VOT
visual object tracking

The Visual Object Tracking Challenge Results
VOT-RGBD 2019

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Why Consider RGB-D?

- RGB tracking well developed
- Recently depth sensors widely used (robotics, multimedia applications)
- Two modalities: RGB + Depth
- Potentially simplifies:
  - Occlusion detection
  - Object-to-background separation
  - Object 3D structure
- New research oportunities
  - How to combine RGB and D?
  - Depth changes or not reliable?

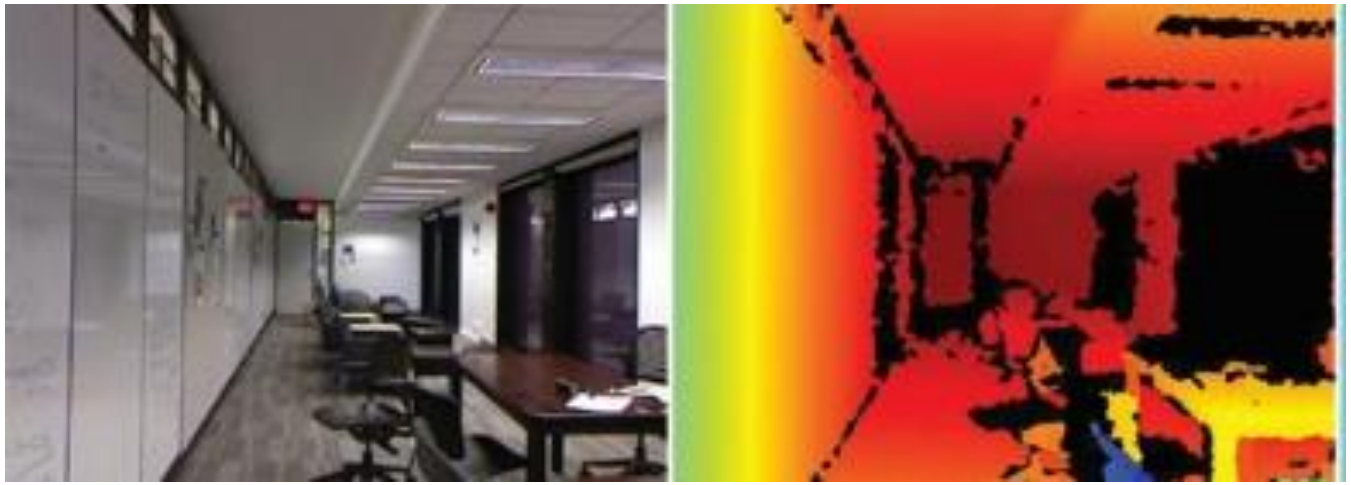
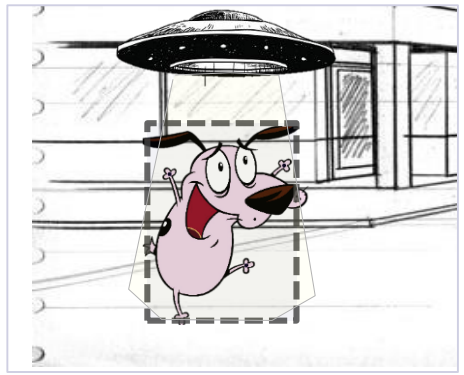
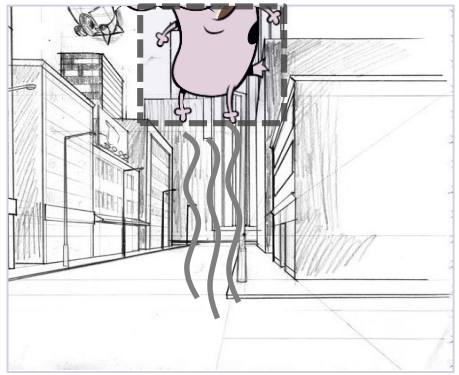
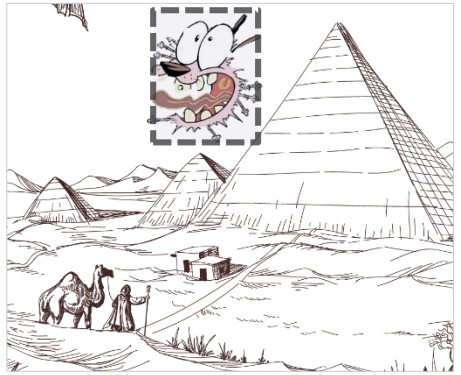


Figure from Silberman et al. ECCV2012

VOT RGB-D Challenge Scope

- Long-term tracking
- Required tracker properties
  - Determine when the target has been lost (or disappeared)
  - Re-detection after loosing the target

- Tracker prediction
  - A single training example in the first frame, target localization in the remaining frames
  - Output required: bounding box and presence confidence

RDB-D Datasets: Related Work

- Existing datasets:
  - PTB [1]: 100 sequences, average sequence length: 214 frames, short disappearances, synchronization problems, indoor only
  - STC [2]: 36 sequences, average sequence length: 255 frames, no target disappearances, limited outdoor scenarios
- Problems:
  - Not proper long-term evaluation (short sequences, short-term occlusions)
  - Lack of out-of-plane rotations
  - Single sensor used to capture video sequences (generalization?)

[1] S. Song et al., Tracking Revisited Using RGBD Camera: Unified Benchmark and Baselines, ICCV 2013.
[2] J. Xiao et al., Robust Fusion of Color and Depth Data for RGBD Target Tracking Using Adaptive Range-Invariant Depth Models and Spatio-Temporal Consistency Constraints. IEEE TCyB 2018..

The VOT-RGBD 2019 Dataset

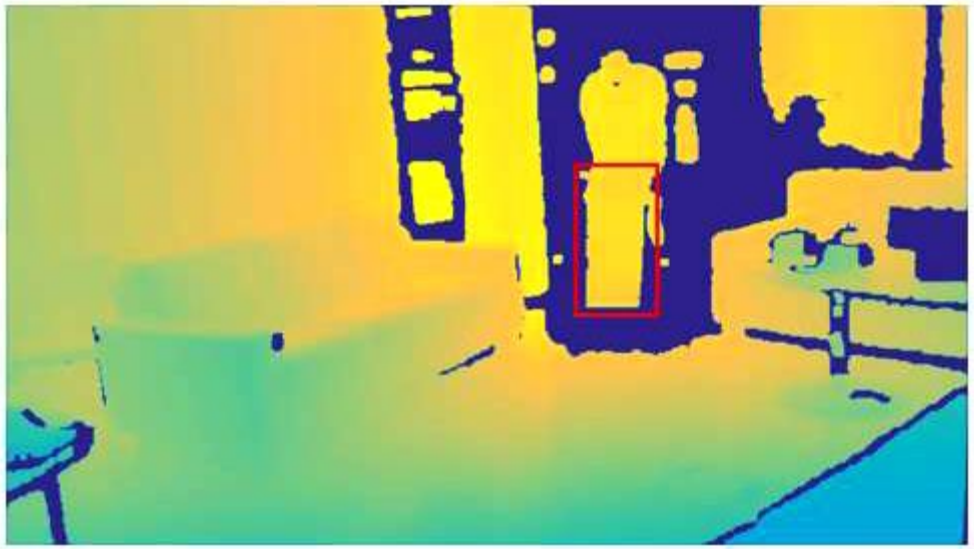
- Diverse sensors:

Kinect-v2:

ToF-RGB pair:

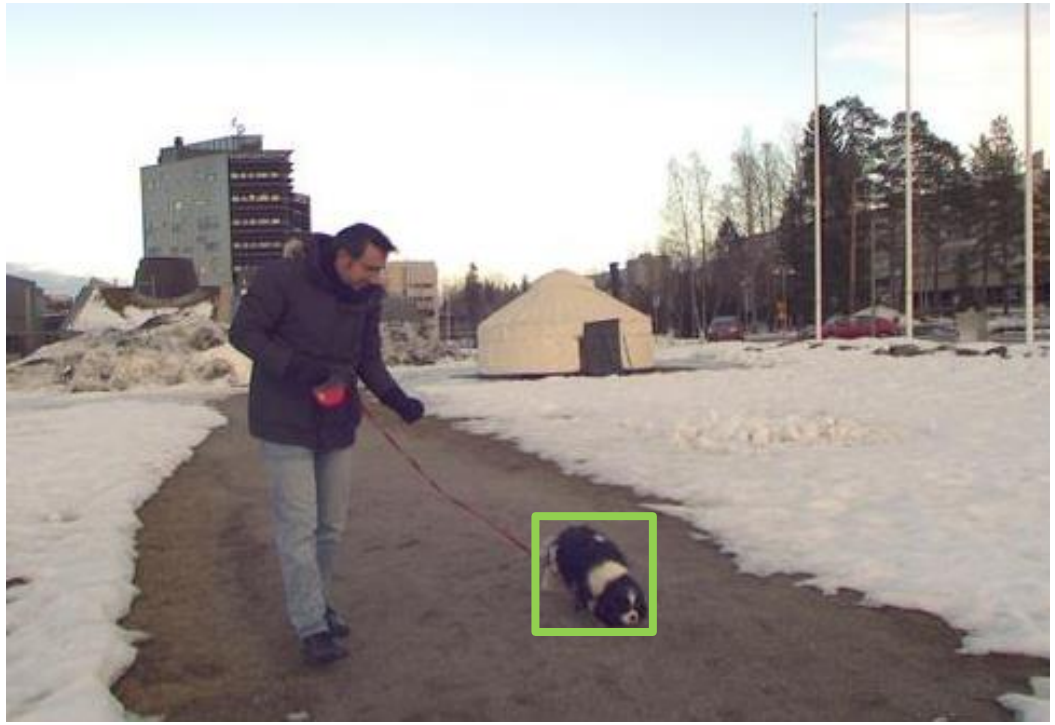
Stereo-camera pair:

- Indoor and outdoor sequences, spatially and temporally synchronized



The VOT-RGBD 2019 Dataset

- 80 sequences, average length 1274 frames
- Frequent and long-lasting target disappearances
  - Average target absence period: 56 frames
- Significant target pose change
- Axis-aligned bounding box



- Per-frame visual attributes:

  Full Occlusion, Target out-of-frame,
  Partial occlusion, Aspect change, Size change, Fast motion, Similar objects, Out-of-plane rotation,
  Reflective target, Depth change, Deformable target, Dark scene, Unassigned

VOT-RGBD 2019 Performance Evaluation

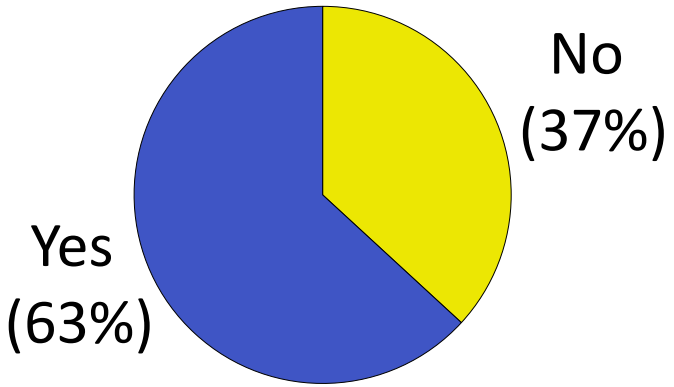
- No-reset experiment
  - Tracker initialized in the first frame, tracks to the end of the sequence
- Long-term tracking performance measures [1,2]
  - Tracking Precision (Pr): accuracy of predicted bboxes (when predictions given)
  - Tracking Recall (Re): accuracy of predicted bboxes (when target visible)
  - Tracking F-measure: F = (2 * Pr * Re) / (Pr + Re)

[1] A. Lukežič et al., Performance Evaluation Methodology for Long-TermVisual Object Tracking, arxiv: abs/1906.08675.
[2] M. Kristan et al., The sixth Visual Object Tracking VOT2018 challenge results, ECCVW 2018.

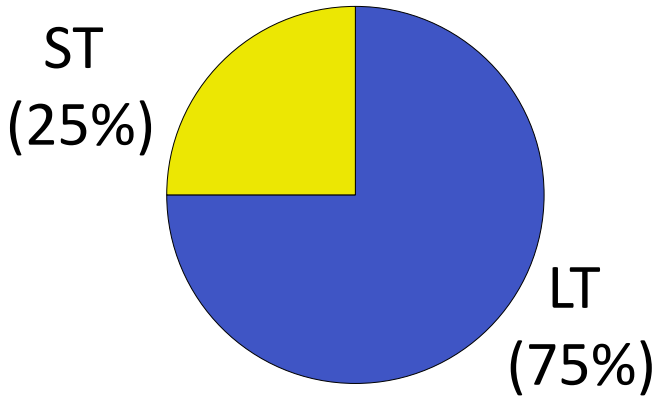
VOT-RBD 2019: Trackers Summary

- 12 trackers tested
- Diverse approaches

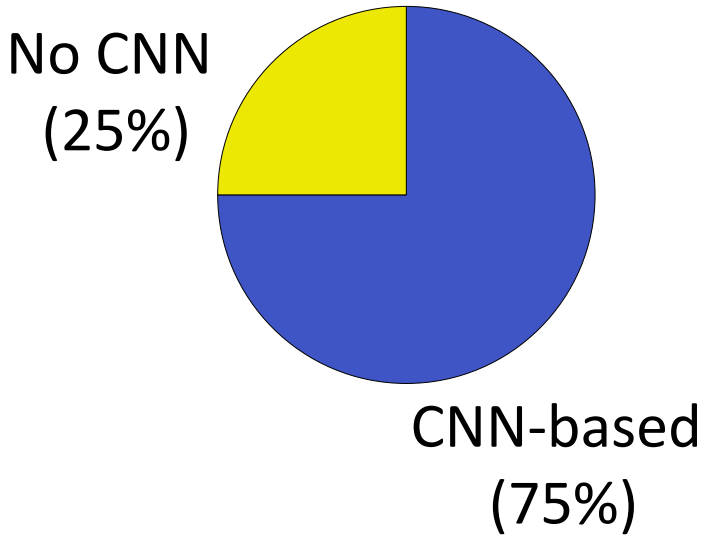
Is depth used?



ST/LT category:



Architecture

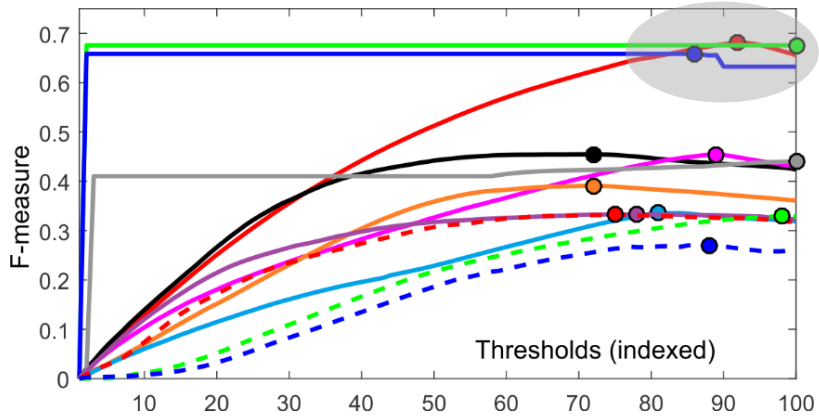


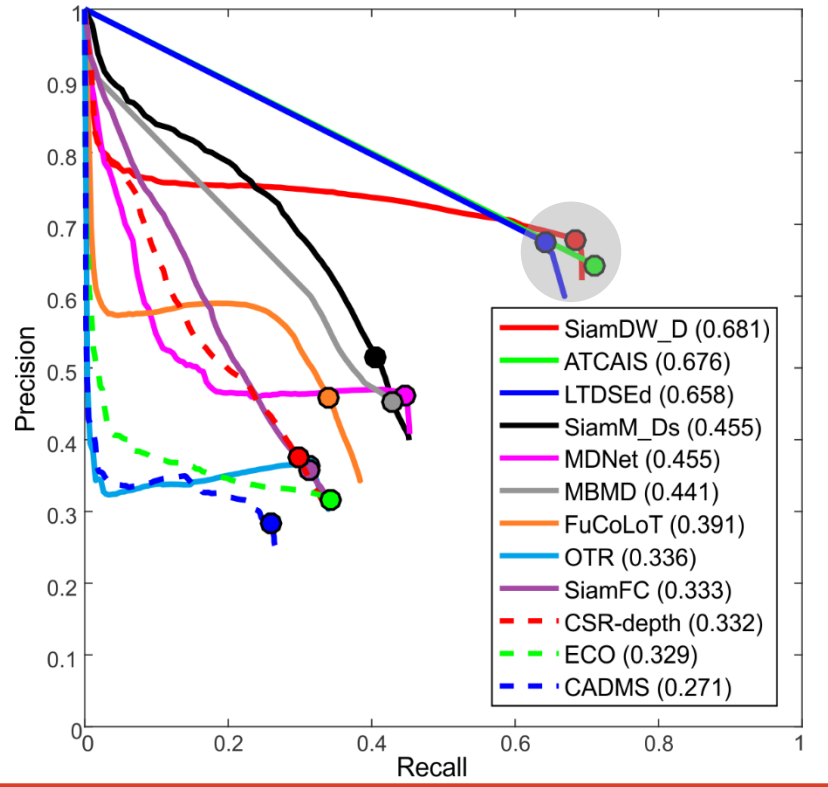
VOT-RGBD 2019 Results

TOP PERFORMERS

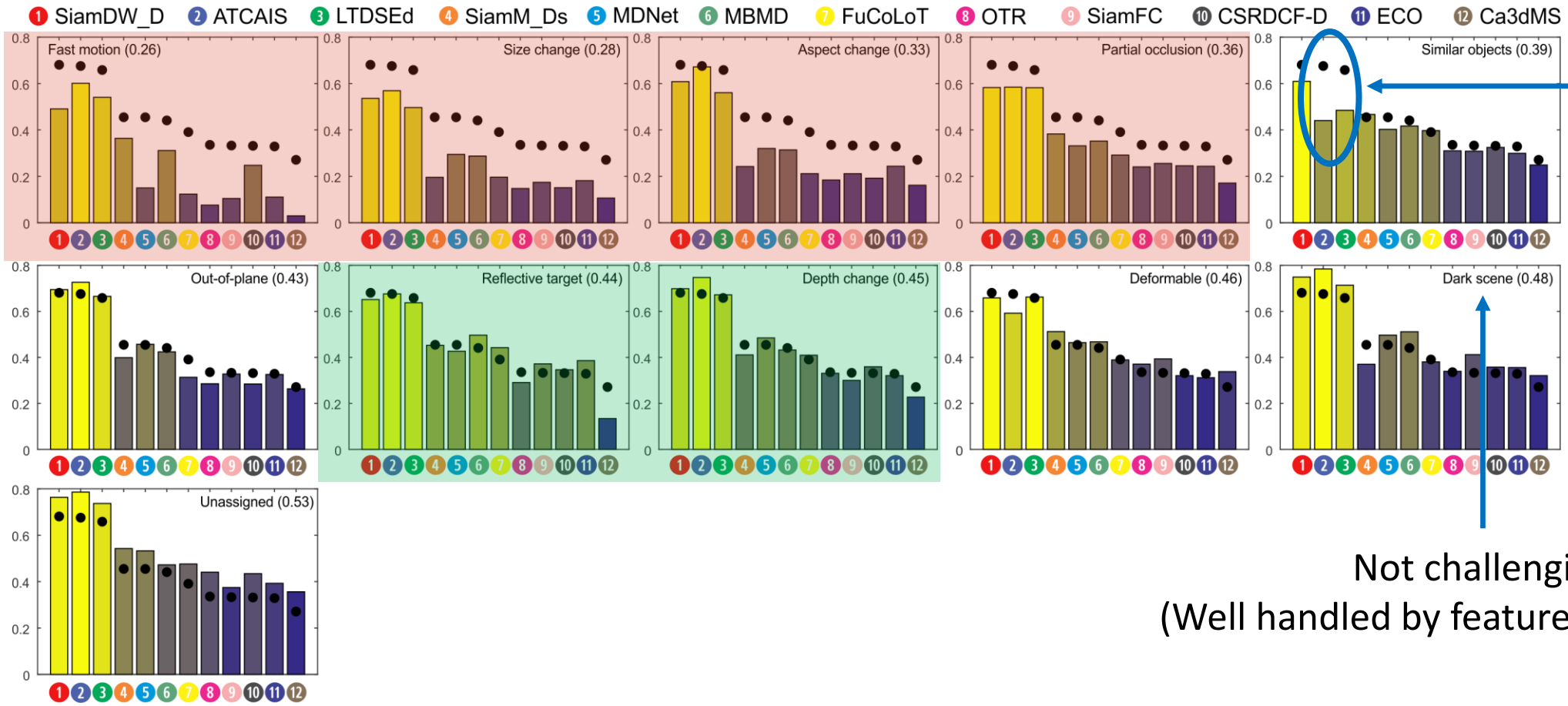
BASELINES (run by committee)

Tracker	Short-Term	Re-detection	Depth	Class
SiamDW_D	SiamRPN++, ATOM (ResNet50 + SENet154)	RPN (MMDet), IoU	Disappearance detection	LT_1
ATCAIS	ATOM, HTC instance segmentation	RPN (MMDet)	Disappearance detection, re-detection	LT_1
LTDSEd	ATOM, SiamMask, RT-MDNet verifier	RPN, RT-MDNet verifier	Disappearance detection	LT_1
SiamM_Ds	SiamMask	SiamMask, enlarged search window	Disappearance detection	LT_1
MDNet	Deep CNN classifier, random sampling	-	-	ST_1
MBMD	Siam bbox regression, MDNet verifier	Sampling, MDNet-based verifier (image-wide)	-	LT_1
FuCoLoT	DCF, color segmentation	DCF (image-wide)	-	LT_1
OTR	DCF, color segmentation	DCF (image-wide)	3D model	LT_1
SiamFC	Deep template, correlation	-	-	ST_1
CSRDCF-D	DCF, color segmentation	DCF (image-wide)	Segmentation	LT_1
ECO	DCF (deep features)	-	-	ST_1
Ca3dMS	3D mean-shift	Occluder tracking, verified by depth	3D tracking, disappearance detection	LT_0





VOT-RGBD 2019 Per-Attribute Analysis (F-measure)

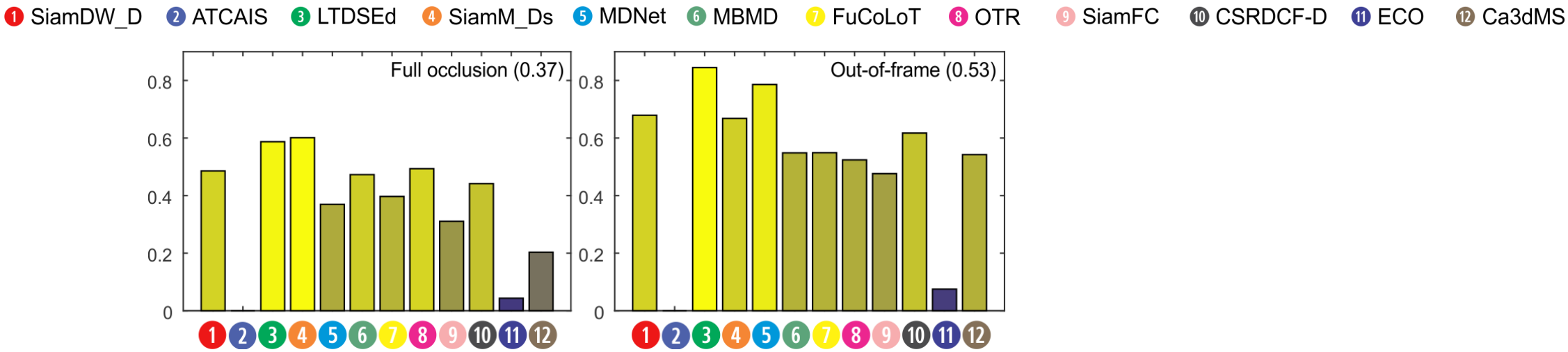


Not discriminative enough (Segmentation)

Not challenging (Well handled by features: deep or HC)

- The most challenging: fast motion, size change, aspect change, partial occlusion
- Well handled: depth change, reflective target

VOT-RGBD 2019 Per-Attribute Analysis (TNR)



- F-measure where target is not visible not defined (Recall = 0)
- True Negative Rate (TNR)
  Percentage of correctly predicted *target not visible*
- Out-of-frame easier to predict than full occlusion
  - Close to the image edge, similar objects at full occlusion

VOT-RGBD 2019 Challenge Summary

Top performers apply:

- Deep features to cope with appearance change (e.g., ResNet [1])
- Robust discriminative localizer (eg., ATOM [2])
- Localization refinement: IoUNet [2], Segmentation [3], RPN [4]
- Powerful detector (for target re-detection)

Research opportunities:

- Depth is mostly used only for target loss detection
- Depth for training: localization, detection or segmentation
- Depth for 3D modeling and foreground-background separation

[1] K. He et al., Deep Residual Learning for Image Recognition, CVPR 2016.
[2] M. Danelljan et al., ATOM: Accurate tracking by overlap maximization, CVPR 2019.
[3] Q. Wang, et al., Fast online object tracking and segmentation: A unifying approach, CVPR 2019.
[4] B. Li et al., High Performance Visual Tracking With Siamese Region Proposal Network, CVPR 2018.

VOT-RGBD 2019 Online Resources

- Paper, presentation, results, trackers code available online on: http://www.votchallenge.net/vot2019/
- Evaluation toolkit on github: https://github.com/votchallenge/vot-toolkit

- Dataset downloaded automatically by the toolkit

VOT-RGBD 2019 Awards

Winners of the VOT-RGBD 2019 challenge:

SiamDW-D by: H. Yu, H. Peng, Z. Wu, Y. Huang, J. Fu, L. Wang

“Online Deeper and Wider Siamese Networks for RGBD Visual Tracking”

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Thanks

- The VOT2019 committee

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- Everyone who participated or contributed

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