VOT
visual object tracking

The Visual Object Tracking VOT2016: Challenge and results

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Outline

1. Scope of the VOT challenge
2. VOT2016 challenge overview
   - Evaluation system
   - Dataset
   - Performance evaluation measures
3. VOT2016 results overview
4. Summary and outlook

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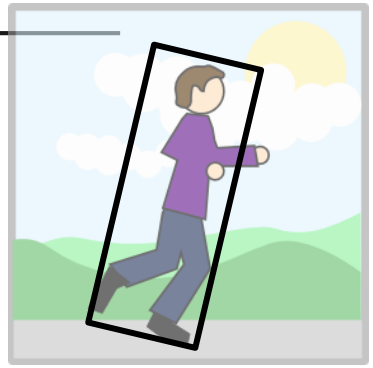
SCOPE OF THE VOT2016 CHALLENGE

Selected class of trackers



- *Single-object, single-camera, model-free, short-term, causal trackers*
- Model-free:
  - Nothing but a single training example is provided by the BBox in the first frame
- Short-term:
  - Tracker does not perform re-detection
  - Once it drifts off the target we consider that a failure
- Causality:
  - Tracker does not use any future frames for pose estimation
- Object state defined as a rotated bounding box (rectangle)

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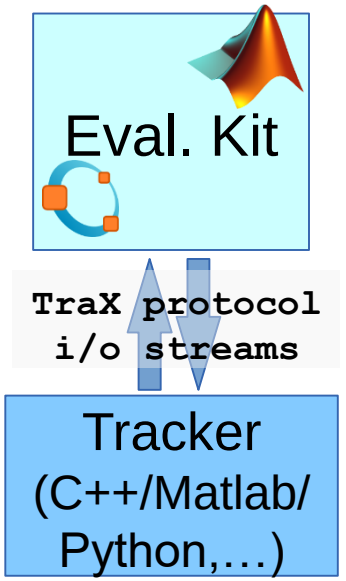
VOT2016 EVALUATION SYSTEM

VOT2016 Challenge evaluation kit

- Matlab-based kit to automatically perform a battery of standard experiments
- Plug and play!
  - Supports multiple platforms and programming languages (C/C++/Matlab/Python, etc.)



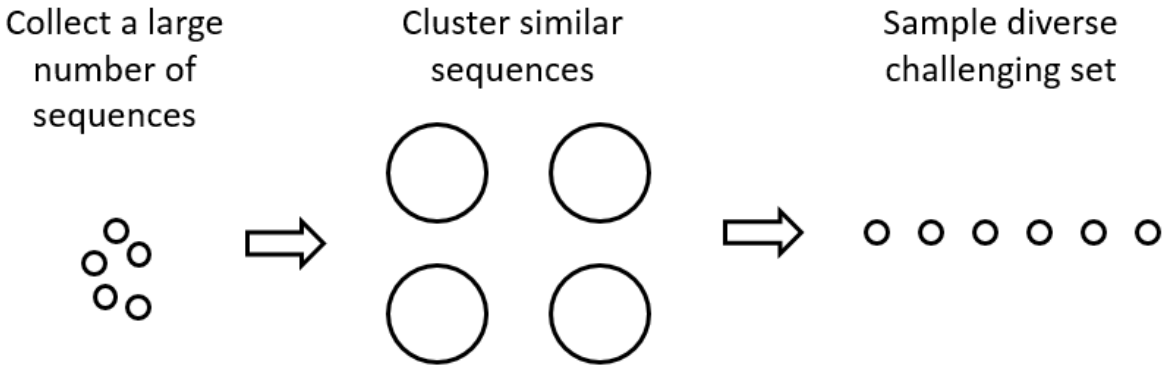
- Easy to evaluate your tracker on all our benchmarks
- Backward compatibility with VOT2013/VOT2014/VOT2015

- Download from our homepage
  https://github.com/vicoslab/vot-toolkit

VOT2016 DATASET

Dataset construction approach

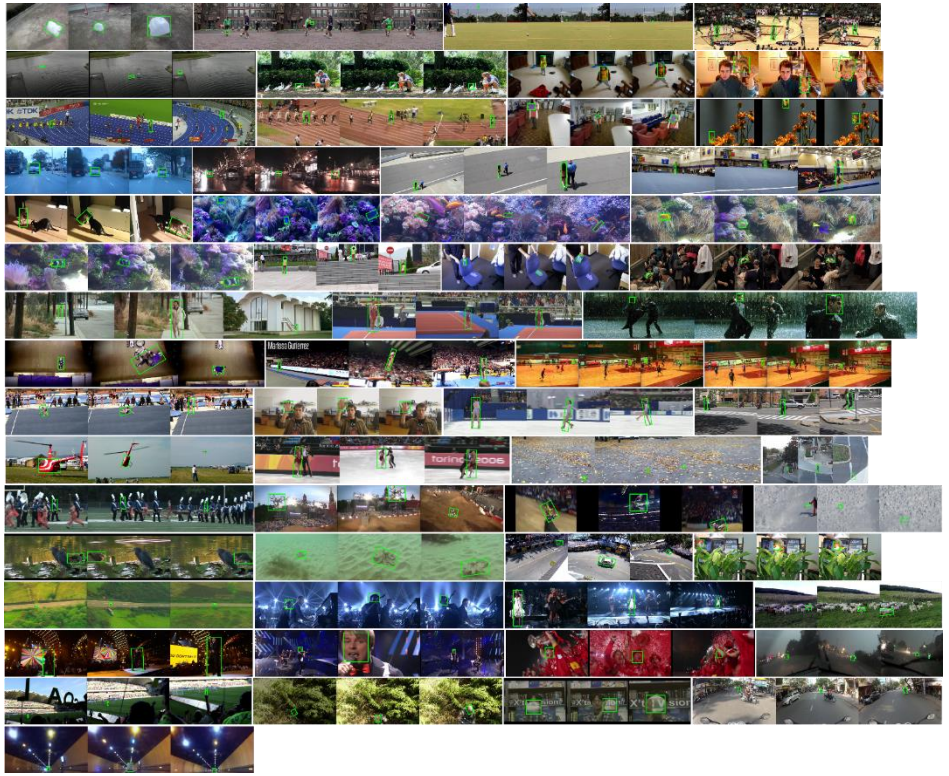
- Current trend [Wu et al. CVPR2013, Smeulders et al. PAMI2013, Wang et al. arXiv2015, Wu et al. PAMI2015]:
  - Large datasets by collecting many sequences from internet
  - Large dataset ≠ diverse or useful
- VOT2013/2014/2015 approach:
  - Keep it sufficiently small, well annotated and diverse
  - Developed the VOT dataset construction methodology



The VOT2016 dataset

- The performance on VOT2015 dataset did not saturate in 2015 challenge
- Kept all 60 sequences from VOT2015 challenge
- NEW:

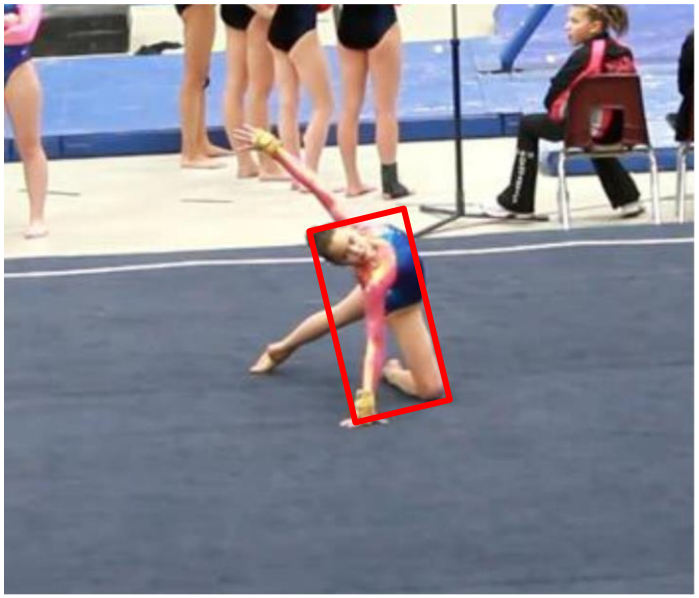
  Objects re-annotated!

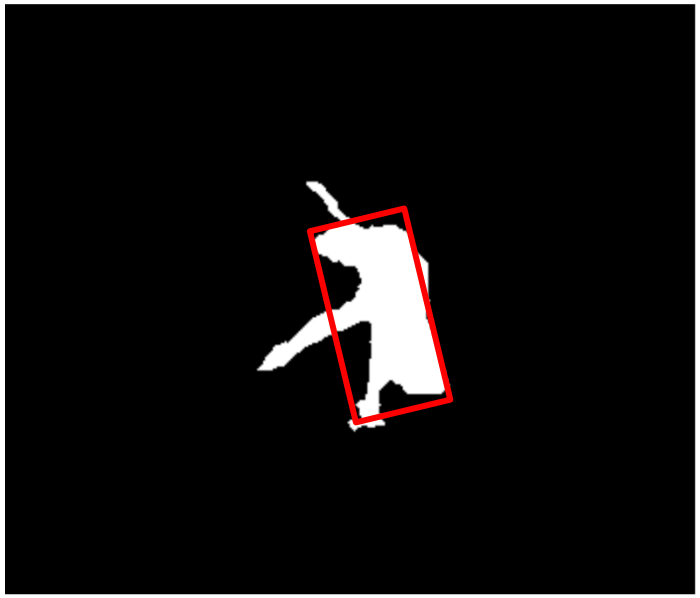


Object annotation

Automatic bounding box placement

1. Segment the target (semi-automatic)
2. Automatically fit a bounding box by optimizing a cost function

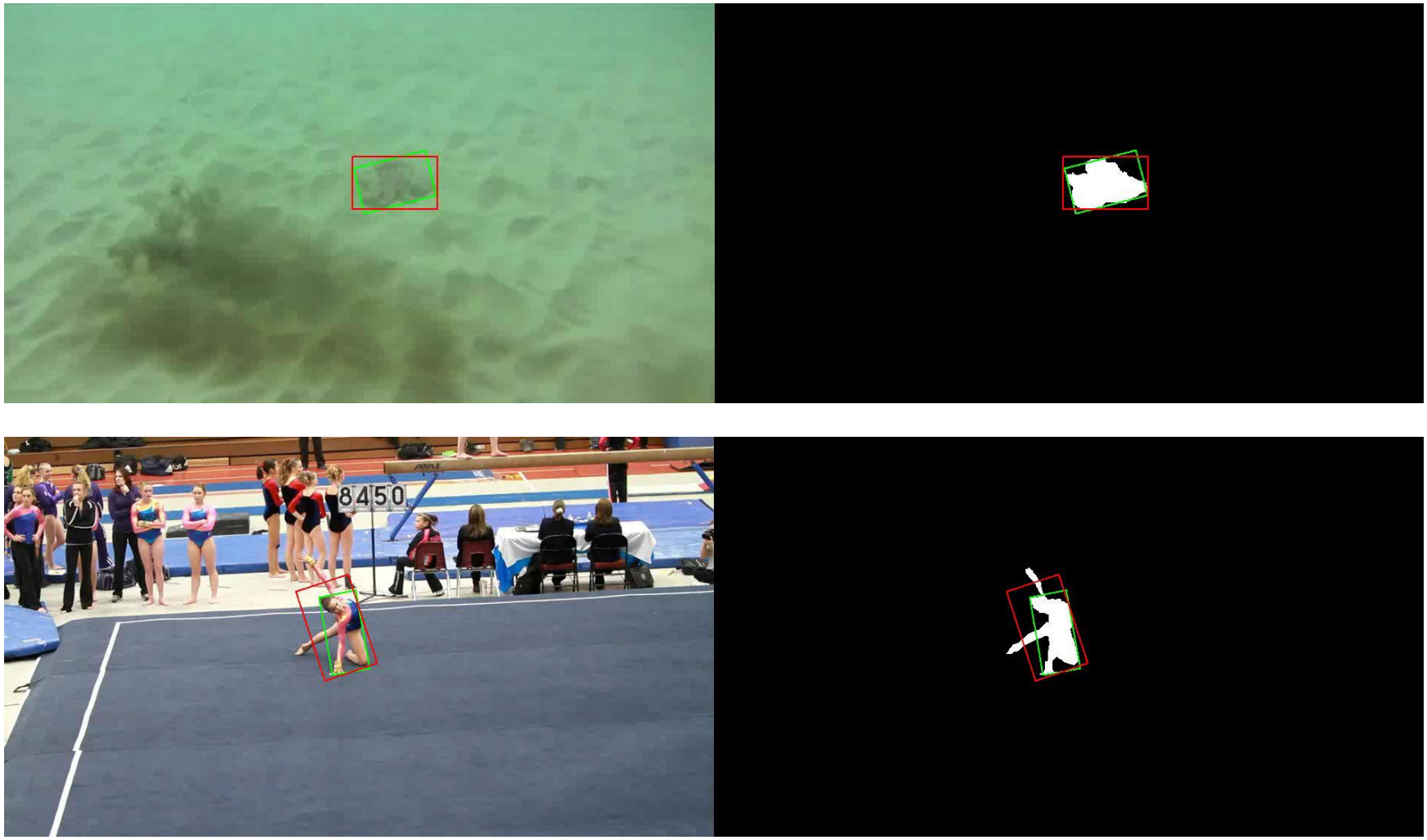




- Visual verification of the results
  - 12% reverted to the VOT2015 annotation

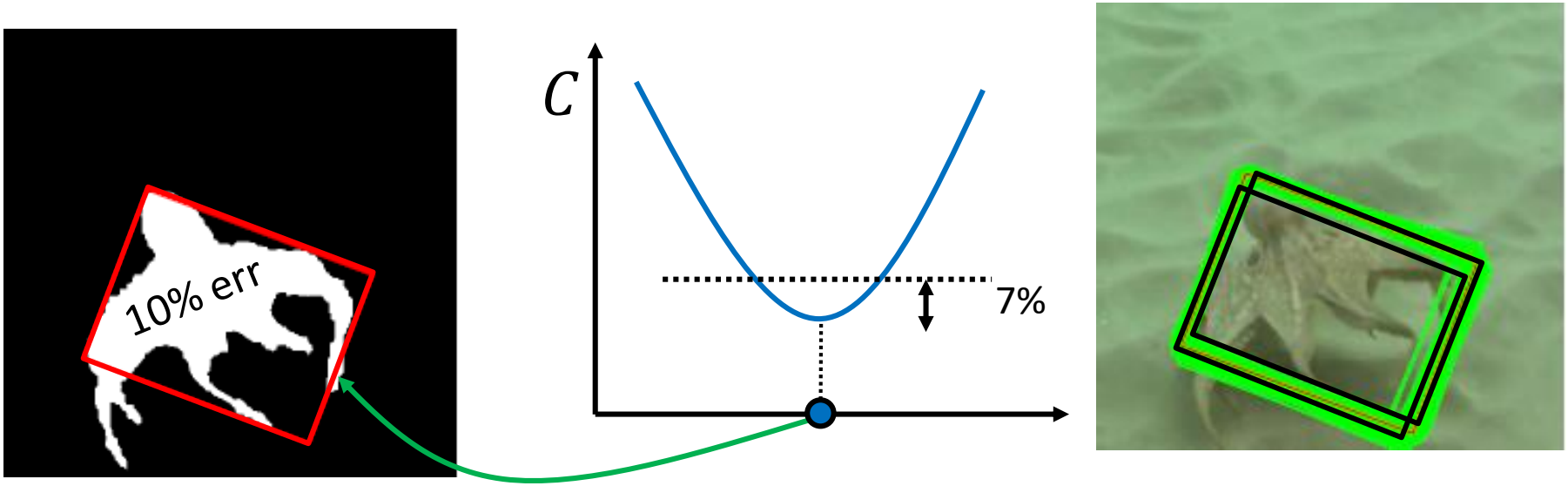
VOT2016 dataset – object annotation

- Average overlap between VOT2015 and VOT2016 BB: 0.74



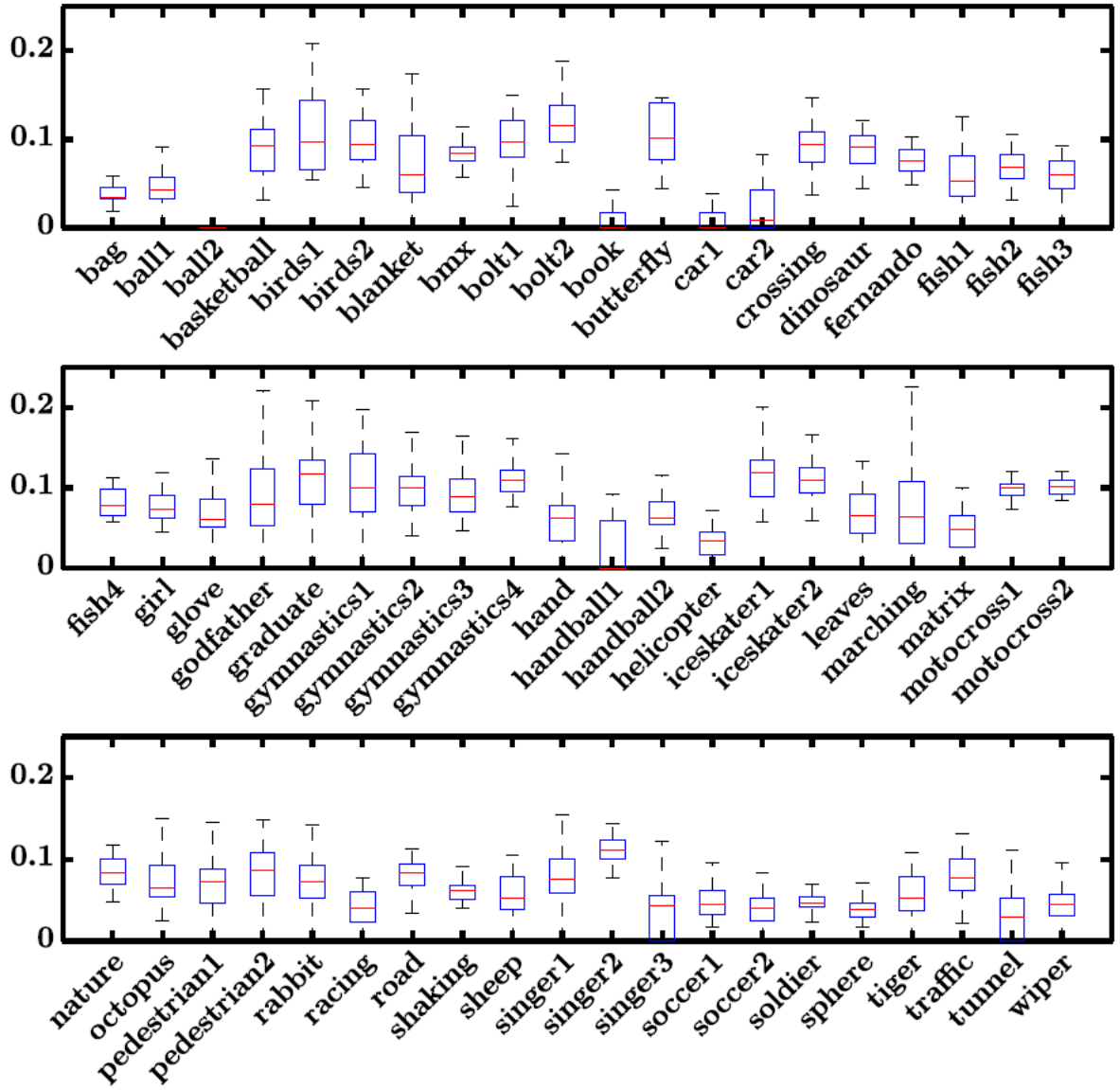
Annotation uncertainty

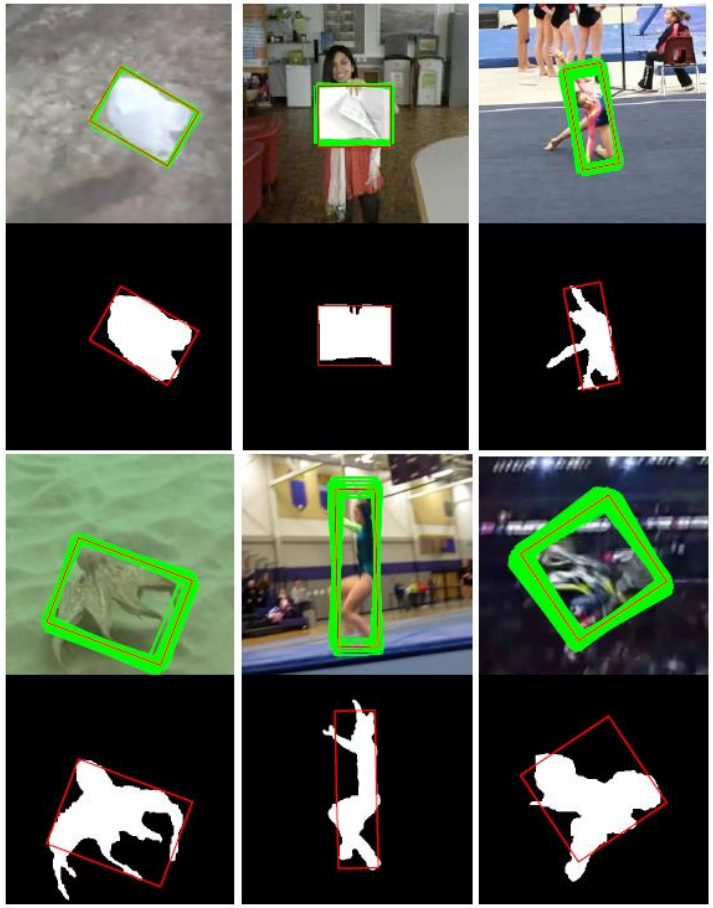
- Segmentation uncertainty results in bounding box uncertainty



- Uncertainty: Average of overlaps between optimal bounding box and those within 7% C increase.

Practical differences





Reduced by half compared to VOT2015

VOT2016 dataset – frame annotation

- Manually and automatically labeled each frame with VOT2013 visual attributes (same as VOT2015):
  - i. Occlusion (M)
  - ii. Illumination change (M)
  - iii. Object motion (A)
  - iv. Object size change (A)
  - v. Camera motion (M)
  - vi. Unassigned (A)

M ... manual annotation, A ... automatic annotation

(i)	0	1	1	0
(ii)	0	0	0	0
(iii)	0	0	0	0
(iv)	1	1	1	0
(v)	0	0	0	0
(vi)	0	0	0	1

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EVALUATION METHODOLOGY

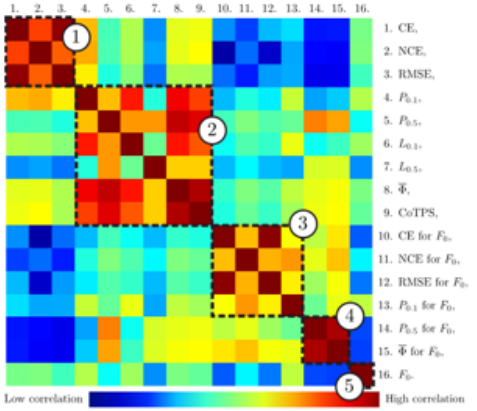
Performance measures

- Target localization properties measured using the VOT2013/VOT2014/VOT2015 methodology.

- Approach in VOT2013/VOT2014:
  - Interpretability of performance measures
  - Select as few as possible to provide clear comparison

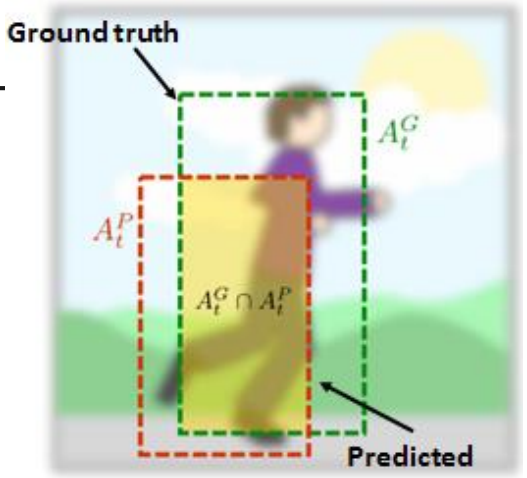
- Based on a recent study[1] two basic weakly-correlated measures are chosen:
  - Robustness
  - Accuracy

Correlation analysis of performance measures[1]



[1]Čehovin, Leonardis, Kristan. *Visual object tracking performance measures revisited*, IEEETIP 2016

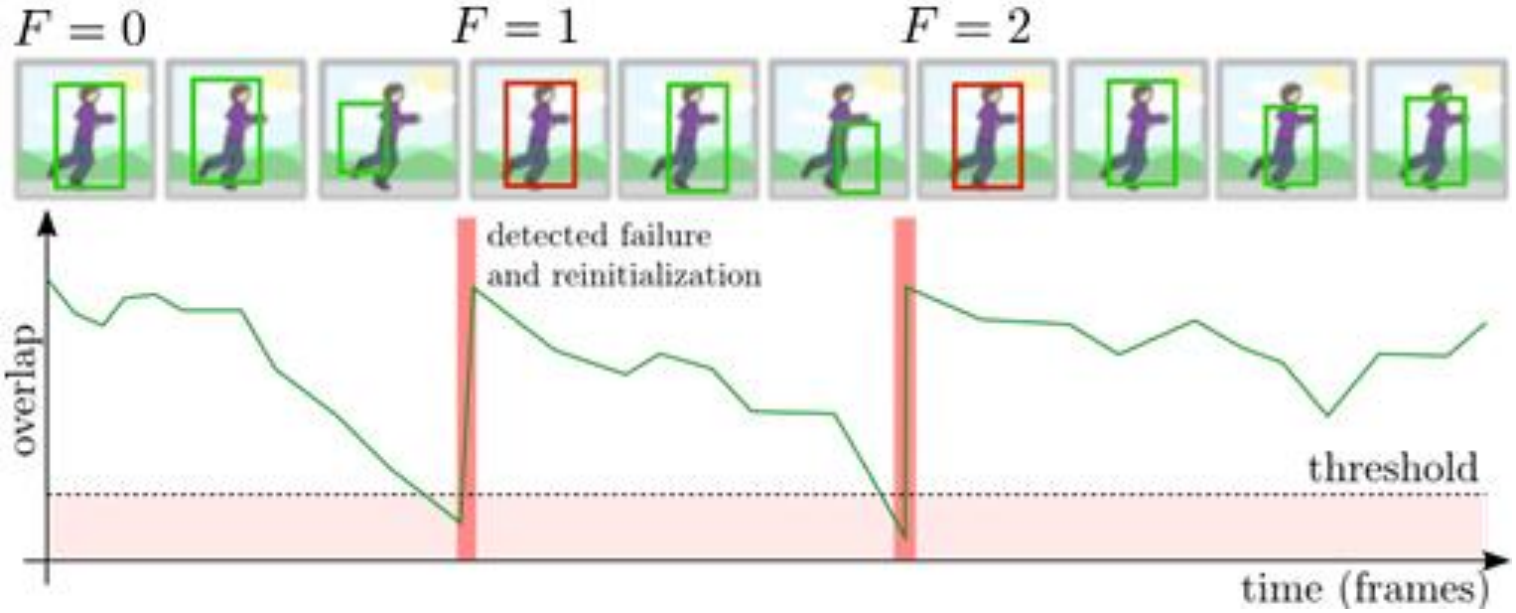
VOT performance measures



- Robustness:

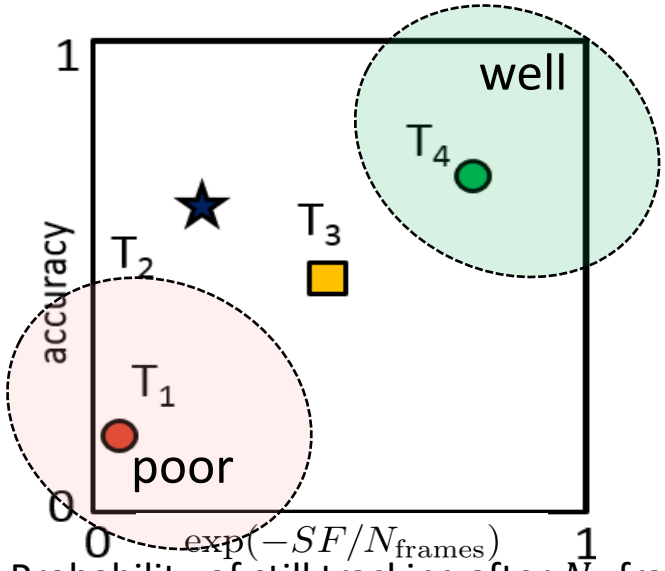
  Number of times a tracker drifts off the target.

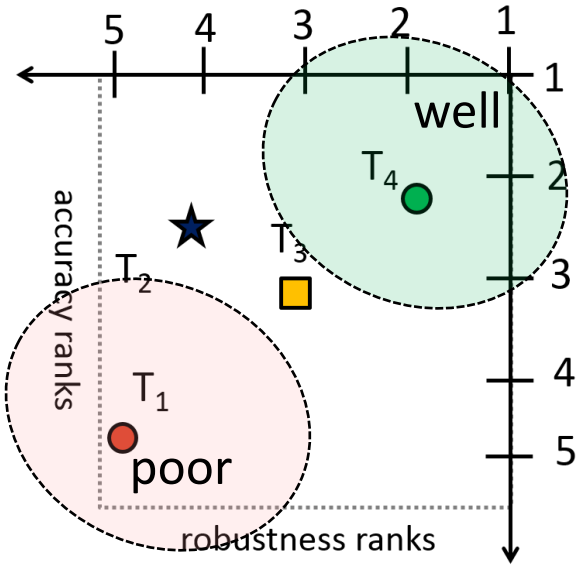
- Accuracy: *Average overlap during successful tracking.*



VOT performance evaluation

- Ranking methodology w.r.t. Accuracy and Robustness
- Assign equal rank to “equally” performing trackers:
  - Statistical significance of results and practical difference

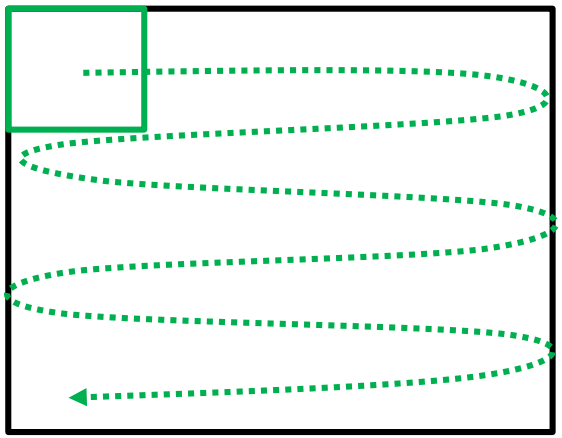




- A principled way to merge Accuracy and Robustness:
  - Expected average overlap (EAO)

VOT2016 Speed measurement

- Reduce the hardware bias in reporting tracking speed.
- Approach: The VOT2014 speed benchmark



600x600 image
Max operation in 30x30 window
Apply this filter to all pixels
Measure the time for filtering

- Divide tracking time with time required to perform the filtering operation
- Equivalent Filter Operations (EFO)

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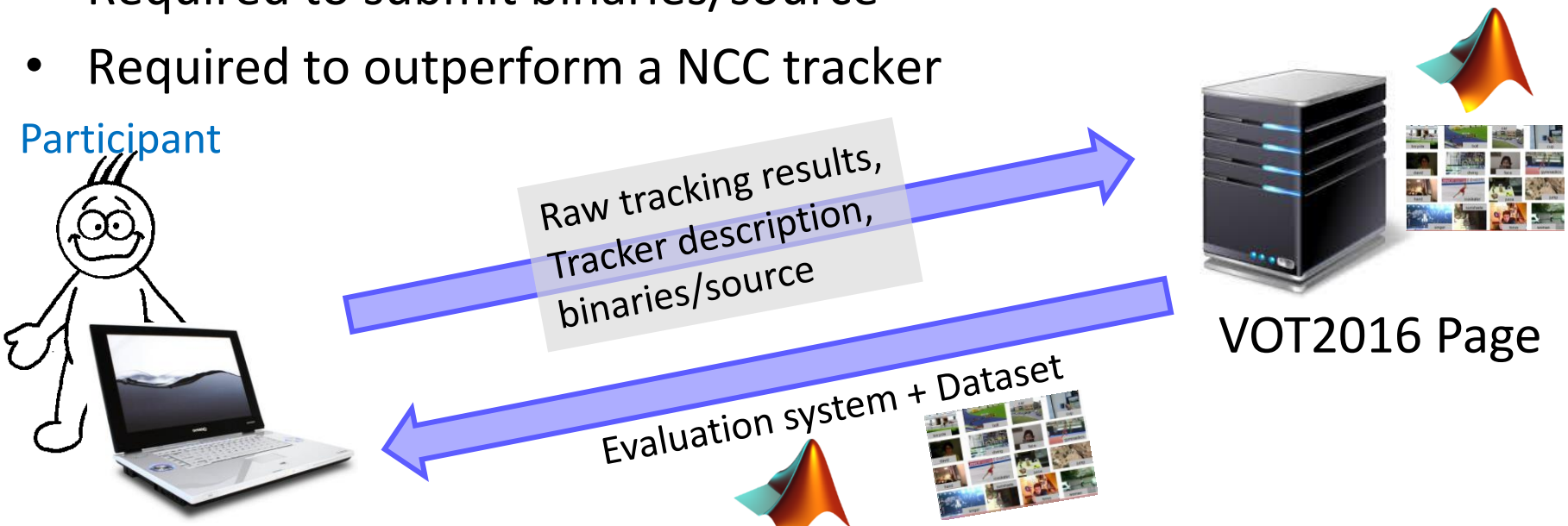
CHALLENGE PARTICIPATION AND SUBMITTED TRACKERS

VOT2016 Challenge: participation

- Participants would download the evaluation kit:
  - Evaluation system + Dataset
- Integrate their tracker into the evaluation system
- Predefined set of experiments automatically performed – submit the results back
- Required to submit binaries/source
- Required to outperform a NCC tracker



70 trackers tested!

Diverse set of entries: 70 = 48 submissions + 22 existing

- Deep convolutional neural networks
  (MLDF, SiamFC-R, SiamFC-A, TCNN, DNT, SO-DLT, MDNet-N, SSAT)
- Correlation filters
  (SRDCF, SWCF, FCF, GCF, ART-DSST, DSST2014, SMACF, STC, DFCT, KCF2014, SAMF2014, OEST, sKCF, Staple, Staple+, MvCFT, NSAMF, SSKCF, ACT, ColorKCF, deepMKCF, HCF, DDC, DeepSRDCF, C-COT, RFD-CF2, NCC)
- Discriminative models – single part
  (MIL, Struck2011, EBT, TGPR)
- Global generative-model-based
  (DAT, SRBT, ASMS, LoFT-Lite, IVT, CCCT, DFT)
- Part-based trackers
  (LT-FLO, SHCT, GGTv2, MatFlow, Matrioska, CDTT, BST, TRIC-track, DPT, SMPR, CMT, HT, LGT, ANT, FoT, FCT, FT, BDF)
- Combinations of multiple trackers
  (PKLTF, MAD, CTF, SCT, HMMTxD)

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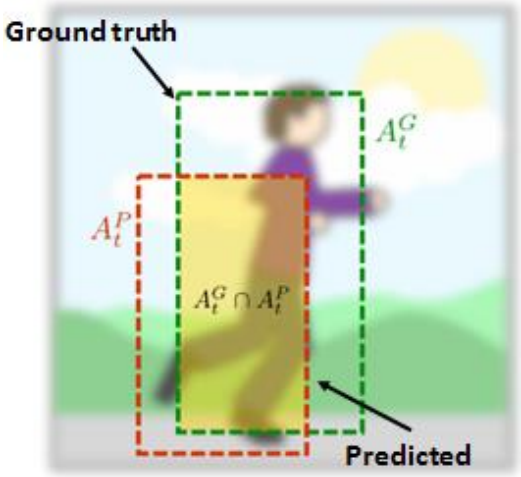
EXPERIMENTS AND RESULTS

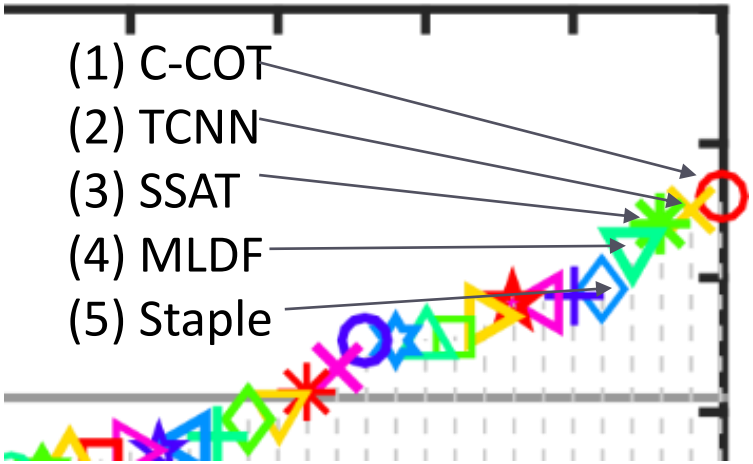
VOT2016 Experiment

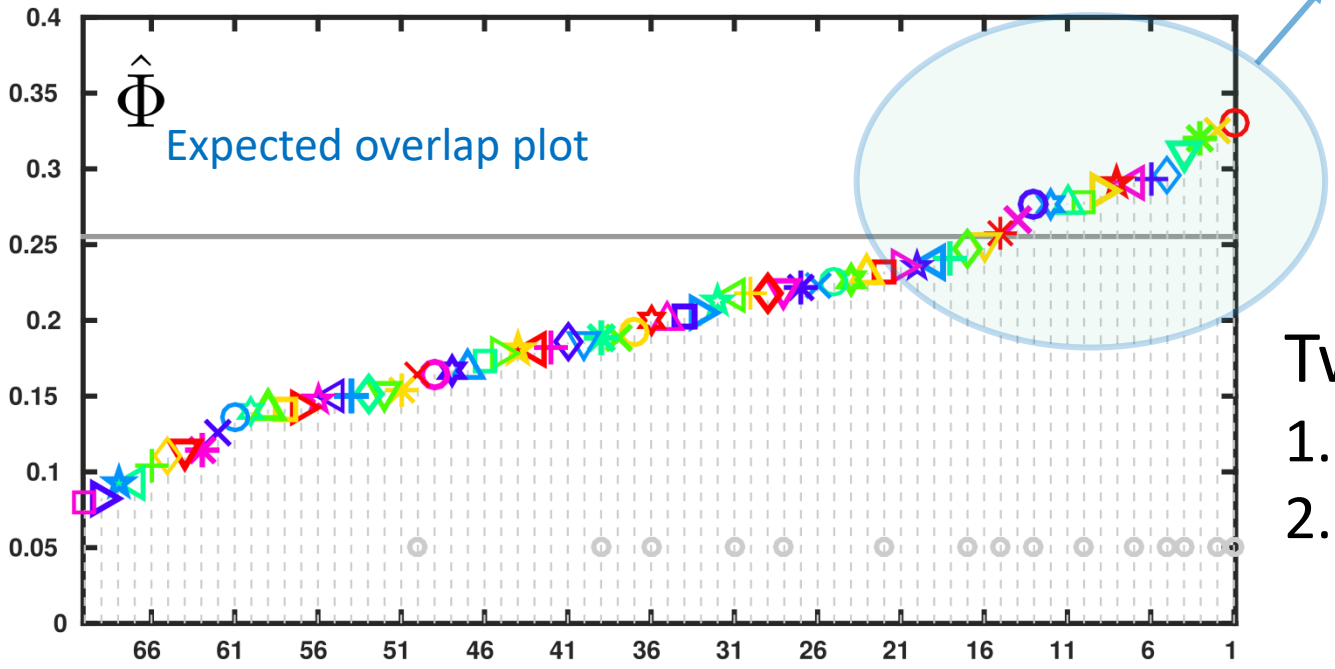
- Initialization on ground truth BBs
- Each tracker run 15 times on each sequence to obtain a better statistic on its performance.
- Reinitialization at overlap 0.



Expected average overlap

Tracker	Type
C-COT	Corr. Filter + CNN feats
TCNN	Multiple parallel CNNs
SSAT	CNN (extension of VOT2015 winner).
MLDF	CNN for position + CNN for scale



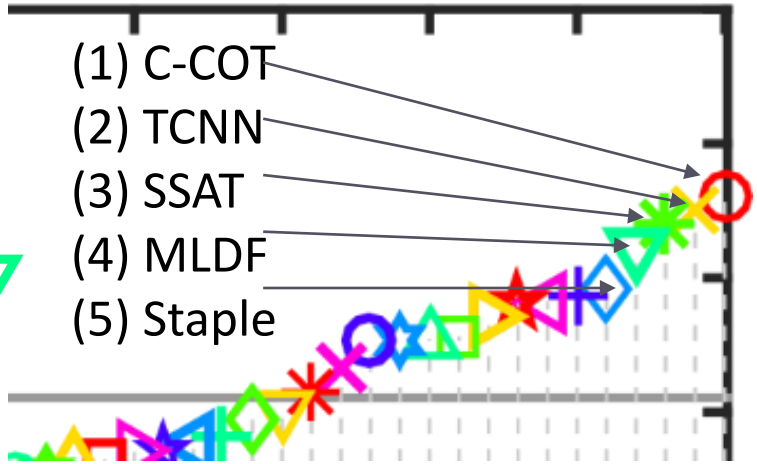


Two classes:

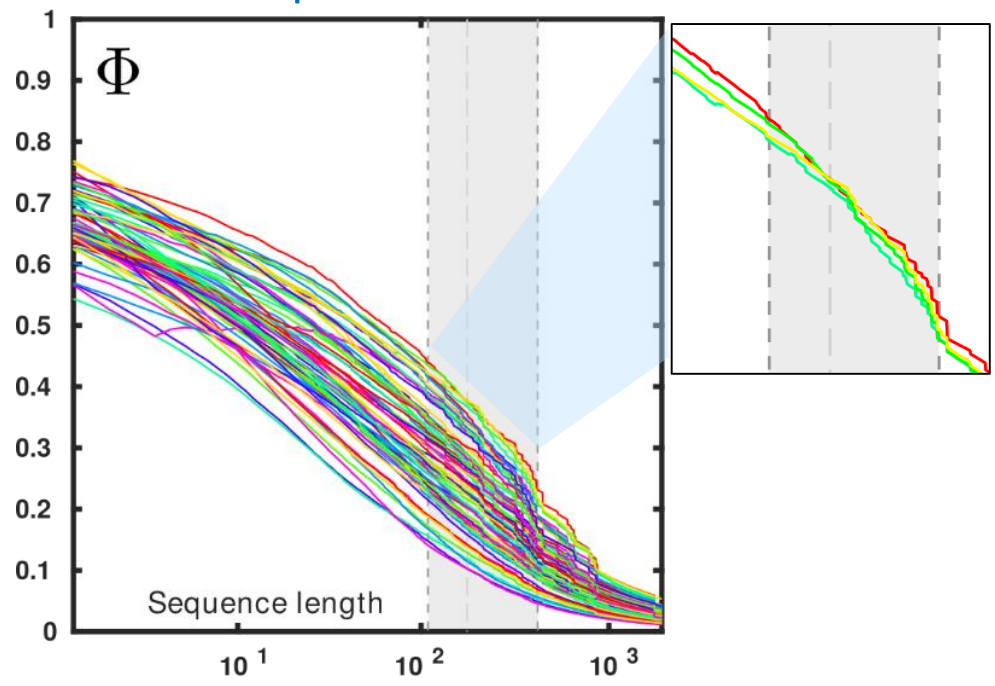
1. CNN-based
2. Correlation filters

Detailed analysis

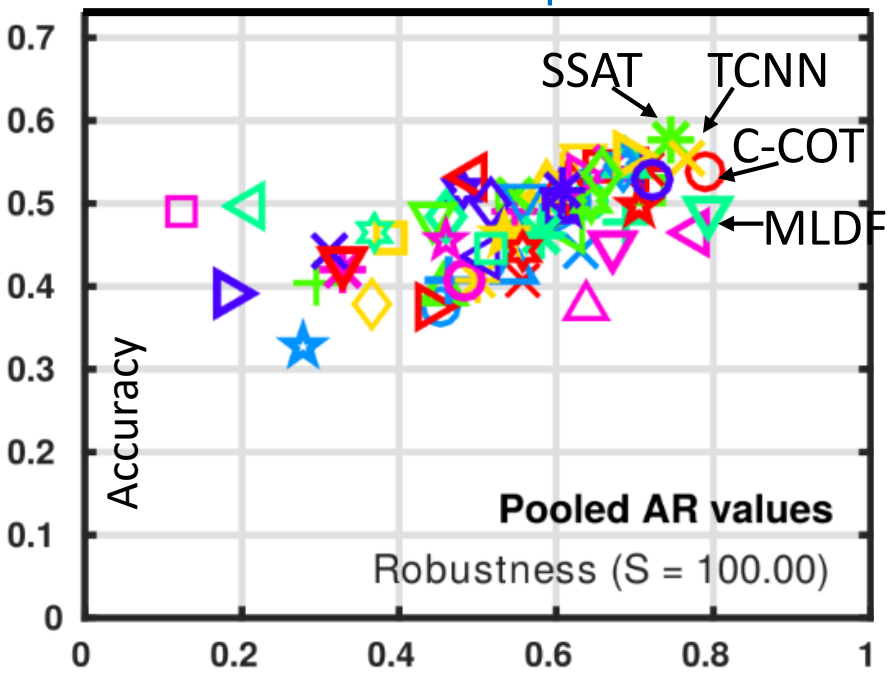
- C-COT slightly ahead of TCNN
- Most accurate: SSAT
- Most robust: C-COT and MLDF



Overlap curves



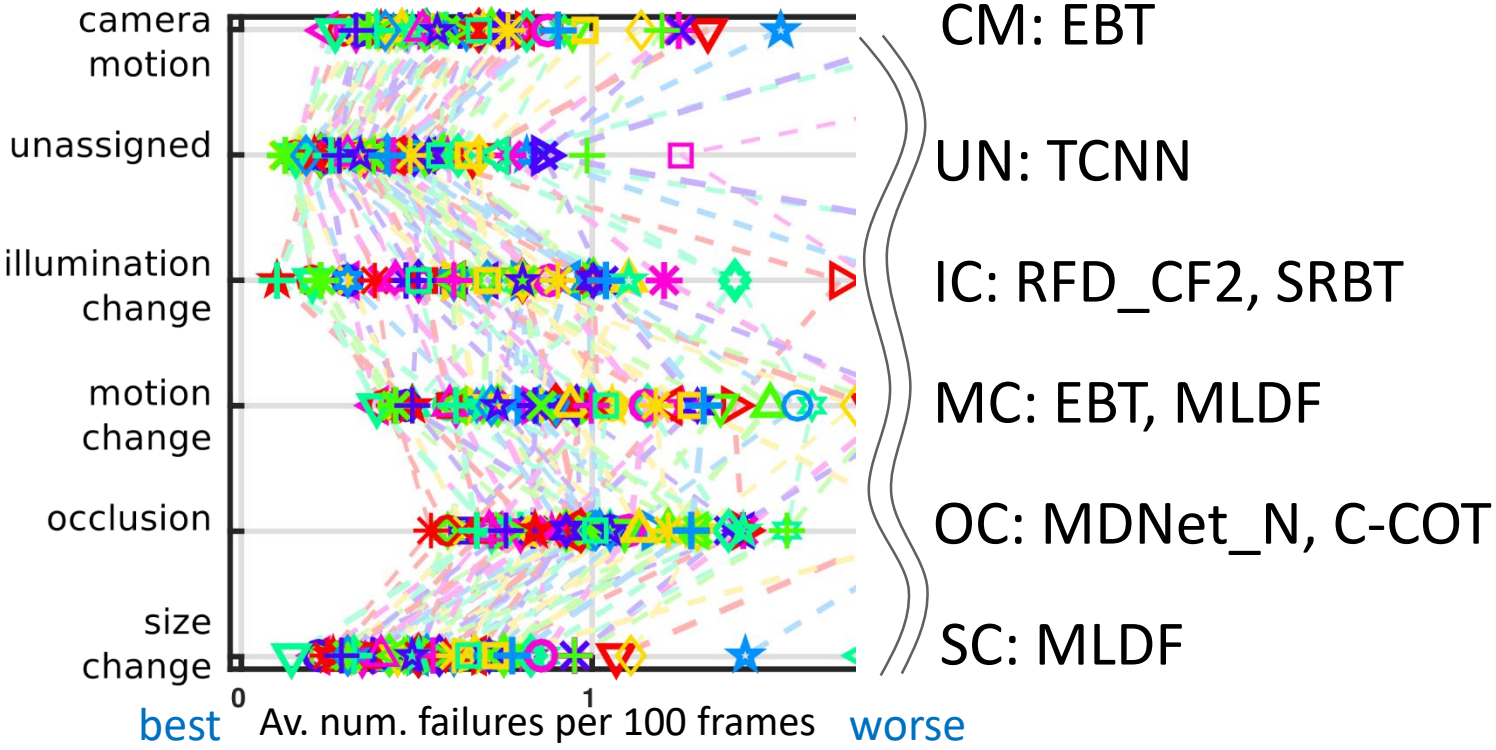
AR-raw plot



Detailed analysis: attributes

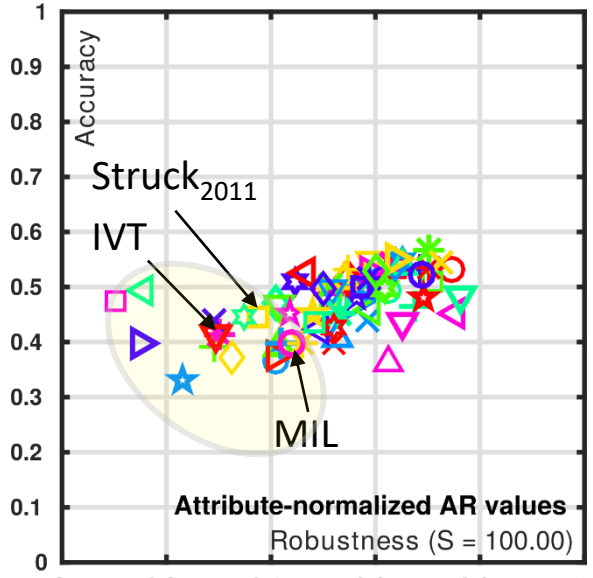
- Top EAO trackers mostly at top per attributes

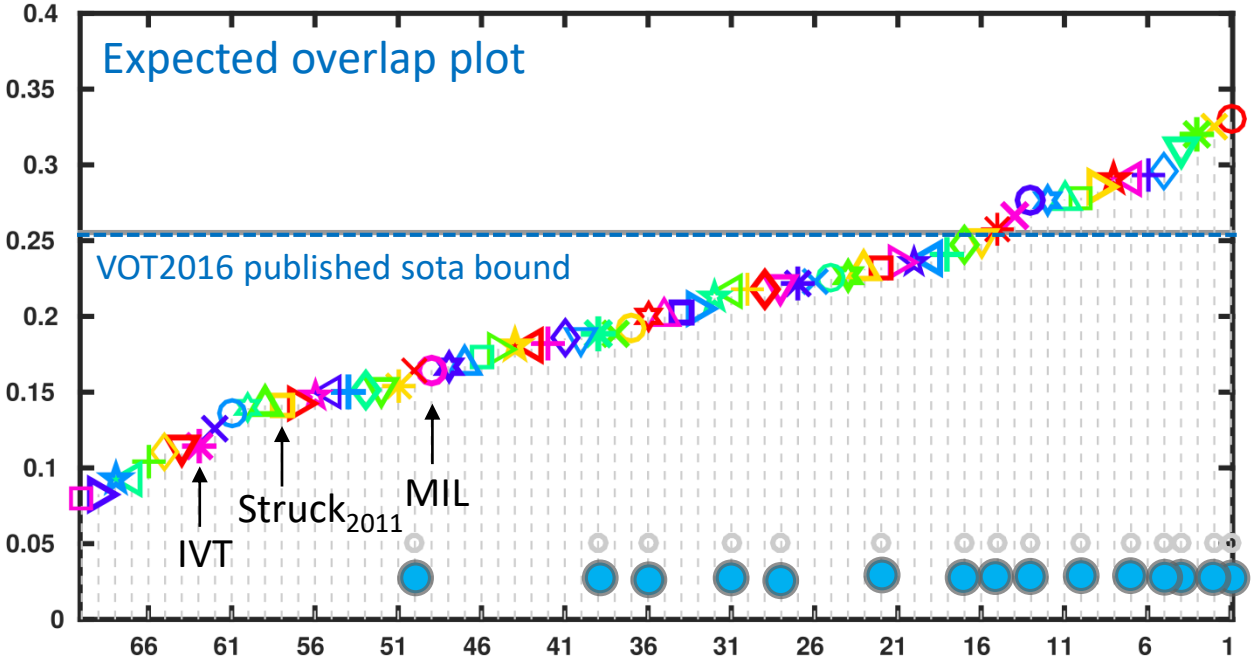
	cam. mot.	ill. ch.	mot. ch.	occl.	scal. ch.
Accuracy	0.49	0.53	0.44	**0.41**	*0.42*
Robustness	0.71	0.81	*1.02*	**1.11**	0.61

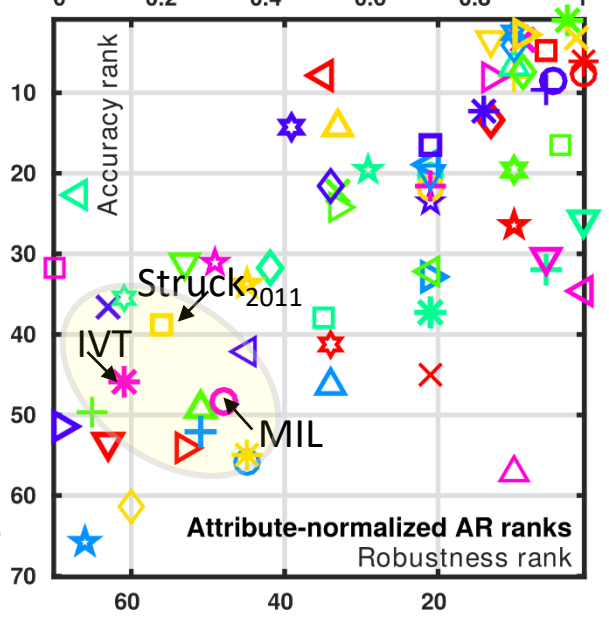


Detailed analysis: baselines + sota

- Baselines: IVT, MIL, Struck
- 15 trackers: (2015-2016) ICCV,ECCV,CVPR,PAMI…
  - Over 20% of tracker exceed their average EAO
- VOT2015: This value was over 40%

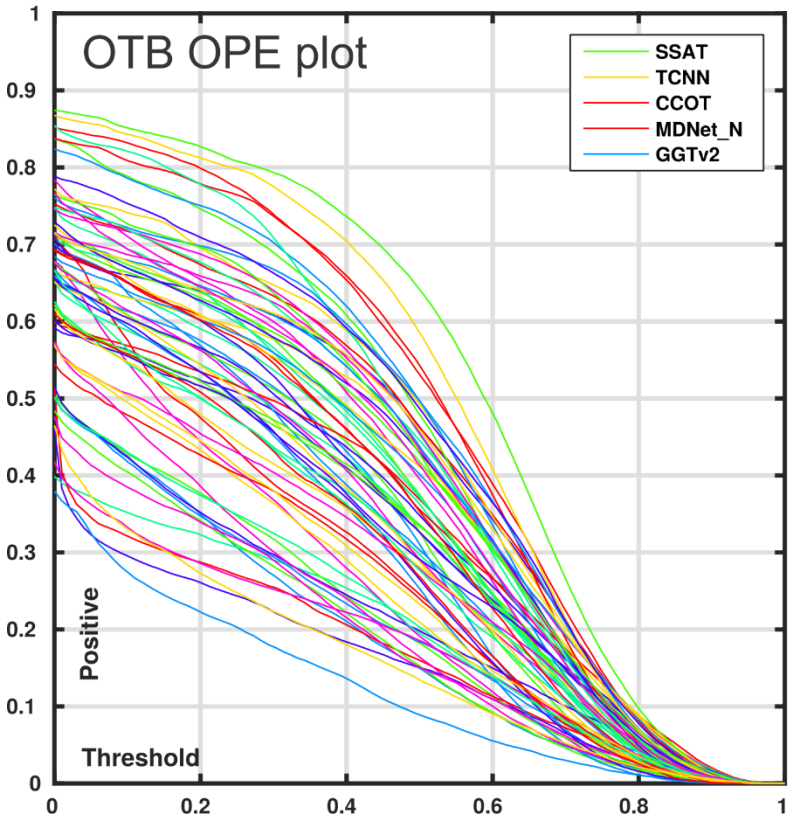


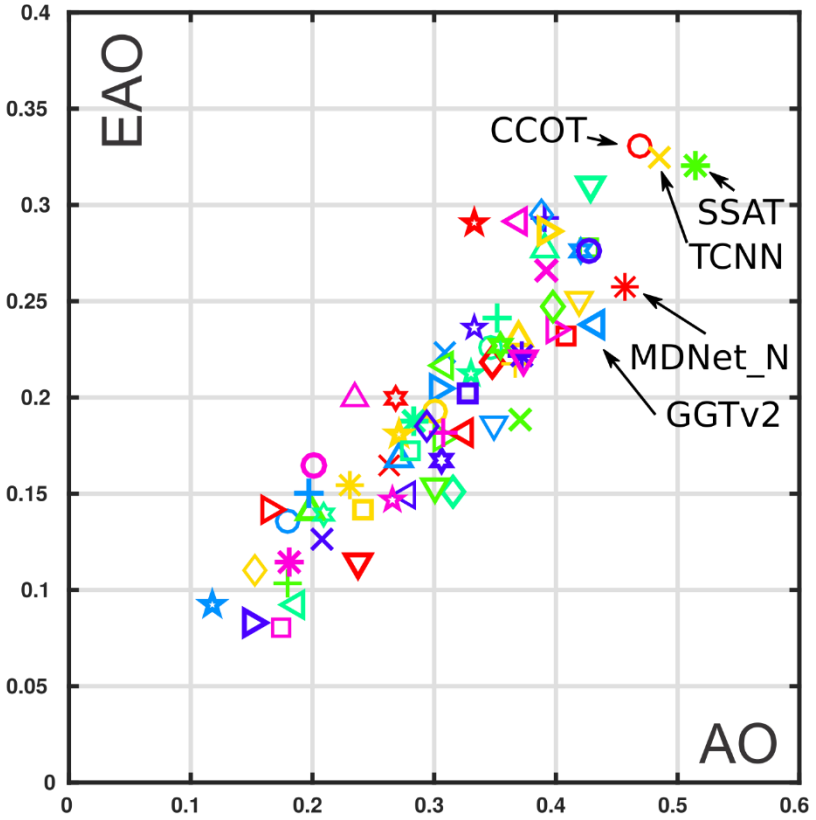




VOT unsupervised experiment

- OTB [Wu et al CVPR2013]: No reset at fail

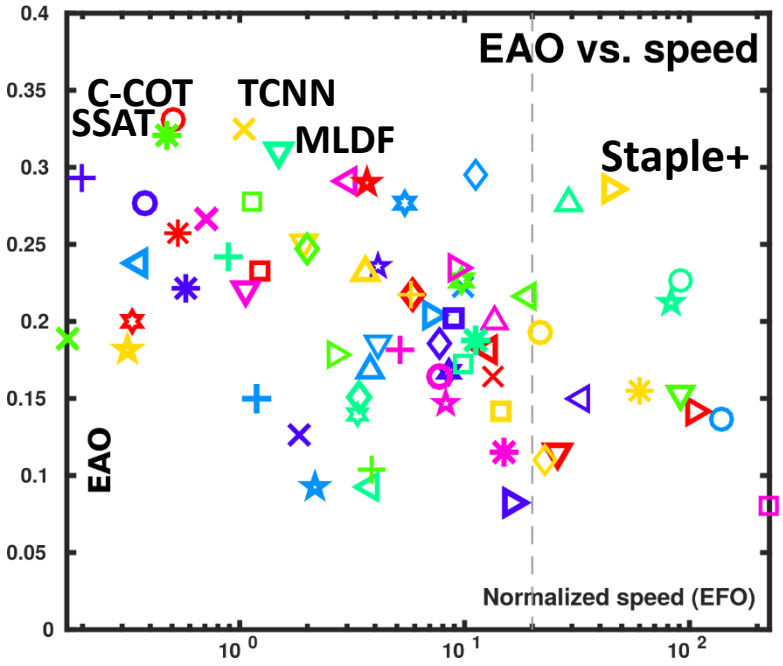


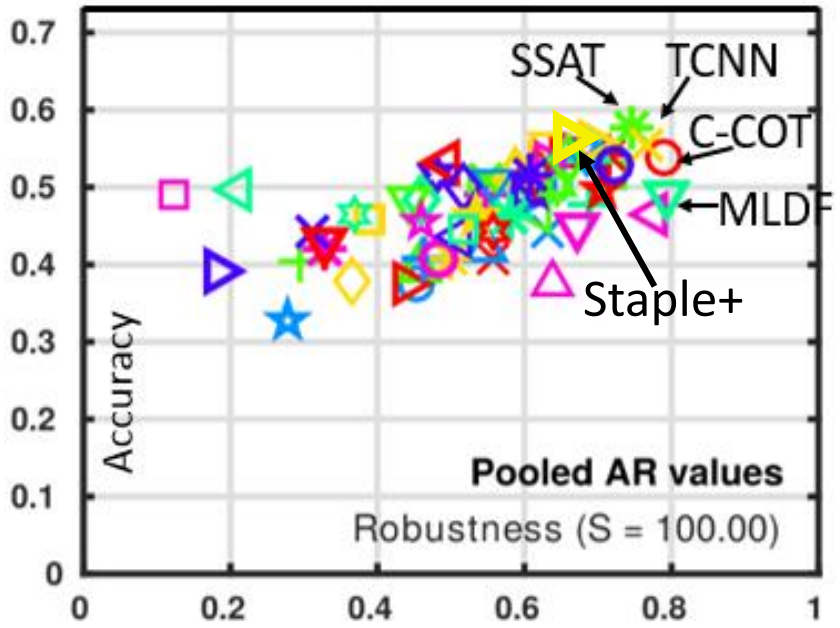


Tracking speed

- Top-performers slowest
  - Plausible cause: CNN
- Real-time bound: Staple+
  - Decent accuracy,
  - Decent robustness

Note: the speed in some Matlab trackers has been significantly underestimated by the toolkit since it was measuring also the Matlab restart time. The EFOs of Matlab trackers are in fact higher than stated in this figure.





Sequence ranking

- VOT2013 approach
  - Average number of trackers failed per frame (A_f)
  - Max. number of trackers failed at a single frame (M_f)

Sequence	Sequence	Sequence	Sequence
Leaves	Fish1	Crossing	Pedestrian2
Soccer2	Nature	Dinosaur	Fish4
Book	Handball2	Iceskater2	Godfather
Matrix	Fish2	Singer2	Bmx
Glove	Ball1	Blanket	Road
Ball2	Tiger	Bolt2	Sheep
Hand	Singer3	Iceskater1	Fish3
Pedestrian1	Gymnastics1	Gymnastics4	Birds2
Gymnastics3	Motocross2	Marching	Tunnel
Butterfly	Handball1	Wiper	Octopus
Rabbit	Soccer1	Helicopter	Singer1
Car1	Graduate	Sphere	Bag
Motocross1	Soldier	Basketball	Racing
Birds1	Bolt1	Shaking	Pedestrian2
Gymnastics2	Fernando	Traffic	Fish4

Challenging:

$A_f \sim [0.19, 0.41]$
$M_f \sim [56, 65]$

$A_f \sim [0.15, 0.17]$
$M_f \sim [45, 56]$

$A_f \sim [0.08, 0.11]$
$M_f \sim [36, 46]$

Intermediate:

$A_f \sim [0.05, 0.07]$
$M_f \sim [16, 30]$

Easiest:

$A_f \sim [0.01, 0.03]$
$M_f \sim [3, 18]$

Sequence ranking

- Among the most challenging sequences

Matrix (A_f = 0.33, M_f = 57)

Rabbit(A_f = 0.31, M_f = 43)

Butterfly ($A_f = 0.22, M_f = 45$)

- Among the easiest sequences

Singer1 ($A_f = 0.02, M_f = 4$)

Octopus ($A_f = 0.01, M_f = 5$)

Sheep ($A_f = 0.02, M_f = 15$)

VOT Summary

- Top-performing trackers C-COT & TCNN (in EAO)
  - AR analysis indicates high accuracy and rare failures
  - Computationally quite complex (EFO)
- All top-performing trackers applied CNN features different localization strategy
- Most submitted trackers outperform standard baselines
- 22% of submitted trackers outperform the published sota bound as defined in VOT2016.

The VOT2016 online resources

Available at: http://www.votchallenge.net/vot2016

- Presentations + papers + Dataset + Evaluation kit
- Guidelines on how to evaluate your trackers on VOT2016 and produce graphs for your papers (directly comparable to 70 trackers!)
- Resources to apply the OTB evaluation as well
- Publish the code/binaries of trackers of coauthors: 66!!
- VOT is open source !

VOT2016 summary

- Results published in a 44 pages joint paper ~ 141 coauthors!

Winners of the VOT2016 challenge:

T-CNN by: Hyeonseob Nam, Mooyeol Baek and Bohyung Han

Tree-structured Convolutional Neural Network Tracker
Presentation at VOT2016 next

visual object tracking challenge

Visual Object Tracking Challenge VOT

USE OF BENCHMARKS IN PAPERS

Current state of the field

- Overviewed tracking papers

  (ICCV2013, ICCV2014, ECCV2014, CVPR2014, CVPR2015, CVPR2016, AVSS2015).

- Most popular datasets:

  OTB [Wu et al.,CVPR2013], VOT [Kristan et al., TPAMI2016]

- Researchers seem to use benchmarks

  (reproducible research)

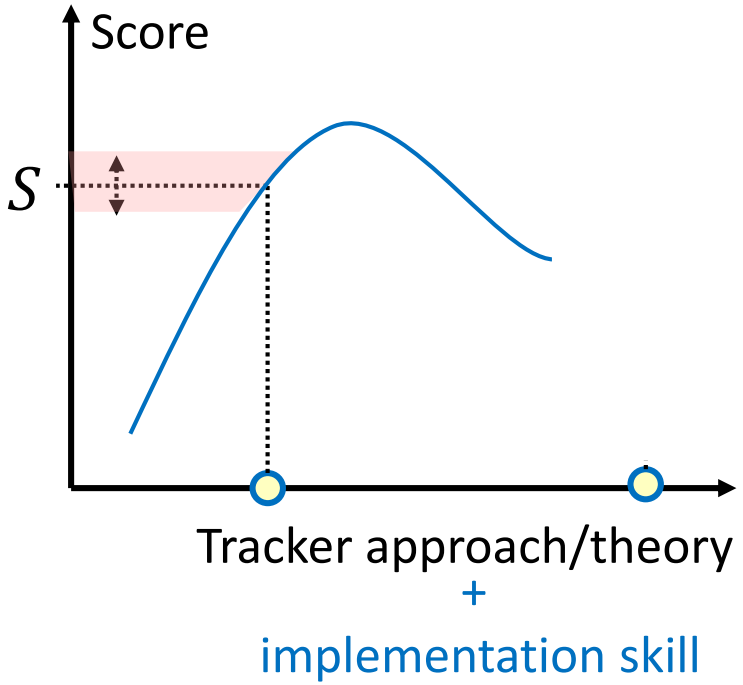
- The presented tracker is always “the best performing”

- BUT: (≤2015) Over 60% of papers did not use the entire benchmark, but only selected sequences!

  (≤2016) this number dropped to ~40%

Flaw of a single score obsession

- Idealized assumptions:
  - Single score ∝ Approach Quality
  - Score is "concave" in Approach
- Nonideal reality:
  - Imperfect/biased datasets:
    $\hat{S} = S + \text{noise}$



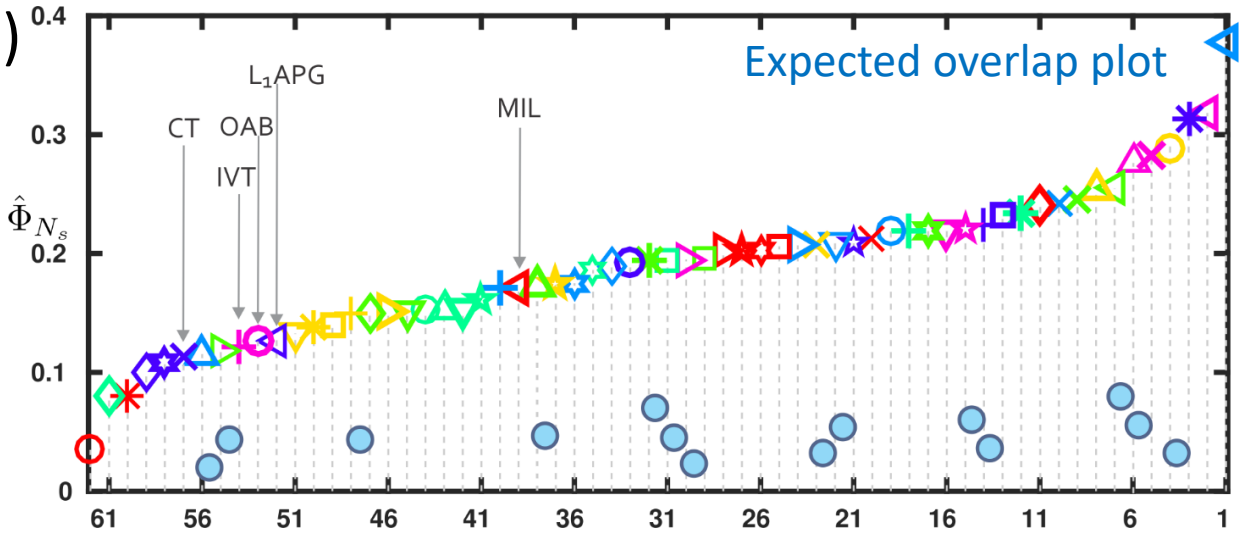
  - Scores also reflect implementation skill:

    Score $= f(\text{Implementation of the Approach})$

  - Score is NOT concave in approach (small increments)
  - Significant improvements may follow a change in paradigm

Flaw of a single score obsession

- VOT2015: 14 trackers published at ICCV, ECCV, CVPR, ICML, BMVC (2014-2015)



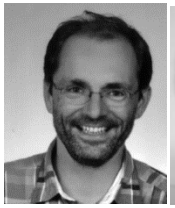
Guideline:

- Use a few non-correlated performance measures
- A tracker that scores reasonably high on a benchmark can be considered state-of-the-art
- Focus on a theory, not on maximizing a single performance measure

Thanks

- The VOT2016 committee


M. Kristan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- Everyone who participated or contributed

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