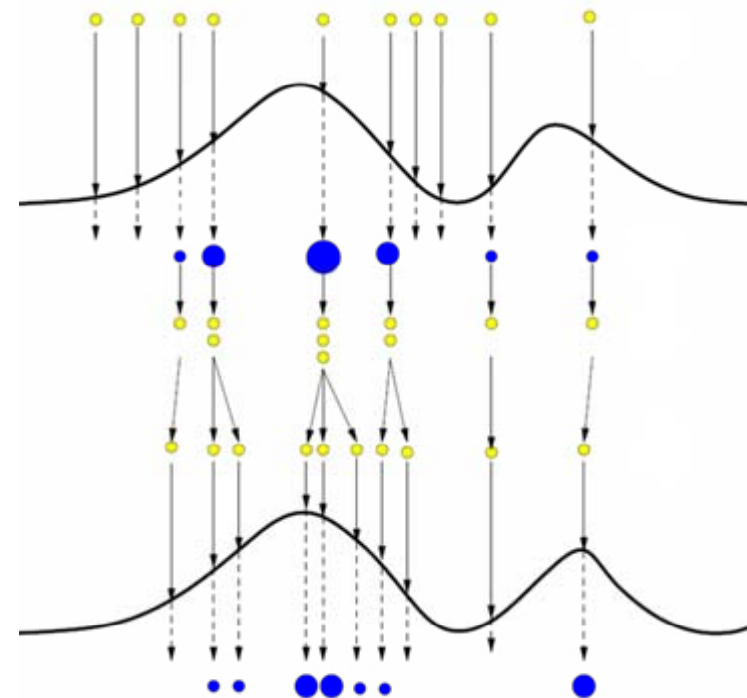
Tracking Loop





Particle Filtering

- Estimate State of a System
 - N_p Particles spread over state space
 - Weighting of Particles by Evaluating their State Estimate
 - Also for non-Gaussian Processes



taken from <http://ia.deis.unibo.it/>



Regular Sampling (23fps)



Particle-Filtering (55fps)

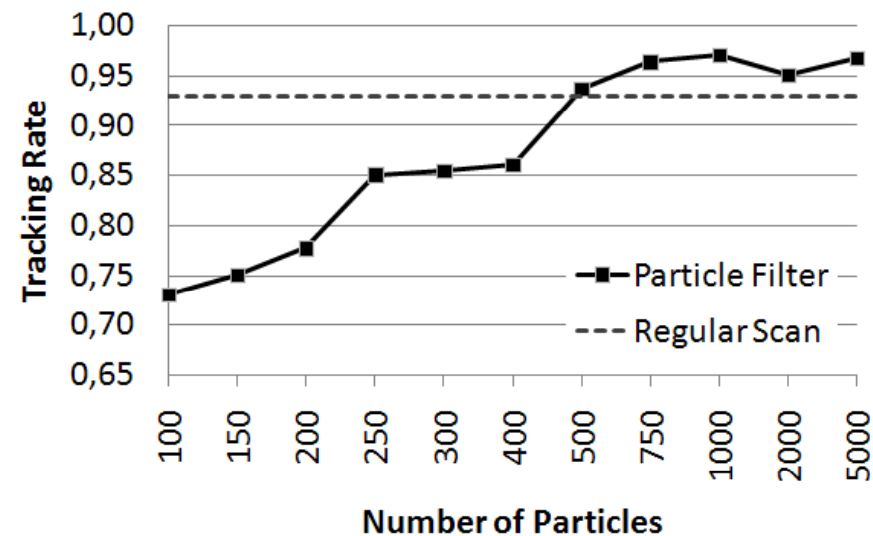
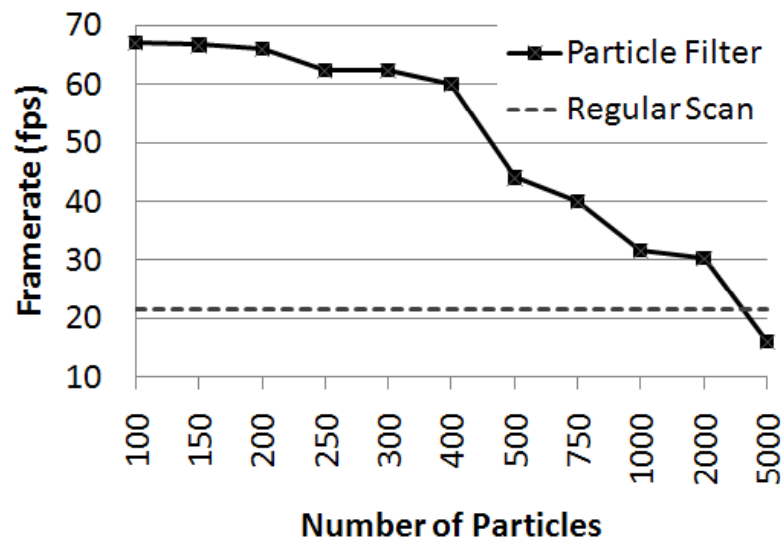


Outline

- Motivation
- Review of Semi-Supervised On-line Boosting
- Speeding up with Particle Filtering
- **Evaluations and Results**
- Conclusion & Outlook



Speedup using Particle Filtering

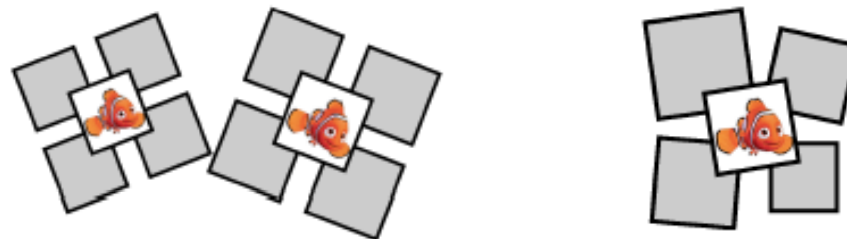


- Reduced evaluations per frame by 90% without decreased Performance



One-Shot Training

- One-shot Training
 - Create virtual examples
 - Simulate natural object behaviour
 - Extend the training set

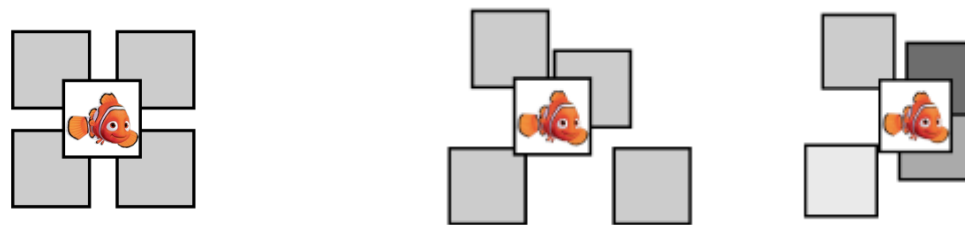


| | Simple | Scale | Rotation | Rot. & Scale | Random |
|---------------|--------|-------|----------|--------------|--------|
| Tracking Rate | 0.96 | 0.98 | 0.87 | 0.98 | 0.92 |
| Precision | 0.96 | 0.98 | 0.88 | 0.99 | 0.93 |



Update Patch Selection

- Update Strategies
 - Which samples should be presented to the learner?
 - Different Schemes have been evaluated



| | Simple | Geometric | Random | Distance | Confidence |
|---------------|--------|-----------|--------|----------|------------|
| Tracking Rate | 0.96 | 0.98 | 0.87 | 0.98 | 0.92 |
| Precision | 0.96 | 0.98 | 0.88 | 0.99 | 0.93 |



Influence of Label Noise

- Influence of Label Noise
 - Manually misaligned update patches
 - Semi-Supervised Learning Algorithm is more robust than supervised one





Outline

- Motivation
- Review of Semi-Supervised On-line Boosting
- Speeding up with Particle Filtering
- Evaluations and Results
- **Conclusion & Outlook**



Conclusion

- Review and Evaluation of SSOB for Tracking
 - Limited Adaptivity
 - Limited Drifting
- Particle Filtering for Speedup
 - „Smarter“ Search-Space Sampling
 - Motion Information
- Initialization and Updates
 - Using virtual Samples
 - Evaluation of different schemes



Outlook

- Representation
 - Feature types
- Search-Space Sampling
 - DOF (Rotation, Scaling, Affine,...)
 - Refinement and Optimizations
- Learning Algorithm
 - Robust to Noise
 - Logit-Boost
 - Random Forests



Thank you for your attention!

QUESTIONS?