Noninvasive bee tracking in videos.

Deep learning algorithms and Cloud Platform design specifications

Pascal Engeli 14671457
Gabriela E. López Magaña 17744830

UZH -Informatics and Sustainability Research Group

Prof. Dr. Lorenz Hilty
Dr. Clemens Mader
Mr. Daniel Boschung (ETHZ – IMSB)

February 12, 2021

Beehives under research

	Erlen Hive04	Erlen Hive11	United Queens	Echolinde	Doettingen Hive1
Night		 *		 *	
Top front view	 *	 *	 *	 *	 *
Diagonal view					
Mobile phone HD					

* «relevant hives», rest are dimensions we tested

Test for Citizen Science:
Low resolution handy

*

Chueried_Hive01

*

Froh14 (BeeWatch)

Clemens Yellow

*

Froh23_TreeCavity

Chueried_Hempbox

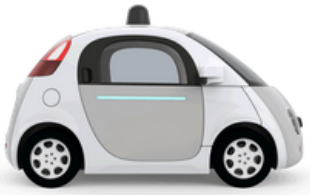
Clemens Red

* «relevant hives», rest are dimensions we tested

Object Detection.

The first goal of our project was to find the best fitting model for each hive, by exploring the space of training possibilities

Object detection models



⅓ Mile, 1760 feet - 536 m

	Pascal 2007 mAP	Speed	
DPM v5	33.7	.07 FPS	14 s/img
R-CNN	66.0	.05 FPS	20 s/img
Fast R-CNN	70.0	.5 FPS	2 s/img
Faster R-CNN	73.2	7 FPS	140 ms/img
YOLO	63.4	45 FPS	22 ms/img

TensorFlow (ETHZ Leonhard)

~~Caffee (FacebookResearch)~~

Yolov3 (Google Colab)
Yolov4 – 04.2020 (Google Colab Pro)

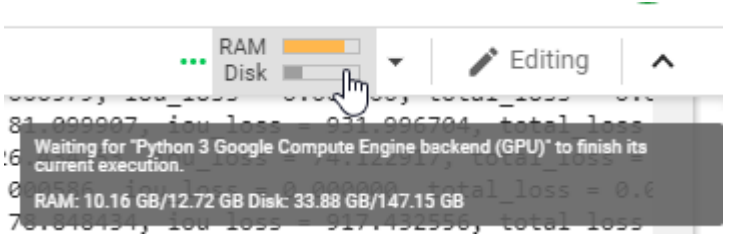
2 feet - 0.6 m

Available Data example for one hive

YOLO Model Training		Benchmark Cross-validation
Train Set	Test Set	Validation Set
80	20	20

Model training

- Installation neural network framework (Darknet) and libraries
- Configuration file of labeled image files (Train 80% / Test 20%)
- Configuration file object classes (Bee)
- Execute weight training



Available Data – Training YOLO Weights

	Training			Test		
Beehive	Nr. Frames	Nr.Bees	Avg Bees/ Frame	Nr. Frames	Nr.Bees	Avg Bees/ Frame
Chueried_Hempbox*	160	3128	20	40	763	19
Chueried_Hive01	80	531	7	20	134	7
ClemensRed	80	1266	16	20	321	16
ClemensYellow	80	1942	24	20	429	21
Doettingen_Hive1*	160	5021	31	40	1359	34
Echolinde	80	3563	45	20	826	41
Echolinde_Night	80	1793	22	20	408	20
Erlen_Hive04_diagonalview	160	2326	15	40	583	15
Erlen_Hive04_frontview	160	2268	14	40	569	14
Erlen_Hive04_smartphone	80	1068	13	20	306	15
Erlen_Hive11	80	5990	75	20	1629	81
Erlen_Hive11_Night	80	3066	38	20	905	45
Froh14	160	1591	10	40	481	12
Froh23_TreeCavity	160	616	4	40	156	4
UnitedQueens	160	1638	10	40	406	10
	1760	35807	23	440	9275	24

Total labeled frames: 3000

Except *, all trained with 80/20

Available Data – Validation Set for cross validation

Beehive	Recording	Nr. Frames	Nr.Bees	Avg Bees/Frame
Chueried_Hempbox	topfrontview	40	774	19
Chueried_Hive01	topfrontview	20	132	7
ClemensRed	topfrontview	20	336	17
ClemensYellow	topfrontview	20	486	24
Doettingen_Hive1	topfrontview	40	1301	33
Echolinde	topfrontview	20	921	46
Echolinde_Night	topfrontview night	20	432	22
Erlen_Hive04_diagonalview	diagonalview	40	607	15
Erlen_Hive04_frontview	topfrontview	40	570	14
Erlen_Hive04_smartphone	diagonal view smartphone	20	302	15
Erlen_Hive11	topfrontview	20	1632	82
Erlen_Hive11_Night	topfrontview night	20	788	39
Froh14	topfrontview	40	419	10
Froh23_TreeCavity	topfrontview	40	158	4
UnitedQueens	topfrontview	40	408	10
		440	9266	24

Available Data – Data augmentation

- Data augmentation on color variances
  - Chueried_Hive01_green80
  - Chueried_Hive01_red70
  - Erlen_Hive11_grayscale
  - Erlen_Hive11_red70

	Training			Test			Validation		
Beehive	Nr. Frames	Nr.Bees	Avg Bees/ Frame	Nr. Frames	Nr.Bees	Avg Bees/ Frame	Nr. Frames	Nr.Bees	Avg Bees/ Frame
Chueried_Hive01	80	531	7	20	134	7	20	132	7
Erlen_Hive11	80	5990	75	20	1629	81	20	1632	82
	160	6521	41	40	1763	44	40	1764	45

Model performance. Comparing dimensions, exploring the space of training possibilities

On number of examples
(Train set)

Validate weights on all hives or single hive
(Test set)

On angle

Night quality

HD/not

Generalization

Individual | “Staged” | All

On hive-similarity training

Researched dimensions

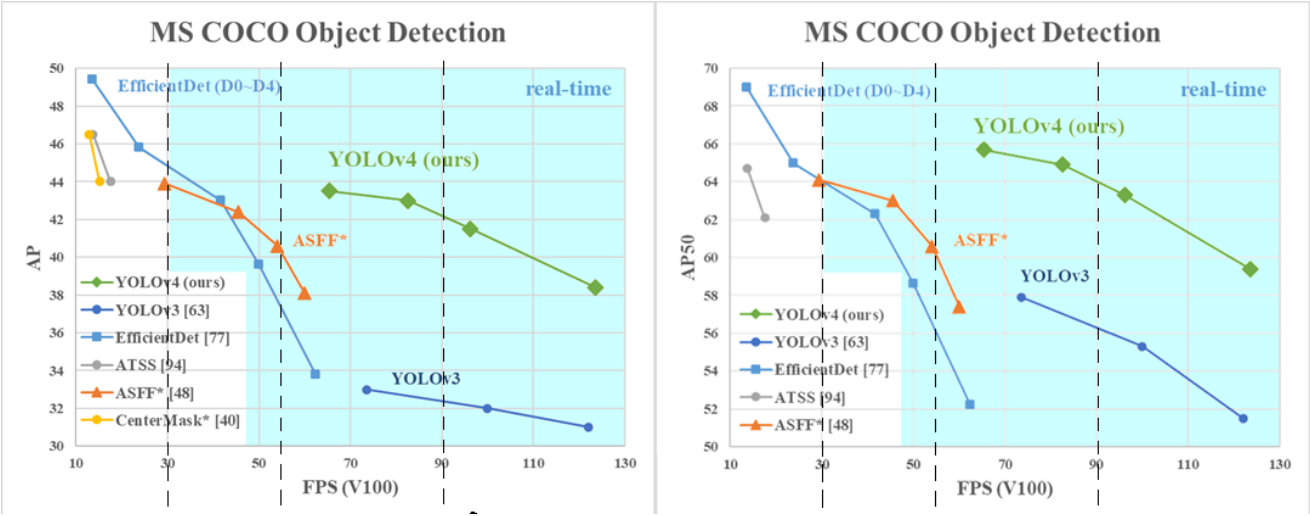
	Night	Individual_training / Single_training (80)	Different Views	On_qty_of_train _images	Color correction	Staged training
Erlen_Hive04		Single	E_H04_smartphone E_H04_diagonalview **E_H04_frontview**			yes
Erlen_Hive11	**Night**	Single Individual			red70 grayscale	yes
UnitedQueens		Single				
Echolinde	Night	Single		10 **20** 40 80		yes
Doettingen_Hive1		Single		160		yes

Researched dimensions

	Night	Individual / Single training (80)	Different views	On_qty_of_train_images	Color correction	Straged trainig
Chueried_Hive01		Single Individual			red70 green80	yes
Froh14		Single Individual		10 **20** 40 80 160		yes
Froh23_TreeCavity		Single Individual				yes
Chueried_Hempbox		Single				
ClemensRed		Single				
ClemensYellow		Single				

Validation – Validation set

- In Object Detection, performance is always measured against standard datasets, like COCO and Pascal VOC
- We created our own validation set

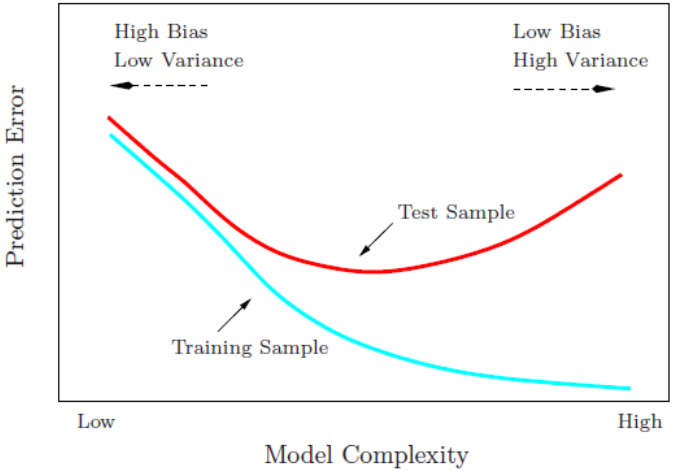


Validation – mAP on training set

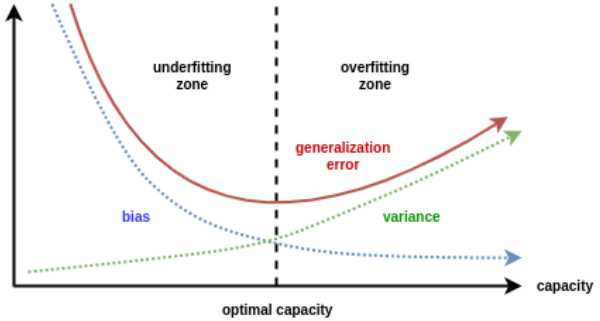
Most models reached good mAP while training: need «external» benchmark

```
 (next mAP calculation at 1100 iterations)
 Last accuracy mAP@0.5 = 99.60 %, best = 99.60 %
 1009: 2.868343, 2.139886 avg loss, 0.000100 rate, 11.810954 seconds, 64576 images, 70.268091 hours left
Loaded: 0.000070 seconds
v3 (iou loss, Normalizer: (iou: 0.07, cls: 1.00) Region 139 Avg (IOU: 0.840355, GIOU: 0.835635), Class: 0.
```

```
 (next mAP calculation at 1100 iterations)
 Last accuracy mAP@0.5 = 99.62 %, best = 99.62 %
 1011: 1.990166, 2.109495 avg loss, 0.000100 rate, 15.872647 seconds, 64704 images, 68.444020 hours left
Loaded: 0.000042 seconds
v3 (iou loss, Normalizer: (iou: 0.07, cls: 1.00) Region 139 Avg (IOU: 0.858330, GIOU: 0.854916), Class: 0.991086, Obj:
v3 (iou loss, Normalizer: (iou: 0.07, cls: 1.00) Region 150 Avg (IOU: 0.798945, GIOU: 0.790318), Class: 0.986687, Obj:
```



Generalization error and model complexity

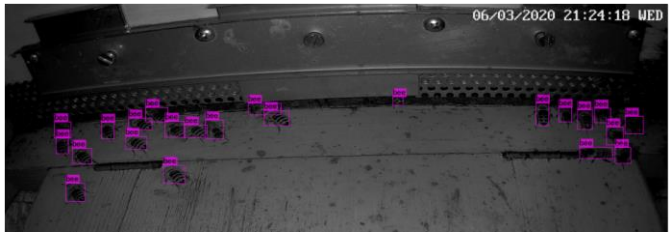


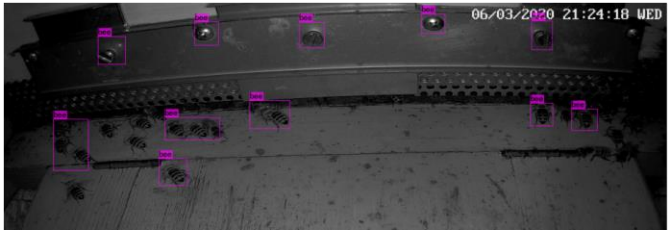
Test Sample = Validation Set in our project

Validation – Cross validation on validation set

~30 minutes per model, running 520 images with <- will be reduced because only "relevant hives" will be included in the future

Cross-validation Model-Hive.
Example: Model *Echolinde_Night* and *Froh23_TreeCavity* on same *Echolinde_Night* Frame





Example: Staged Model vs Individual_Training for Chuerhied_Hive01 +10% improvement

trained_model	hive_name	precision	recall	f2	f1
staged_2/BeeWatch_Chueried_01_Erlen_Hive_11_Froh_23_UnitedQueens	Chueried_Hive01	1	0.984848	0.987842	0.992366
staged_2/Froh14_20_Chueried_Hive01	Chueried_Hive01	0.97619	0.931818	0.940367	0.953488
individual_training/Chueried_Hive01	Chueried_Hive01	1	0.909091	0.925926	0.952381
single_hive/Chueried_Hive01	Chueried_Hive01	0.991453	0.878788	0.899225	0.931727
individual_training/Chueried_Hive01_red70	Chueried_Hive01	0.974359	0.863636	0.883721	0.915663

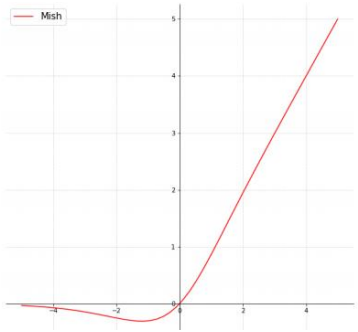
⚠

F2 - Score

- We chose to use F2-Score, because in our view, recall has a higher weight than precision.
- Misclassification inexistent, precision deals with FP.
- But FP is less problematic as not finding the bees…

We usually use Recall and Precision for comparisons
When Model Rank is used, it is based on F2-Score

Results. Activation functions - Mish vs Leaky

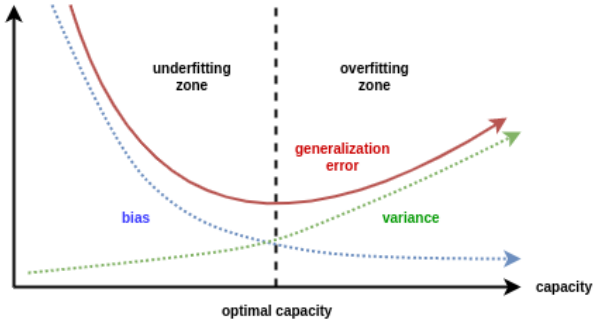


- Mish supported in April 29, 2020
- For «relevant hives» the recall increased by 9.8% and the precision by 5%.
- **Conclusion**: Do. Use Mish for training, validation and user of model

Img Src: https://arxiv.org/pdf/1908.08681.pdf

Results. Number of train images

- Started labeling many frames (>300 UnitedQueens)
- Question: how many images are really necessary?

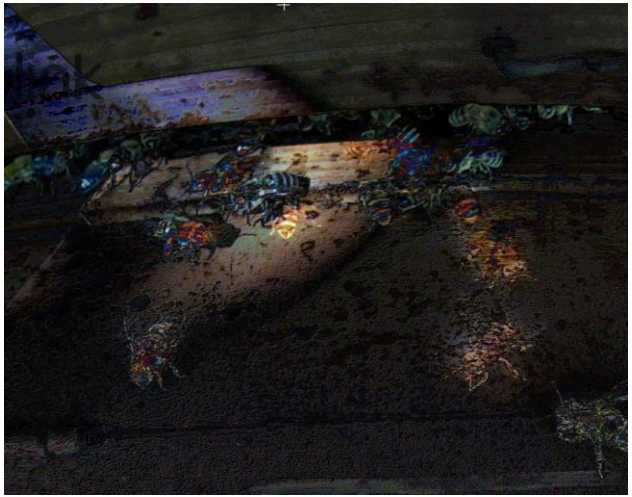


- Froh14: 10, 20, 40, 80, 160
- Echolinde: 10, 20, 40, 80

- Froh14: 80 is Top model (R: 0.916, P:0.909)
- Echolinde: 80 is 2nd top model (R:0.925, P:0.974, difference to 1st R:-0.013 P:0.012

- **Conclusion**: Enough. 80 train images reaches the best, 2nd best, model. Generally most top models had >0.9 F2-score
    - Except aiming to build a “general” model, if expecting to reduce variance <- conscious evaluation of trade off ensuring constant validation…

Results. Background subtraction



- **Conclusion**: Don’t. Backgrounds are too structured, because it’s out in the nature the shadows change constantly, there is not enough contrast from background and bees.

Data Augmentation - Color Casting/Jiterring

- The average ranking of the color casted trained models was 16th for the related beehive
  - Chueried_Hive01 – *red70* 6th , after *individual_training/Chueried_Hive01* at 3rd, and *single_hive/Chueried_Hive01* at 5th
  - Erlen_Hive11 – *grayscale* 4th, after *individual_training/Erlen_Hive11 3rd*

- Only in *Erlen_Hive11_Night: single_hive/Erlen_Hive11_grayscale* rank 3rd: -4.4% recall and -4.5% precision difference to the top model

- **Conclusion**: Don’t. Both beehives performed better with unchanged colors.

Results. Camera Angles

- Best performance was the top frontal (best F2-Score of 0.982, 0.960, 0.936).

- **Conclusion**: Don’t.

Results. General model

- Train/Test sets include the relevant beehives
- In average, the top model has 4% more recall than the general model.
- In average the precision had strong difference
- Ranged 4th in average

- **Conclusion**: Inconclusive. Future work: evaluate if constant re-training is worth (always make cross-validation) -> Or try staged training of similar hives better

Results. General model against top model of hive

Beehive	General ModelRank	Diff. Precision **Top** vs General	Diff. Recall **Top** vs General
Froh23_TreeCavity	4	0.014	**0.120**
Chueried_Hive01	4	0.017	**0.098**
Doettingen_Hive1	3	-0.003	**0.044**
UnitedQueens	6	0.011	**0.042**
Echolinde_Night	2	**-0.060**	**0.042**
Froh14	7	0.006	0.038
Echolinde	7	-0.001	0.029
Erlen_Hive11	5	0.023	0.029
Erlen_Hive11_Night	2	0.019	0.016
Erlen_Hive04_frontview	4	0.002	0.012
Average	**4**	**0.003**	**0.047**
Max	7	0.023	0.120
Min	1	-0.060	0.012

In average, the top model has 4% more recall than the general model.

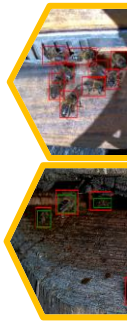
Results. Night videos

- Top model: _night model
- 2nd top: general model, because it included the night images
- Daylight models: 9th and 10th place, 29% and 39% less recall.

- **Conclusion**: Do. Models trained specifically perform better. If only one model per hive then include night images.

Results. Set of test frames (“Individual vs Single”)

- Same set of Training Frames
- Test Frames
    - Individual : Train + Test frames belong to one hive
    - Single: Train frames only for hive + Test frames all hives



- **Conclusion**: Inconclusive, but with some strong differences…

Beehive	Diff. Precision Ind_over_Single	Diff. Recall Ind_over_Single	Diff. F2-Score Ind_over_Single	Best of Ind/Single	Model Rank Individual	Model Rank Single
Chueried_Hive01	0.0085	0.0303	0.0267	Ind	3	5
Erlen_Hive11	-0.0066	**0.0882**	0.0706	Ind	2	7
Froh14	-0.0129	**-0.0430**	-0.0370	Sing	9	1
Froh23_TreeCavity	0.0114	-0.0190	-0.0142	Sing	3	2

Results «Staged» training

Staged – round shaped hives

Chueried_Hive01 + Froh14

Model	Chueried_Hive01		Froh14	
	Model Rank	F2-Score	Model Rank	F2-Score
individual_training/Chueried_Hive01	3	0.925		
single_hive/Froh14			1	0.915
staged_2/Froh14_20_Chueried_Hive01	2	0.940	6	0.884

Staged – 2 not similar

Chueried_Hive01 + UnitedQueens

Model	Chueried_Hive01		UnitedQueens	
	Model Rank	F2-Score	Model Rank	F2-Score
individual_training/Chueried_Hive01	3	0.925		
single_hive/UnitedQueens			2	0.985
staged_2/Chueried_Hive01_UnitedQueens	19	0.598	9	0.927

Staged – 3 similar «common-shaped» hives

Erlen_Hive04 + Erlen_Hive11 + UnitedQueens

Model	Erlen_Hive04_frontview		Erlen_Hive11		UnitedQueens	
	Model Rank	F2-Score	Model Rank	F2-Score	Model Rank	F2-Score
single_hive/Erlen_Hive04_frontview	1	0.982				
individual_training/Erlen_Hive11			2	0.947		
single_hive/UnitedQueens					2	0.985
staged_2/Erlen_Hive04_Hive11_UnitedQueens	3	0.975	3	0.946	4	0.970



Staged – 4 «common-shaped» hives

Doettingen + Echolinde + Erlen_Hive04 + UnitedQueens

	Doettingen_Hive1		Echolinde		Erlen_Hive04_frontview		UnitedQueens	
	Model Rank	F2-Score	Model Rank	F2-Score	Model Rank	F2-Score	Model Rank	F2-Score
single_hive/Doettingen_Hive1	1	0.961						
single_hive/Echolinde			2	0.934				
single_hive/Erlen_Hive04_frontview					1	0.982		
single_hive/UnitedQueens							2	0.985
staged_2/Doettingen_Echolinde_Erlen_UnitedQueens	2	0.948	1	0.942	2	0.98	5	0.966




Staged – adding one different hive shape

Doettingen + Echolinde + Erlen_Hive04 + UnitedQueens + Froh14 (Beewatch)

	Doettingen_Hive1		Echolinde		Erlen_Hive04_fv		UnitedQueens		Froh14	
	Model Rank	F2-Score	Model Rank	F2-Score	Model Rank	F2-Score	Model Rank	F2-Score	Model Rank	F2-Score
single_hive/Doettingen_Hive1	1	0.961								
single_hive/Echolinde			2	0.934						
single_hive/Erlen_Hive04_frontview					1	0.982				
single_hive/UnitedQueens							2	0.985		
single_hive/Froh14									1	0.915
staged_2/Doettingen_Echolinde_Erlen_UnitedQueens_Froh14	4	0.912	4*	0.902	6	0.965	8	0.939	8	0.881

The model got worst when adding one not-similar beehive

staged_2/Doettingen_Echolinde_Erlen_UnitedQueens_Froh14	4	0.912	4*	0.902	6	0.965	8	0.939	8	0.881
staged_2/Doettingen_Echolinde_Erlen_UnitedQueens	2	0.948	1	0.942	2	0.98	5	0.966	24	0.498




+

* Adjusted score because "on_qty_of_images" models

Staged – mix-shaped beehives

Froh14 + Chueried_01 + Erlen_Hive11 + Froh23_TreeCavity + UnitedQueens

	Froh14		Chueried_Hive01		Erlen_Hive11		Froh23_TreeCavity		UnitedQueens	
	Model Rank	F2-Score	Model Rank	F2-Score	Model Rank	F2-Score	Model Rank	F2-Score	Model Rank	F2-Score
single_hive/Froh14	1	0.915								
individual_training/Chueried_Hive01			3	0.925						
individual_training/Erlen_Hive11					2	0.947				
single_hive/Froh23_TreeCavity							2	0.822		
single_hive/UnitedQueens									2	0.985
staged_2/BeeWatch_Chueried_01_Erlen_Hive_11_Froh_23_UnitedQueens	6*	0.873	1	0.987	1	0.96	1	0.899	1	0.987

- Most seem to gain from variance in data. Froh14 -> inconclusive
- On not-included hives Rank avg is 9, and F2-S is 0.84 -> does not perform well on unknown hives (but general model was worst)





* Adjusted score because "on_qty_of_images" models.

Staged vs top model

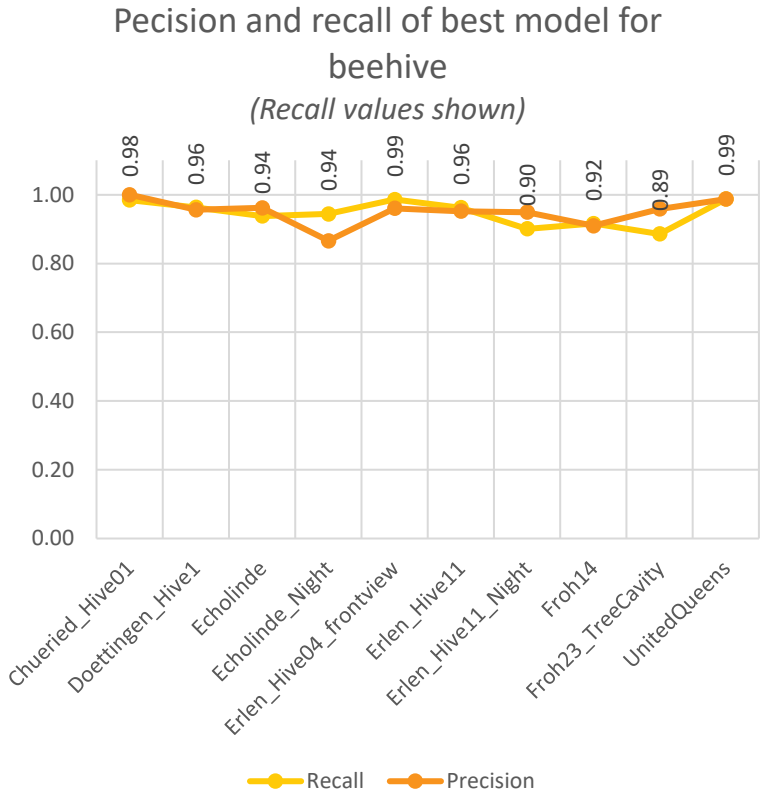
Model	Beehive	Precision	Recall	F2-score	Model Type	Next best Model Rank	Diff F2-Score	Avg. Diff F2-Score
single_hive/Doettingen_Hive1	Doettingen_Hive1	0.956	0.963	0.962	single_hive	2	-0.013	-0.016
single_hive/Erlen_Hive04_frontview	Erlen_Hive04_frontview	0.976	0.984	0.982	single_hive	2	-0.002	
single_hive/Froh14	Froh14	0.910	0.916	0.915	single_hive	4*	**-0.034**	
staged_2/BeeWatch_Chueried_01_Erlen_Hive_11_Froh_23_UnitedQueens	Chueried_Hive01	1.000	0.985	0.988	staged_2	3	**-0.062**	-0.032
staged_2/Doettingen_Echolinde_Erlen_UnitedQueens	Echolinde	0.962	0.938	0.943	staged_2	2	-0.008	
staged_2/BeeWatch_Chueried_01_Erlen_Hive_11_Froh_23_UnitedQueens	Erlen_Hive11	0.952	0.963	0.961	staged_2	2	-0.013	
staged_2/BeeWatch_Chueried_01_Erlen_Hive_11_Froh_23_UnitedQueens	Froh23_TreeCavity	0.959	0.886	0.900	staged_2	2	**-0.077**	
staged_2/BeeWatch_Chueried_01_Erlen_Hive_11_Froh_23_UnitedQueens	UnitedQueens	0.988	0.988	0.988	staged_2	2	-0.002	

* Adjusted score because “on_qty_of_images” models.

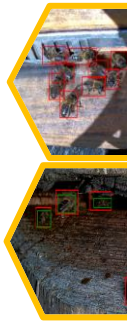
Staged training

- **Conclusion**: Inconclusive. For “common shaped” beehives it seems that single training was better but only avg. 1.6% better than the all-similar staged model.
- Staging of one not-similar shaped beehives reduced the performance; but the test of mix-shaped performed well in *known* hives
- Future work. Except individual model performance <0.9 or <0.95 avoid staging (reduce complexity)

Object recognition summary



- For relevant beehives
- Recall
  - over 0.95 for 5/10
  - over 0.9 for 9/10
  - one with 0.89
- Precision
  - over 0.95 for 7/10
  - over 0.9 for 9/10
  - one with 0.86
- All top models trained with 80 frames
- Five of the models where “single training” models, five were “staged training”



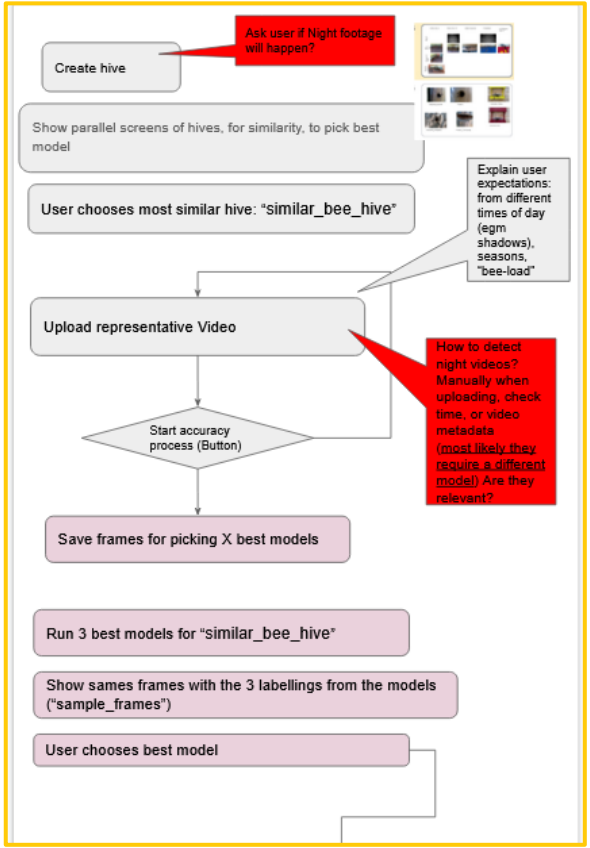
Cloud platform specifications

Cloud platform specifications

With stakeholders:

- Define User Functionality,
- Define System Functionality,
- Set priorities and defining of MVP

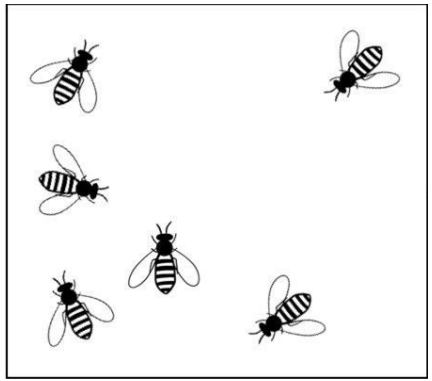
- With Platform Team, defining platform workflows and sharing our scripts:
  - New hives
  - Training new models
  - Validation



Bee Tracking

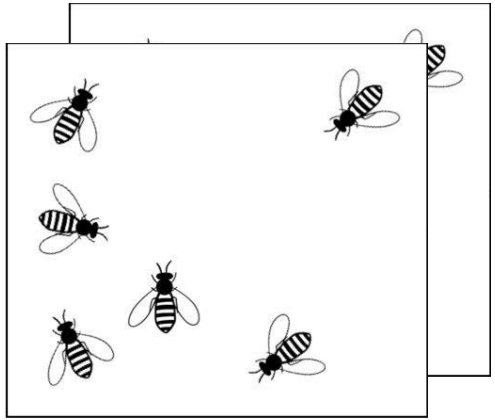
Problem

Video as a sequence of frames



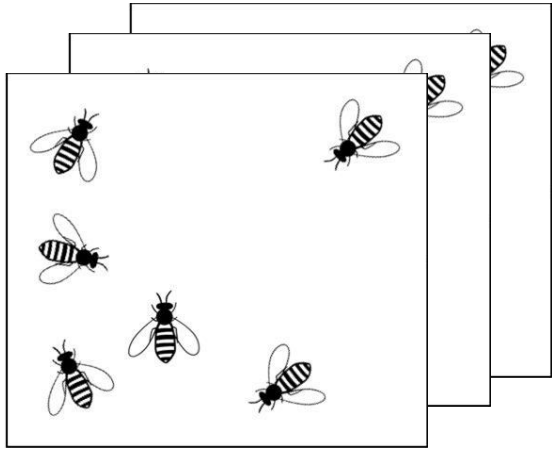
Problem

Video as a sequence of frames



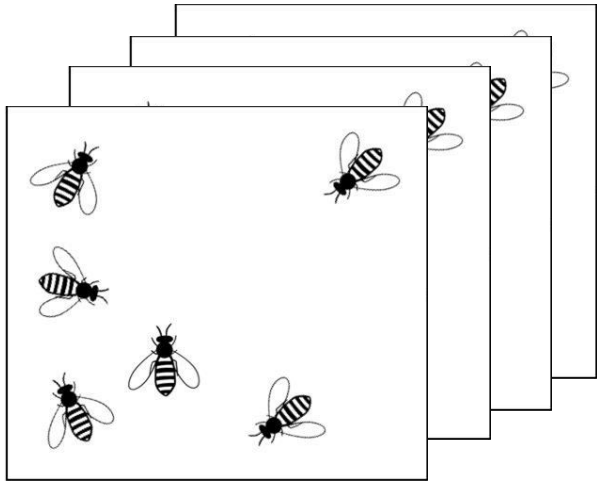
Problem

Video as a sequence of frames



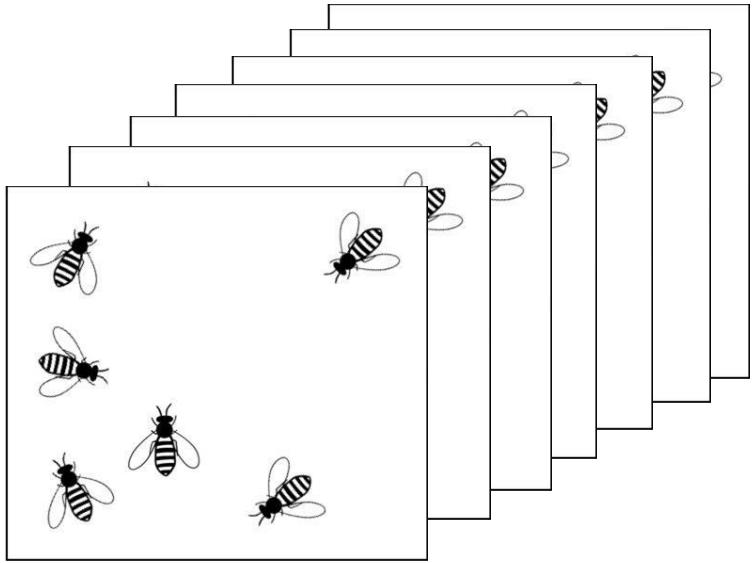
Problem

Video as a sequence of frames



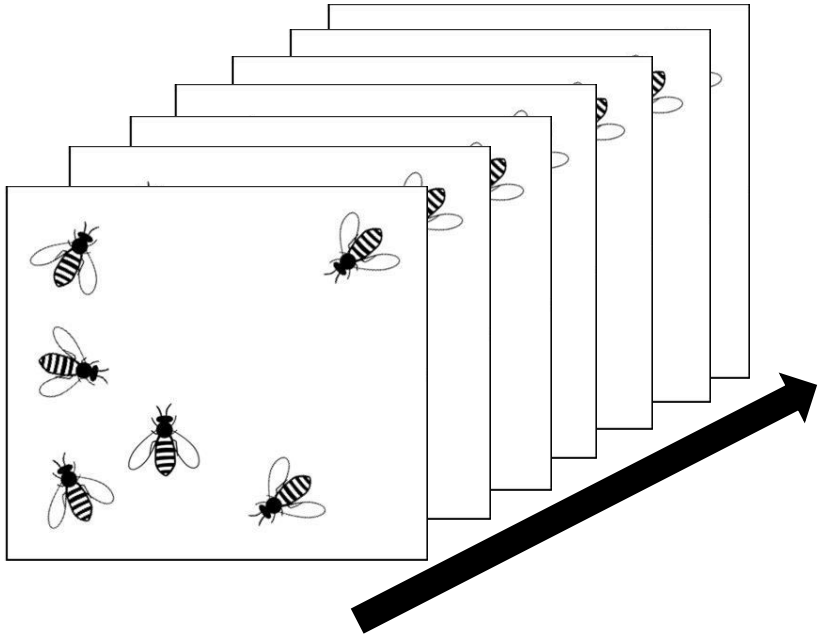
Problem

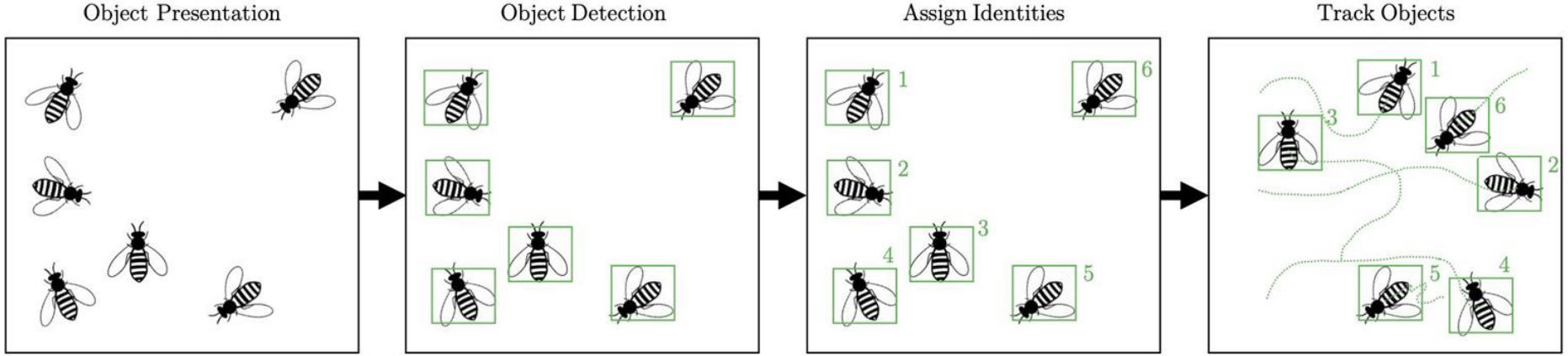
Video as a sequence of frames

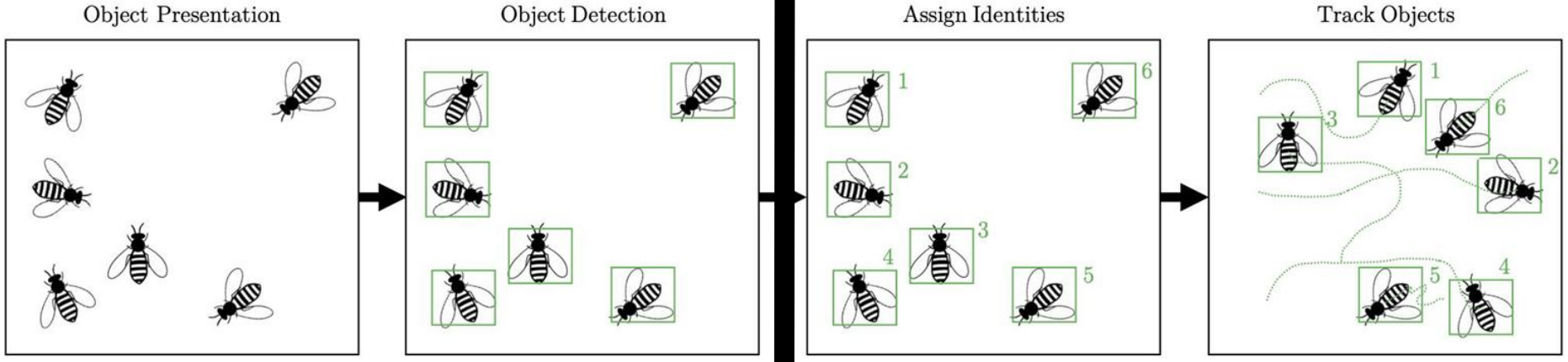


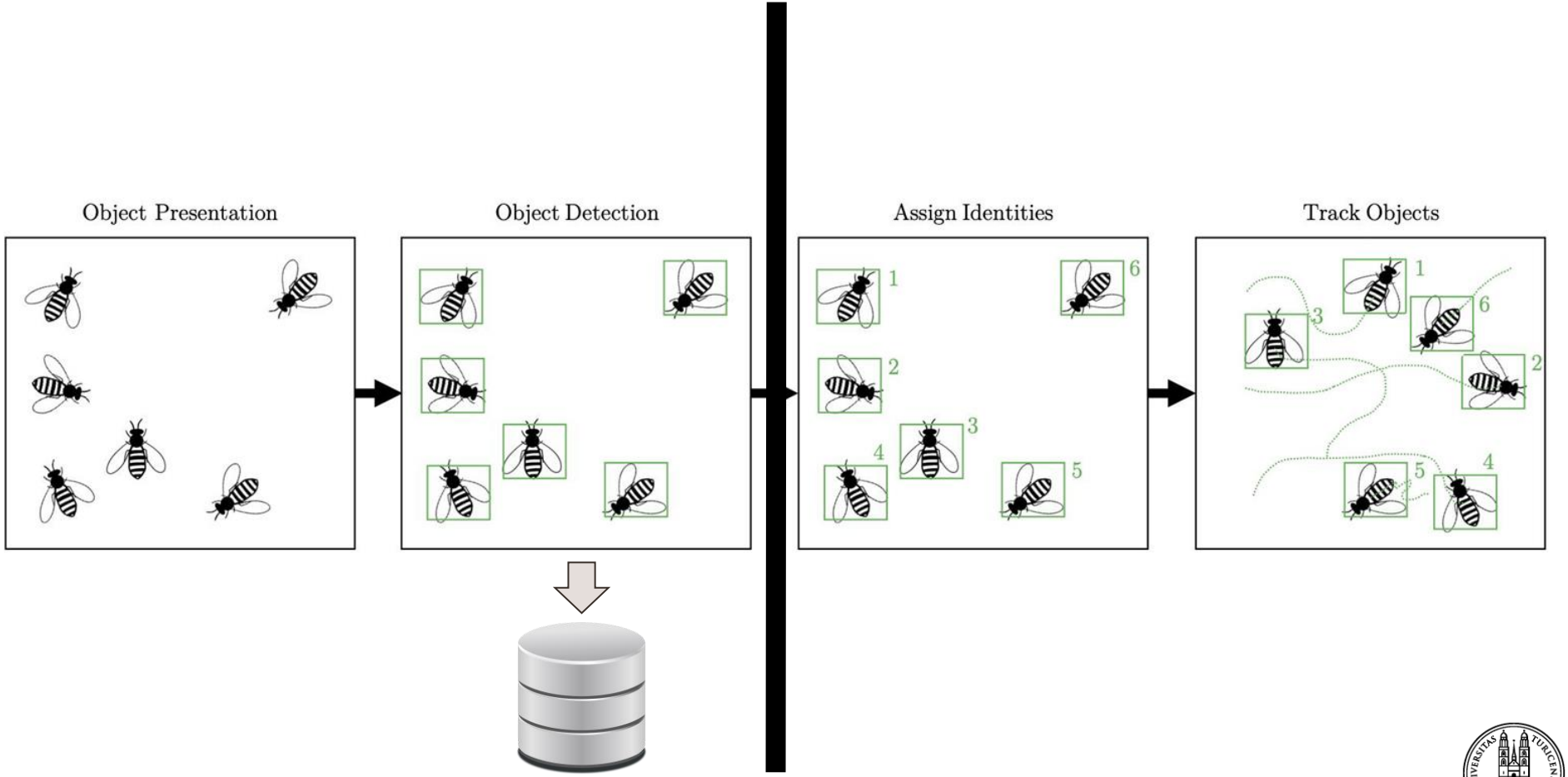
Problem

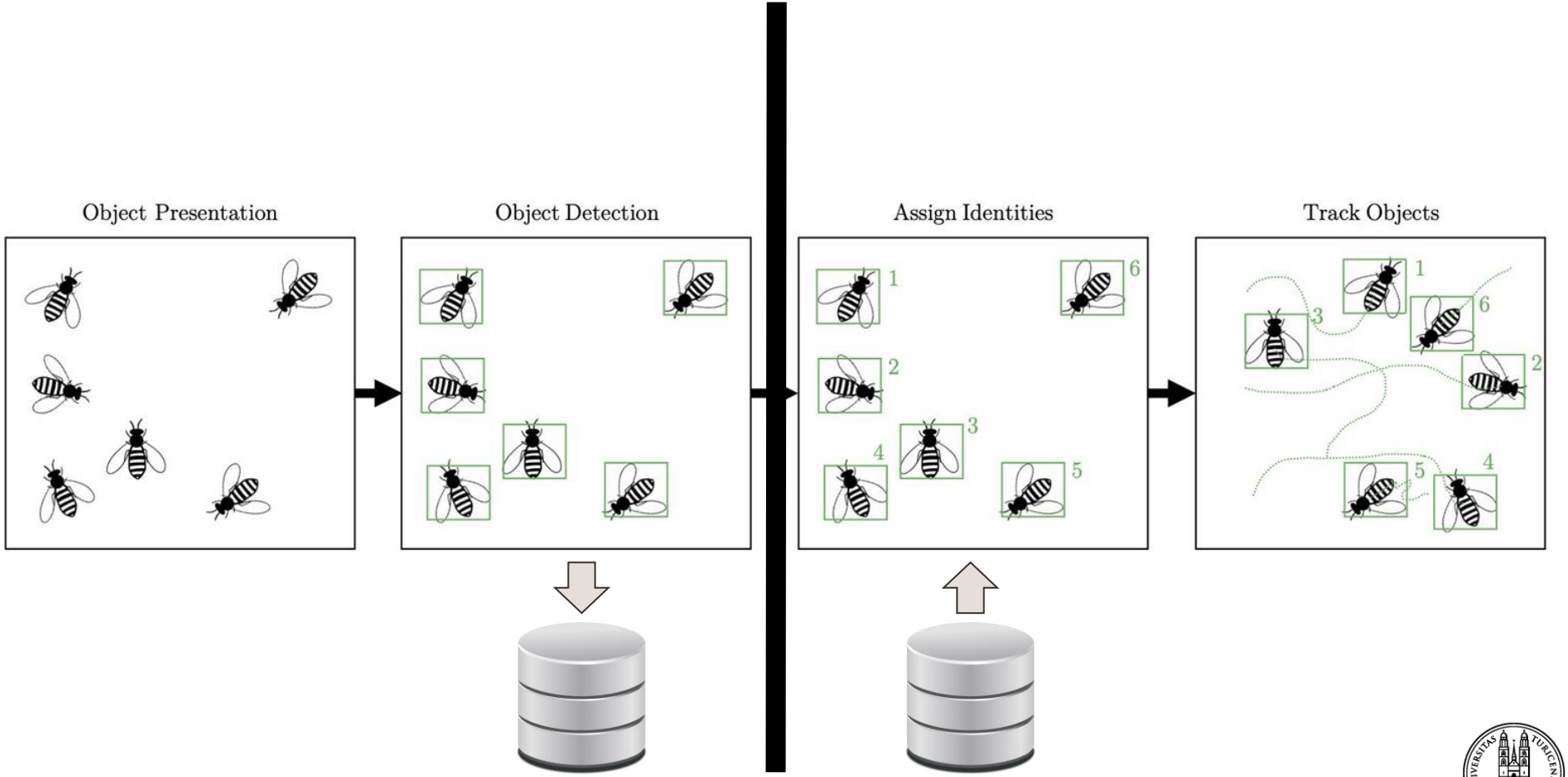
Video as a sequence of frames



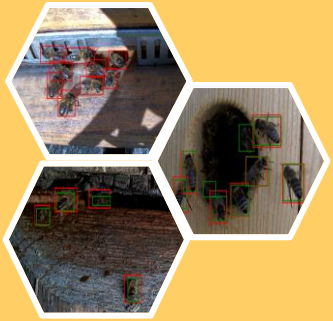

Object Presentation
Object Detection
Assign Identities
Track Objects
1
6
2
3
4
5
1
6
3
2
5
4

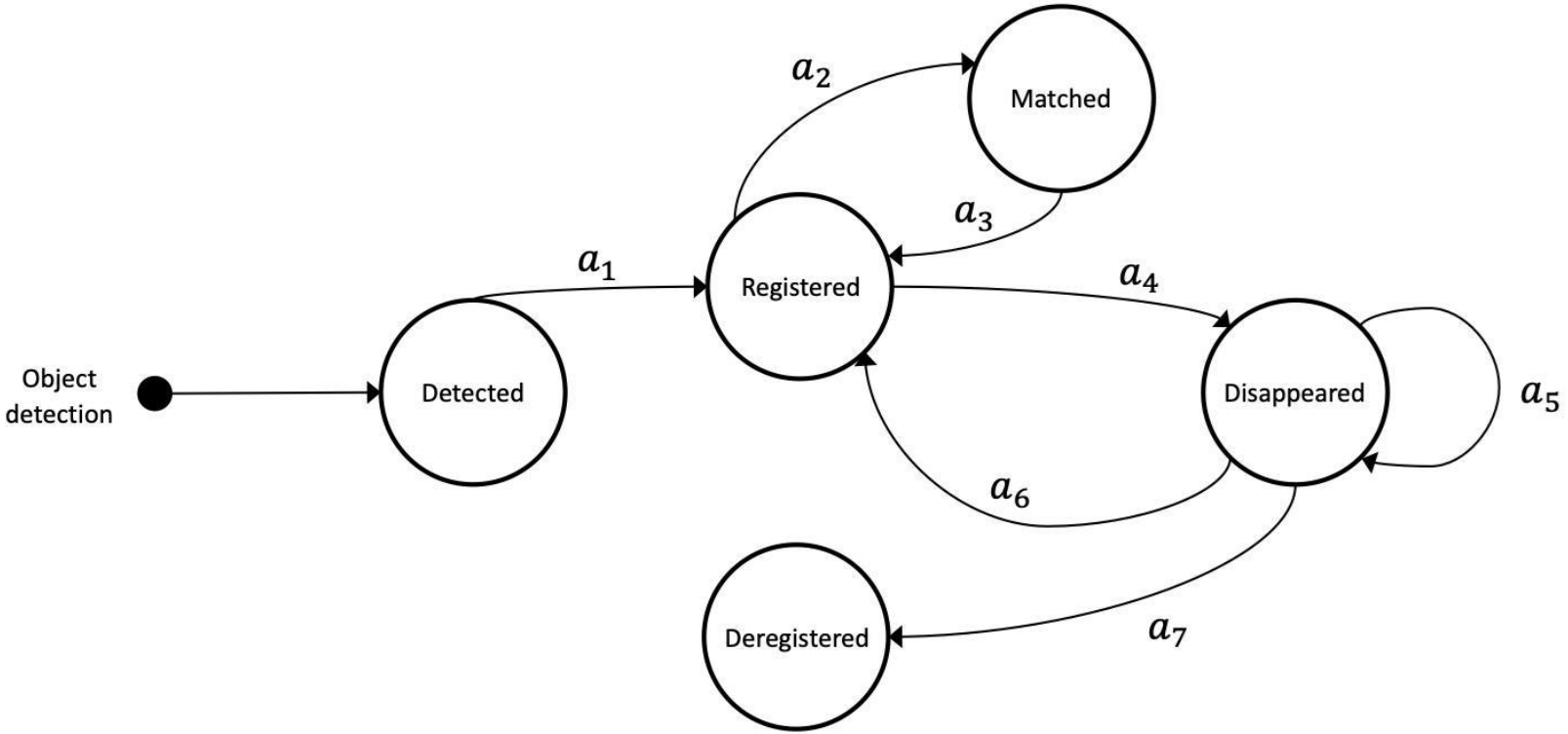

Object Presentation
Object Detection
Assign Identities
Track Objects
1
6
2
3
4
5
1
6
3
2
5
4

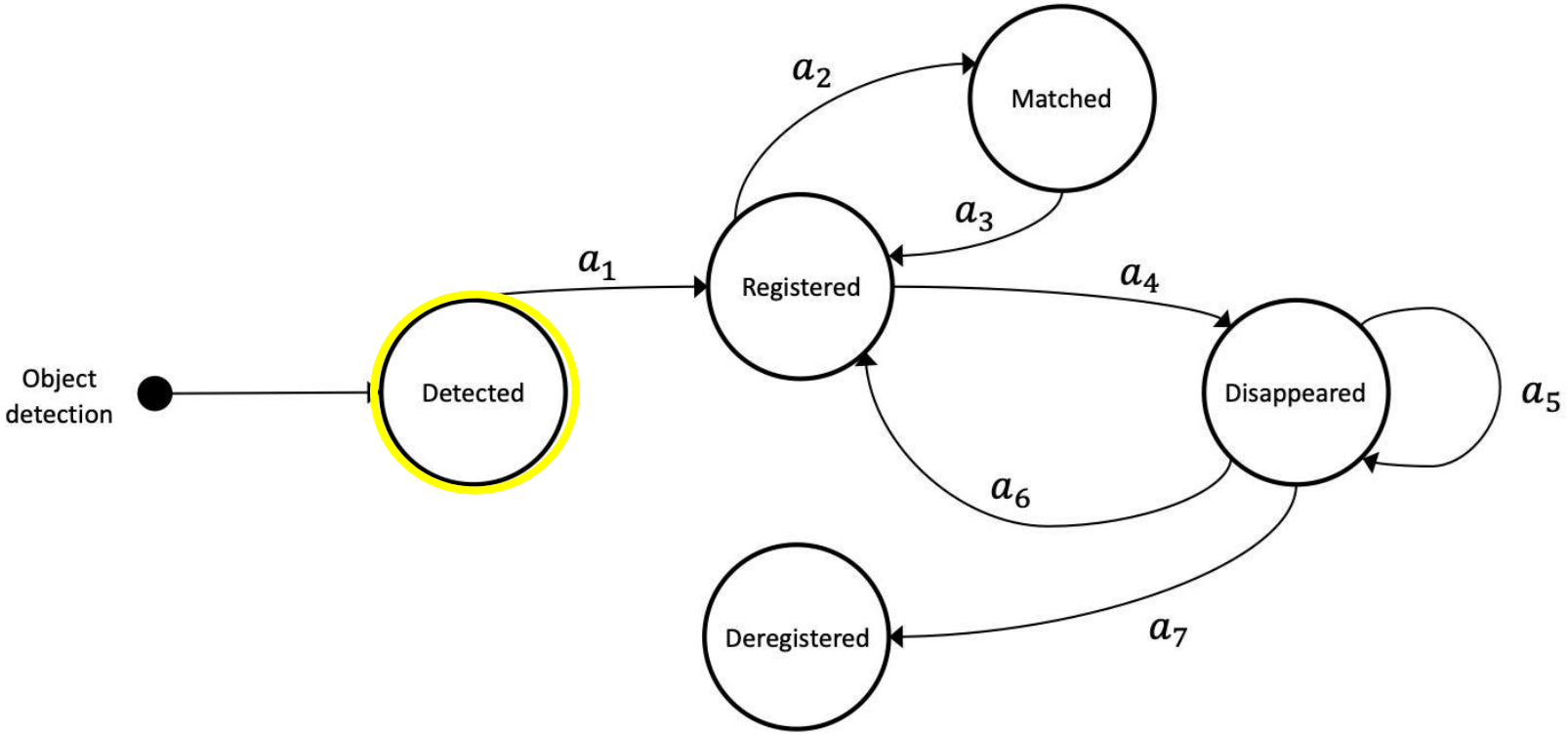

Object Presentation
Object Detection
Assign Identities
Track Objects
1
6
2
3
4
5
1
6
3
2
5
4


Object Presentation
Object Detection
Assign Identities
Track Objects
1
2
3
4
5
6

Our Approach

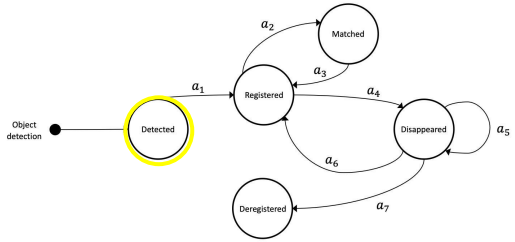



Object detection
Detected
Registered
Matched
Deregistered
Disappeared
a_1
a_2
a_3
a_4
a_5
a_6
a_7

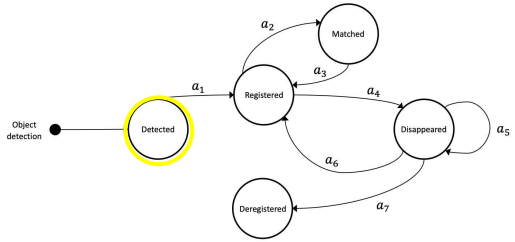

Object detection
Detected
Registered
Matched
Disappeared
Deregistered
a_1
a_2
a_3
a_4
a_5
a_6
a_7

Detection

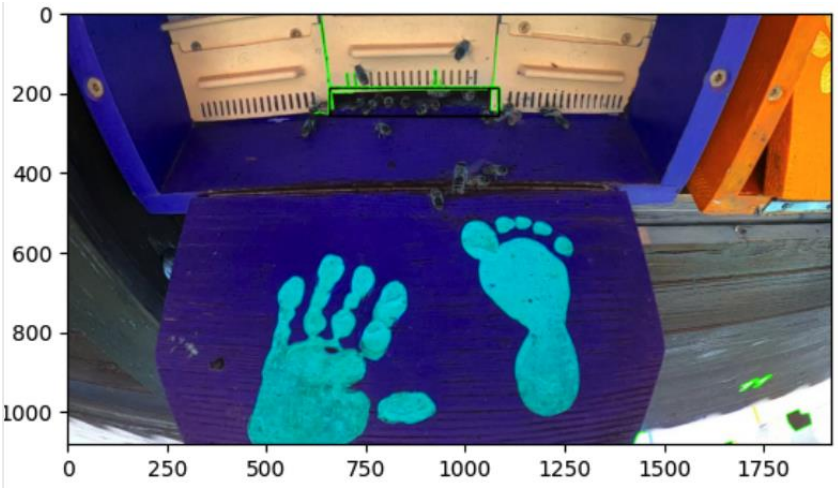
- Hive entrance detection



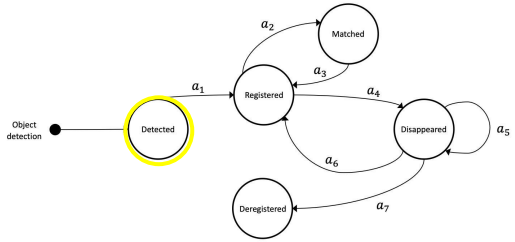
Detection



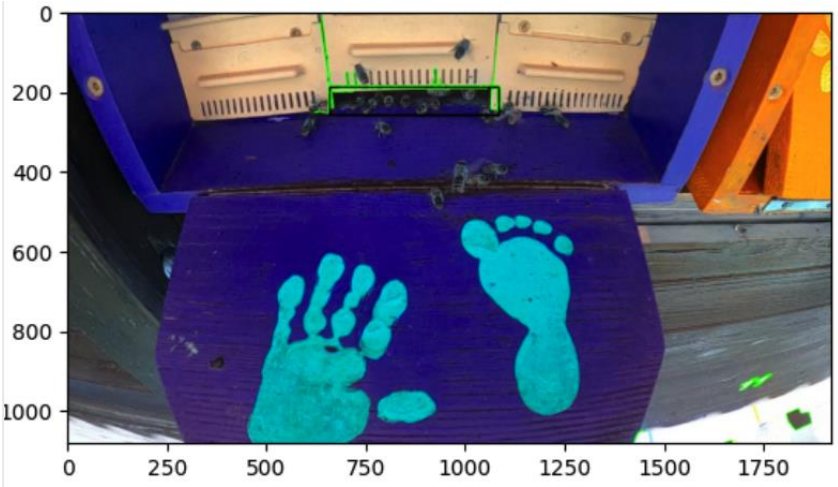
- Hive entrance detection

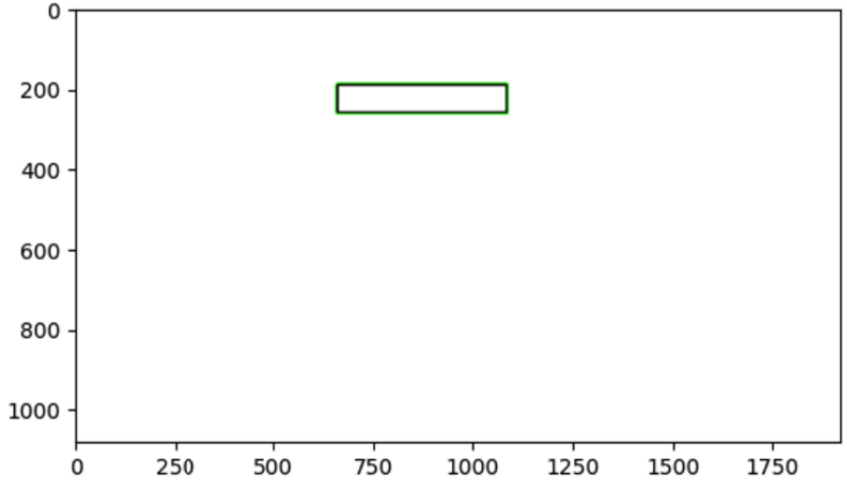


Detection



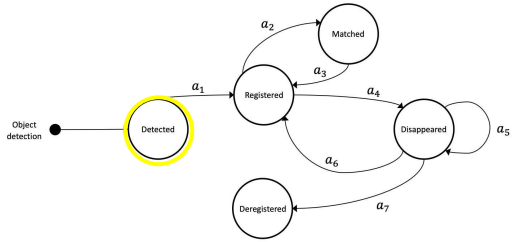
- Hive entrance detection



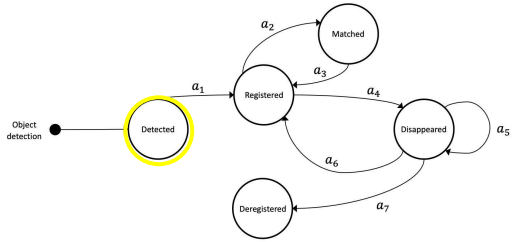


Detection

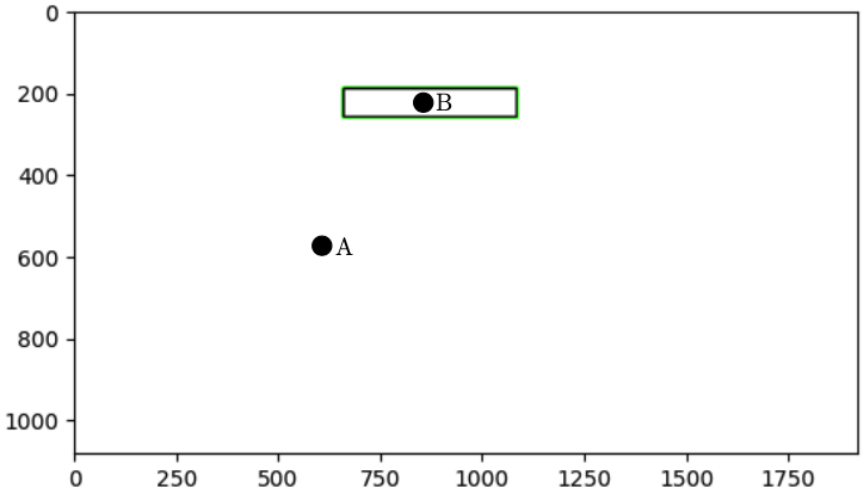
- Hive entrance detection
- Point Polygon Test



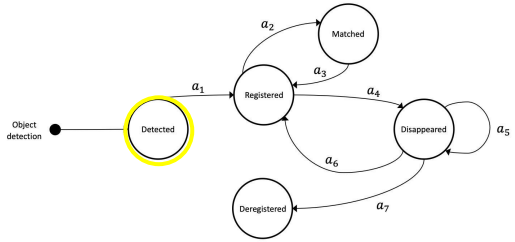
Detection



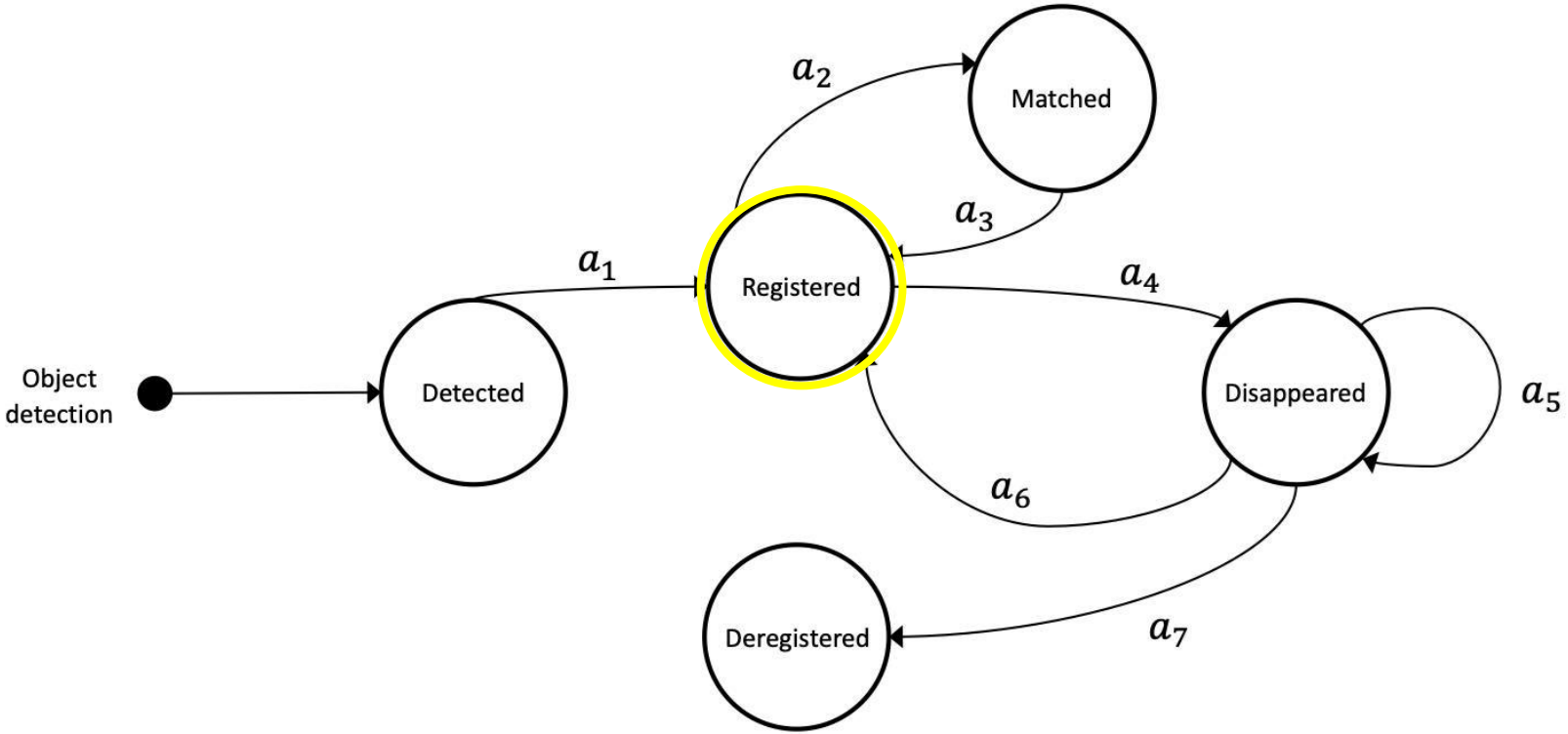
- Hive entrance detection
- Point Polygon Test



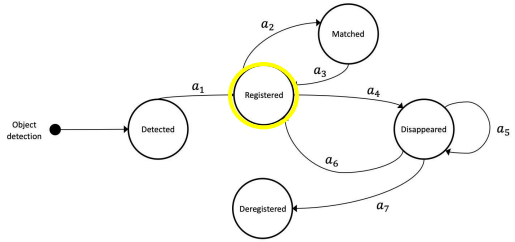
Detection



- Hive entrance detection
- Point Polygon Test
- Combining database and video

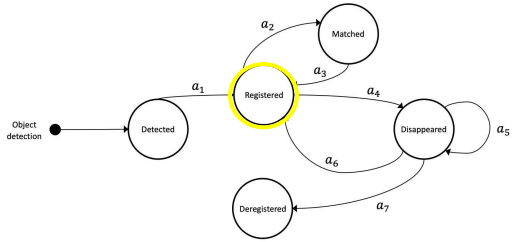

Object detection
Detected
Registered
Matched
Disappeared
Deregistered
a_1
a_2
a_3
a_4
a_5
a_6
a_7

Registration



- First frame: register all objects

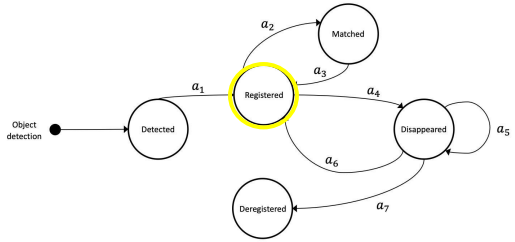
Registration



- First frame: register all objects

Frame 1

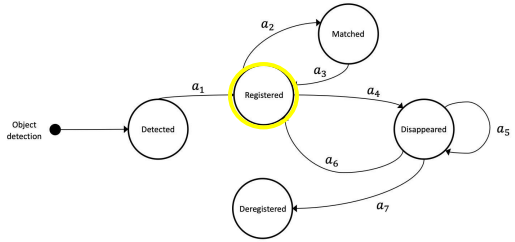
Registration



- First frame: register all objects

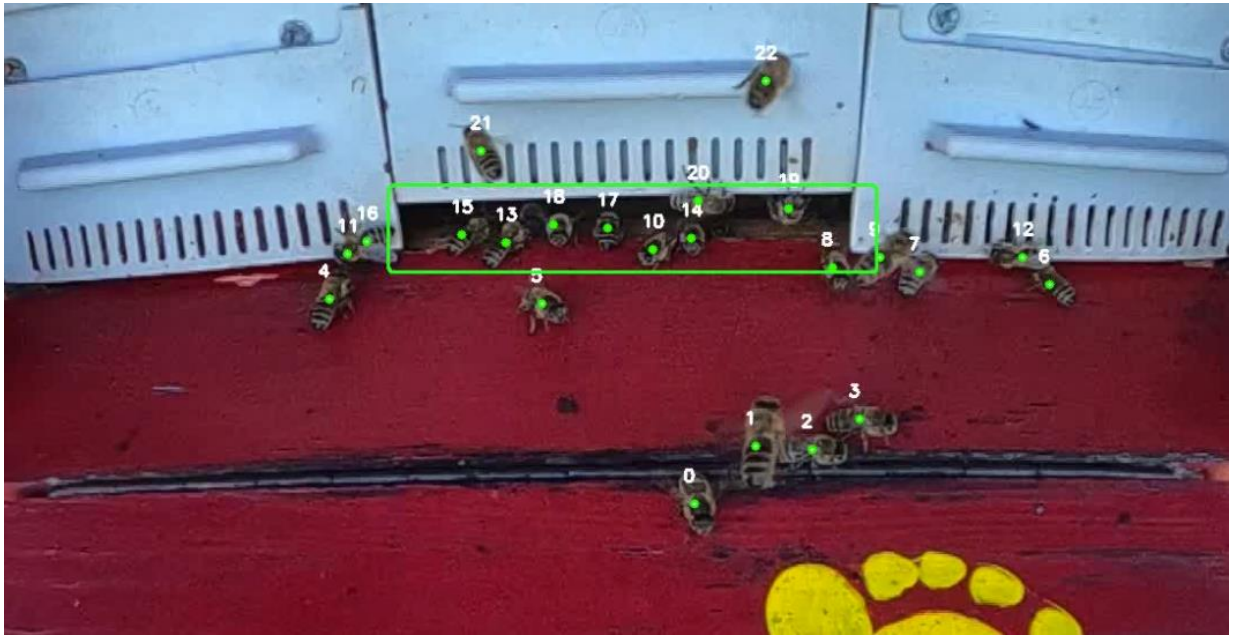
Frame 1	
0	
1	
2	

Registration

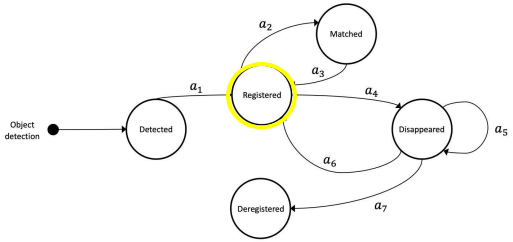


- First frame: register all objects

Frame 1
0 
1 
2 



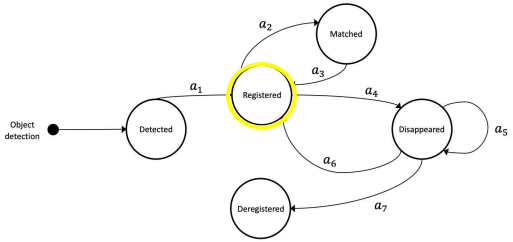
Registration



- First frame: register all objects
- Every subsequent frame: check for numbers mismatch

Frame 1
0 
1 
2 

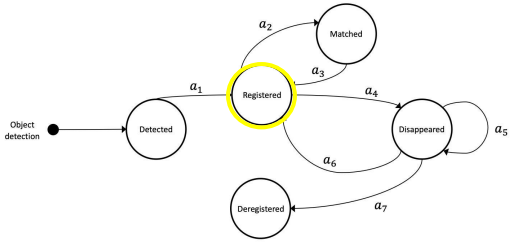
Registration



- First frame: register all objects
- Every subsequent frame: check for numbers mismatch

	Frame 1	Frame 2
0		
1		
2		

Registration

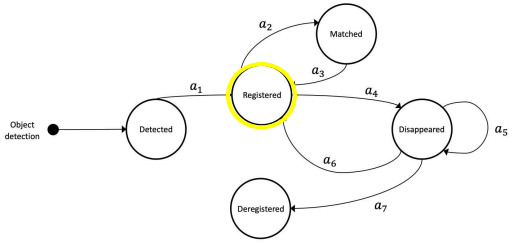


- First frame: register all objects
- Every subsequent frame: check for numbers mismatch

	Frame 1	Frame 2
0		
1		
2		

Nr. registered = Nr. new objects

Registration

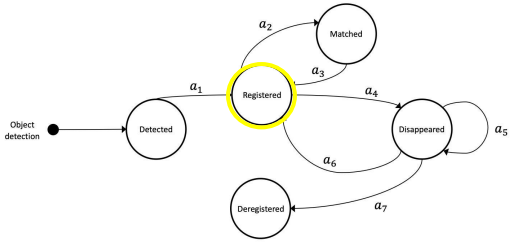


- First frame: register all objects
- Every subsequent frame: check for numbers mismatch

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered = Nr. new objects	

Frame 1	Frame 2
0 	
1 	
2 	

Registration

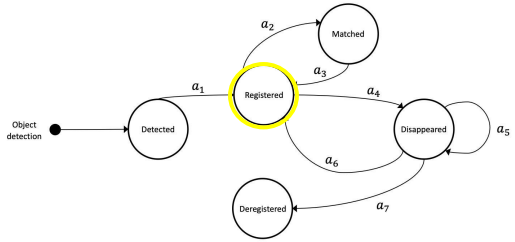


- First frame: register all objects
- Every subsequent frame: check for numbers mismatch

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered = Nr. new objects	

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered > Nr. new objects	

Registration



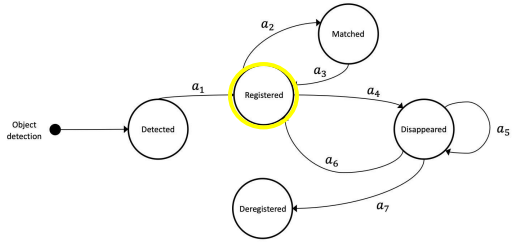
- First frame: register all objects
- Every subsequent frame: check for numbers mismatch

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered = Nr. new objects	

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered > Nr. new objects	

Frame 1	Frame 2
0 	
1 	
	

Registration



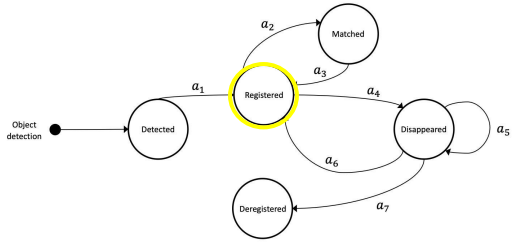
- First frame: register all objects
- Every subsequent frame: check for numbers mismatch

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered = Nr. new objects	

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered > Nr. new objects	

Frame 1	Frame 2
0 	
1 	
	
Nr. registered < Nr. new objects	

Registration



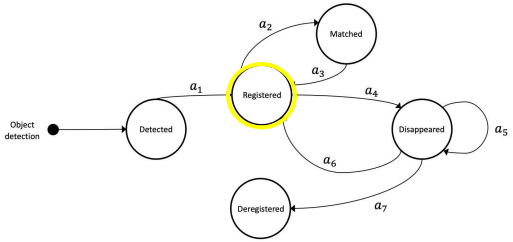
- First frame: register all objects
- Every subsequent frame: check for numbers mismatch

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered = Nr. new objects	

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered > Nr. new objects	

Frame 1	Frame 2
0 	
1 	
	
Nr. registered < Nr. new objects	

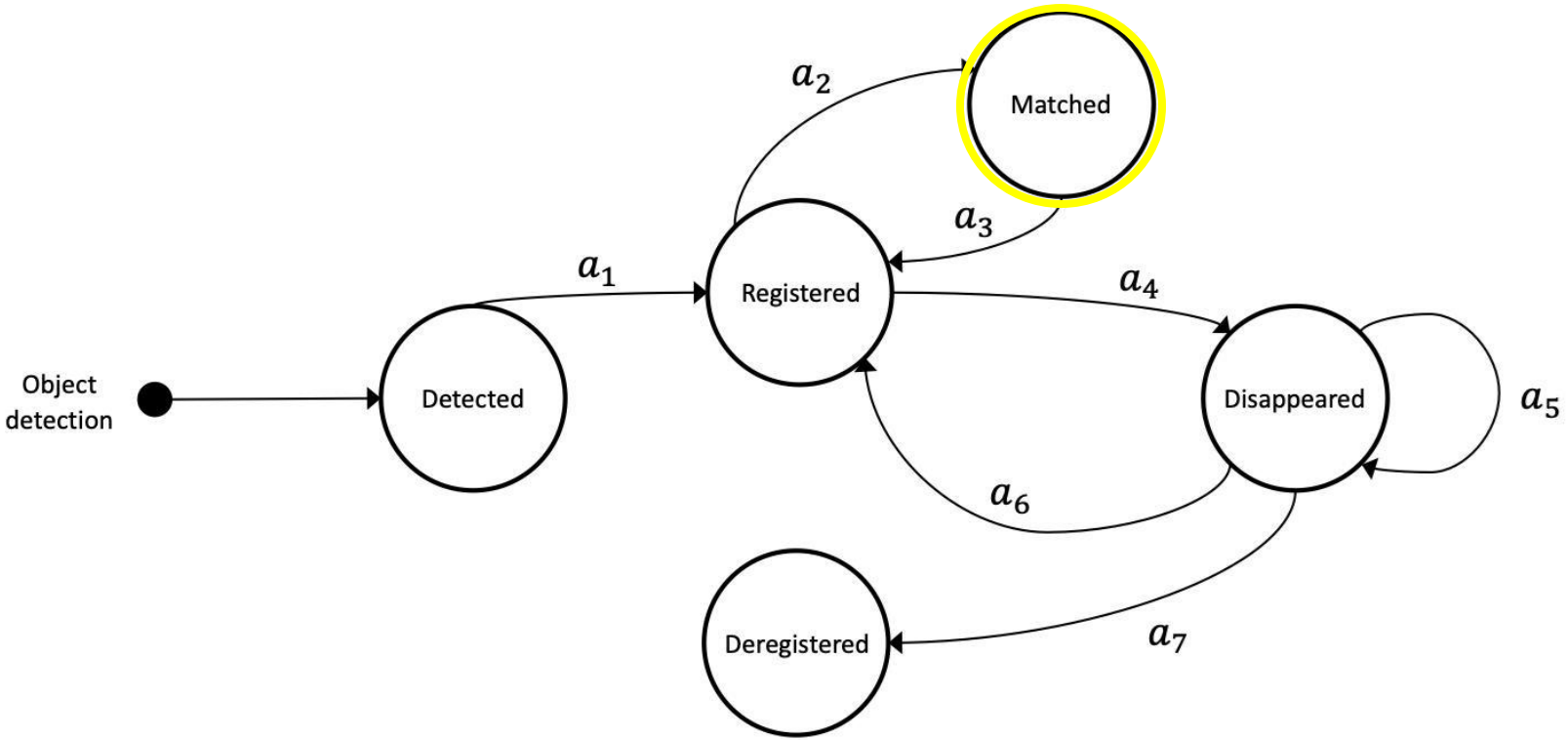
Registration



- First frame: register all objects
- Every subsequent frame: check for numbers mismatch

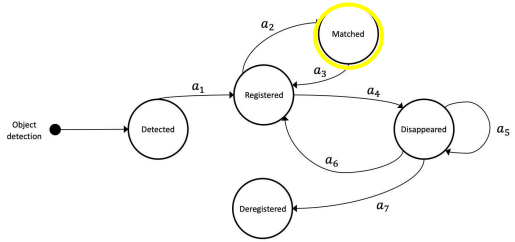
Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered = Nr. new objects	

Frame 1	Frame 2
0 	
1 	
2 	
Nr. registered > Nr. new objects	

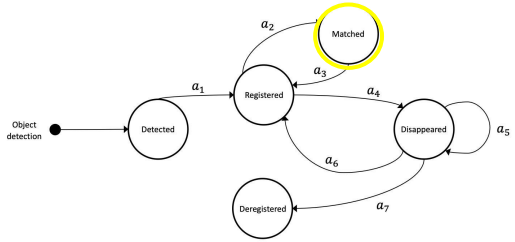

Object detection
Detected
Registered
Matched
Disappeared
Deregistered
a_1
a_2
a_3
a_4
a_5
a_6
a_7

Matching

- Find best match between objects



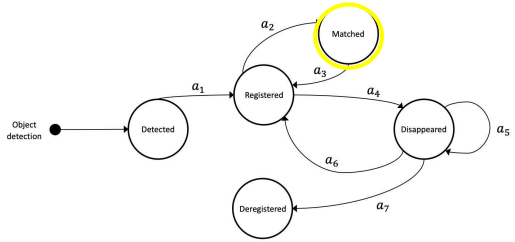
Matching



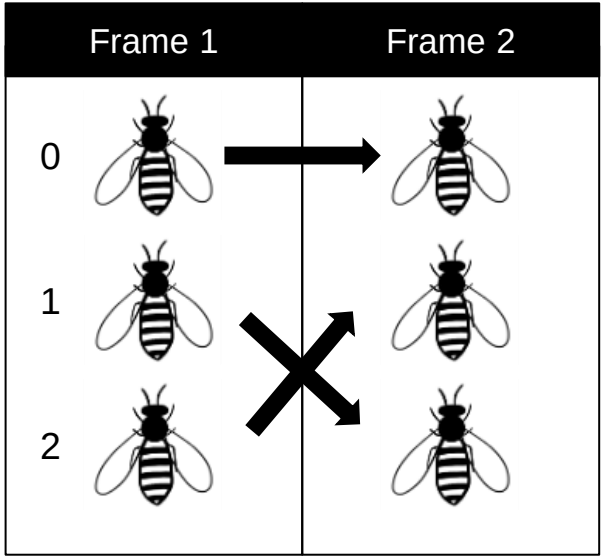
- Find best match between objects

	Frame 1	Frame 2
0		
1		
2		

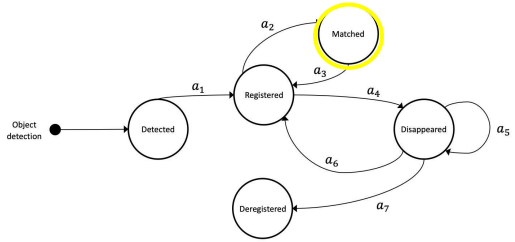
Matching



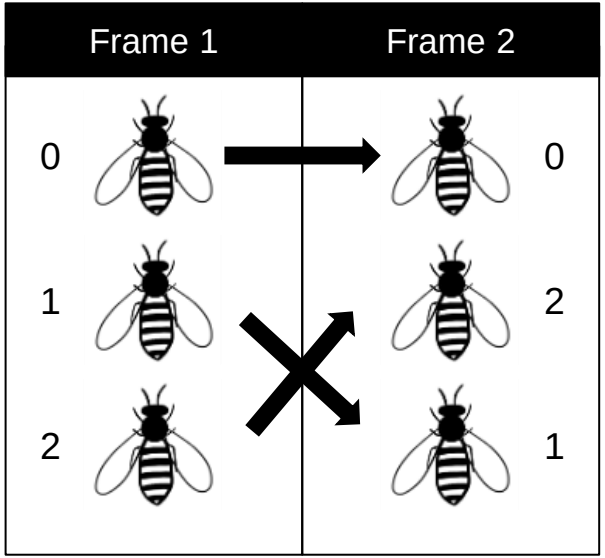
- Find best match between objects



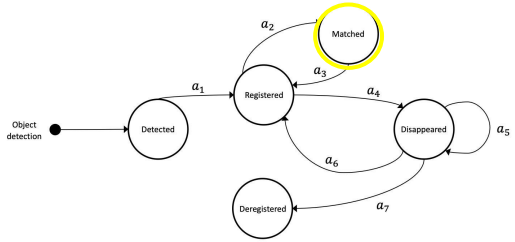
Matching



- Find best match between objects

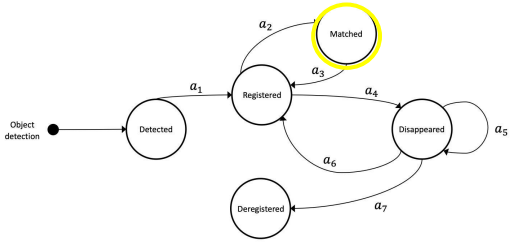


Matching



- Find best match between objects
  - Using euclidean distance

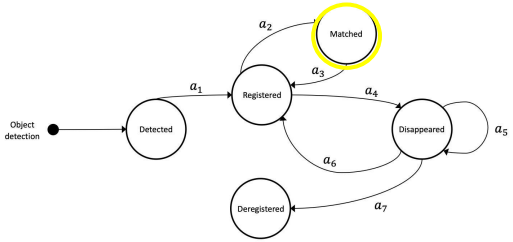
Matching



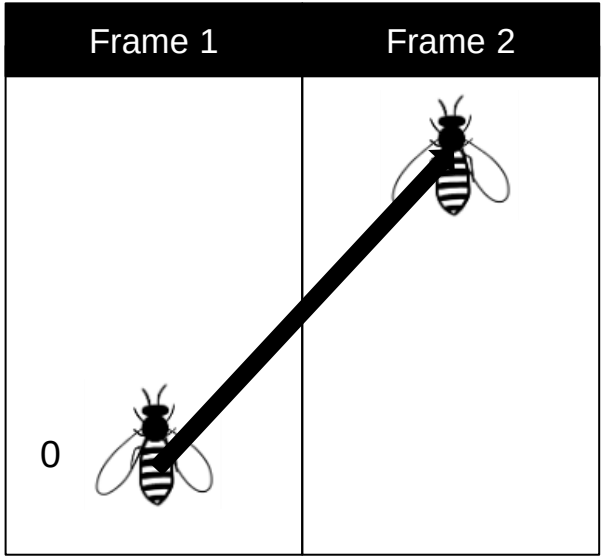
- Find best match between objects
  - Using euclidean distance

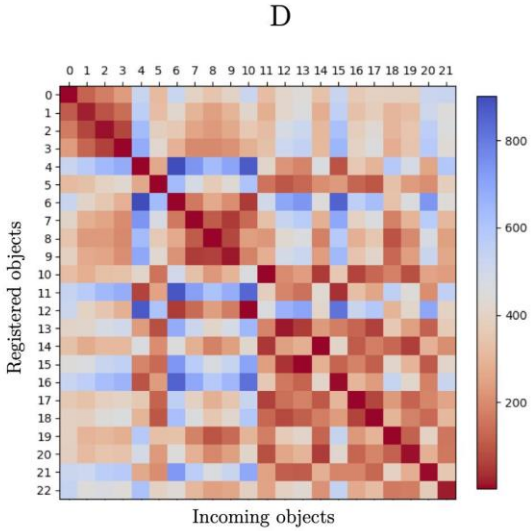
Frame 1	Frame 2
0 	

Matching

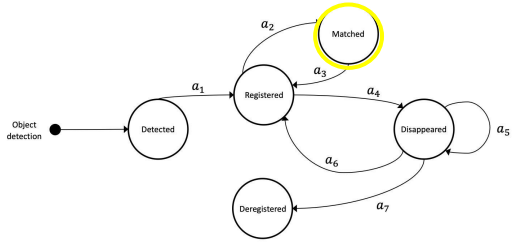


- Find best match between objects
  - Using euclidean distance

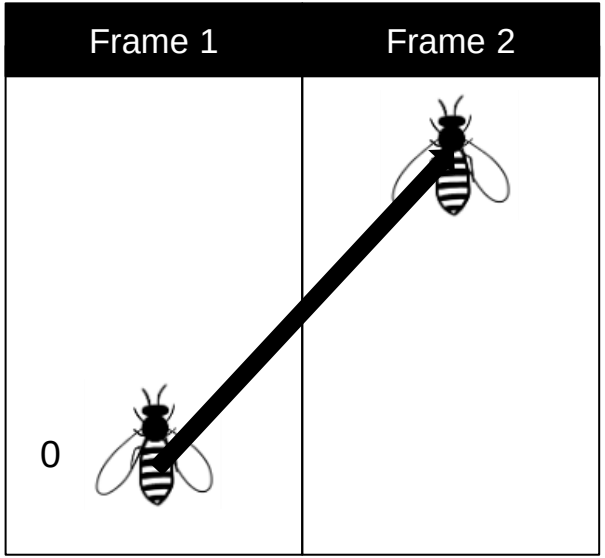


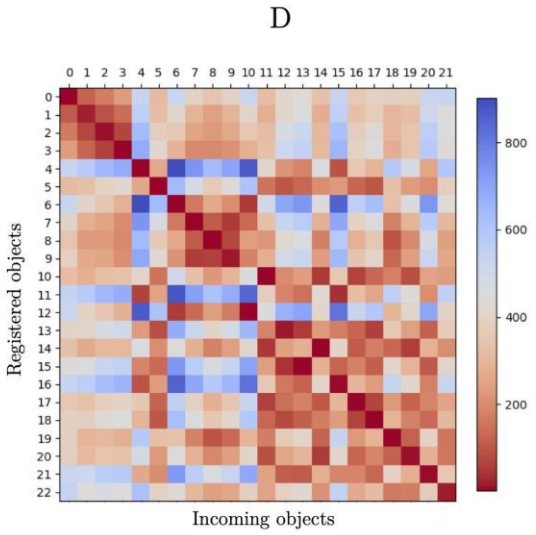


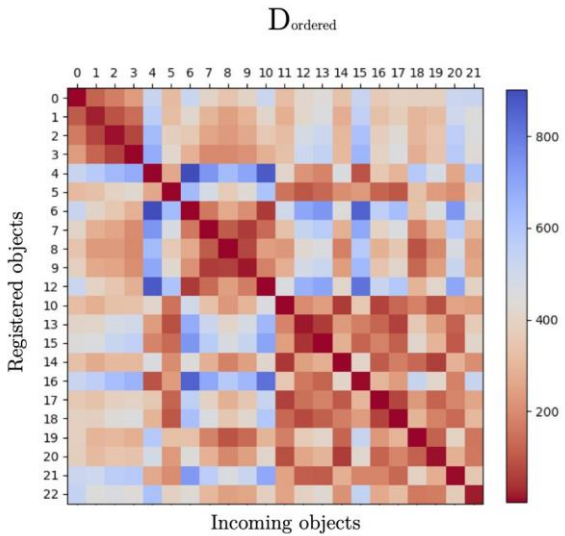
Matching



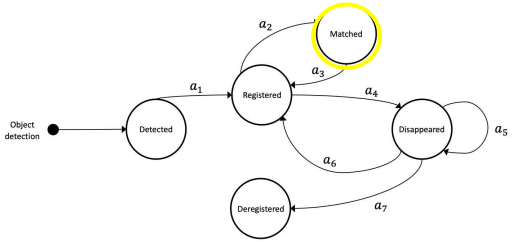
- Find best match between objects
  - Using euclidean distance



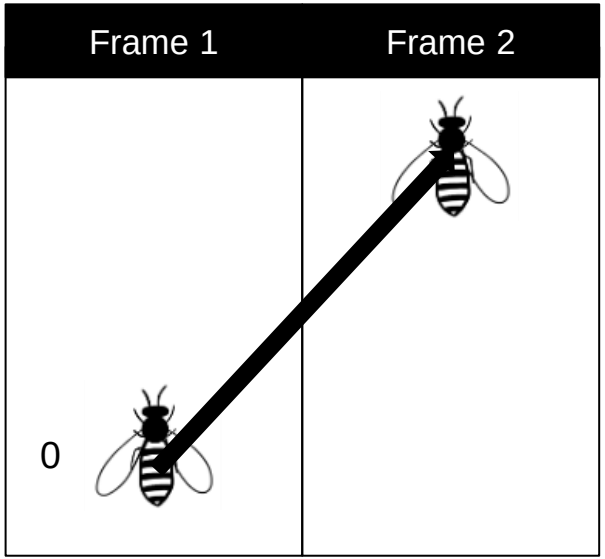




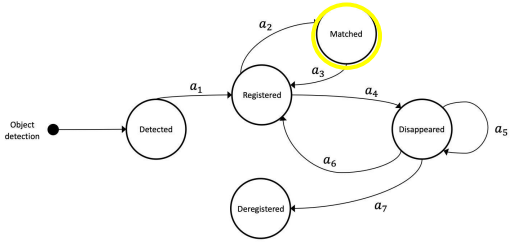
Matching



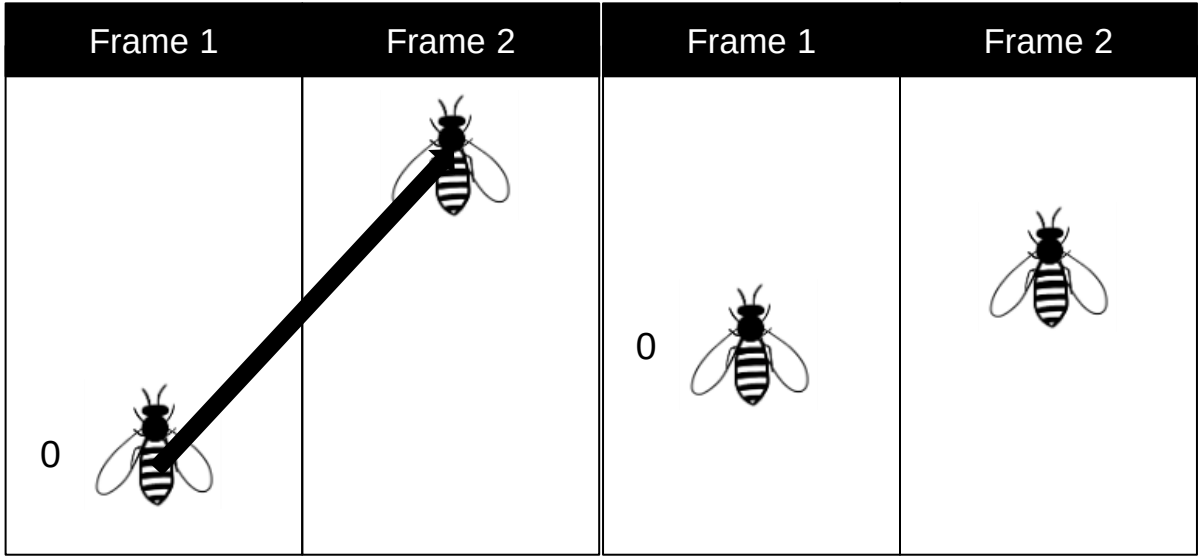
- Find best match between objects
  - Using euclidean distance & intersection over union (IOU)



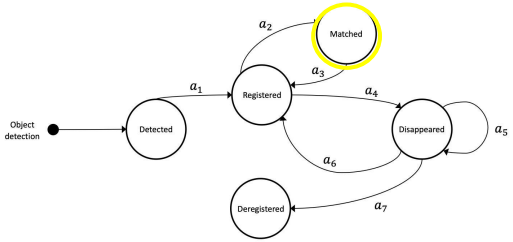
Matching



- Find best match between objects
  - Using euclidean distance & intersection over union (IOU)



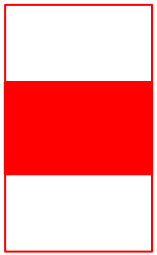
Matching



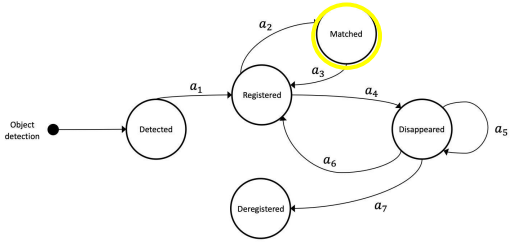
- Find best match between objects
  - Using euclidean distance & intersection over union (IOU)

Frame 1	Frame 2
0	

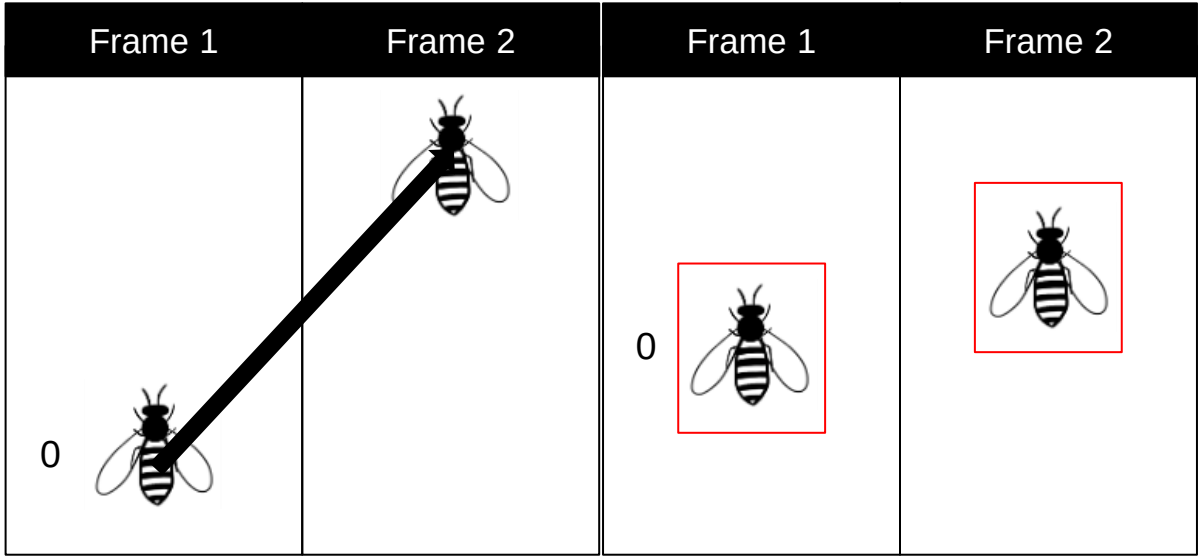
Frame 1	Frame 2
0	

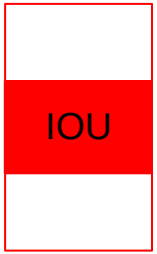


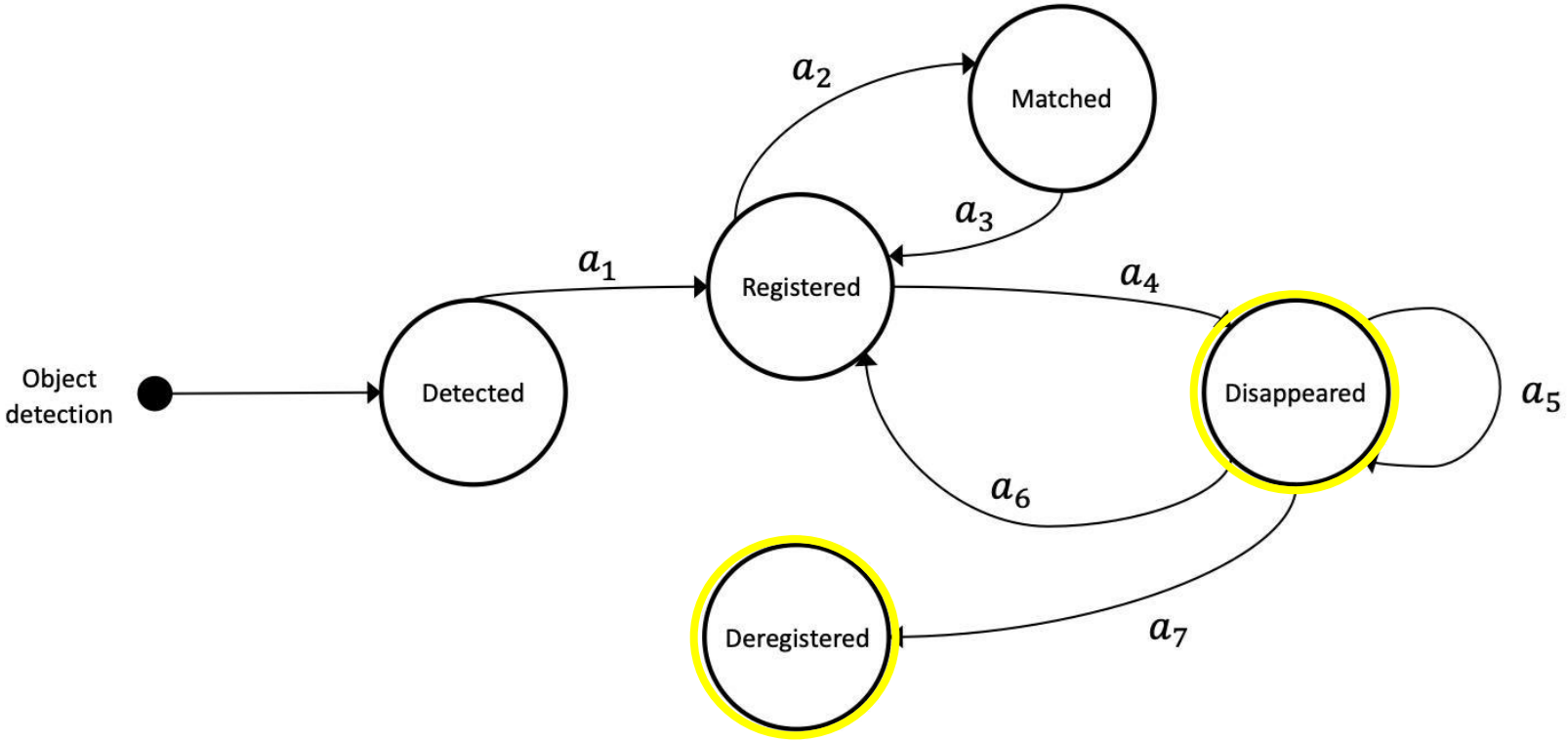
Matching



- Find best match between objects
  - Using euclidean distance & intersection over union (IOU)

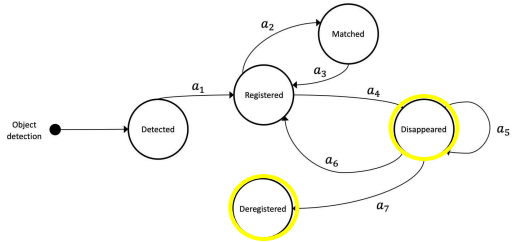




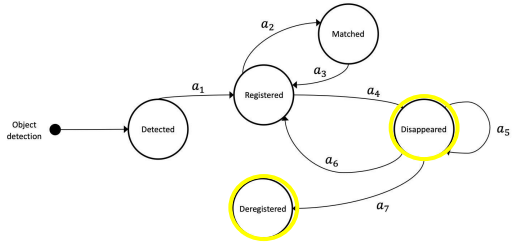

Object detection
Detected
Registered
Matched
Disappeared
Deregistered
a_1
a_2
a_3
a_4
a_5
a_6
a_7

Missing Objects

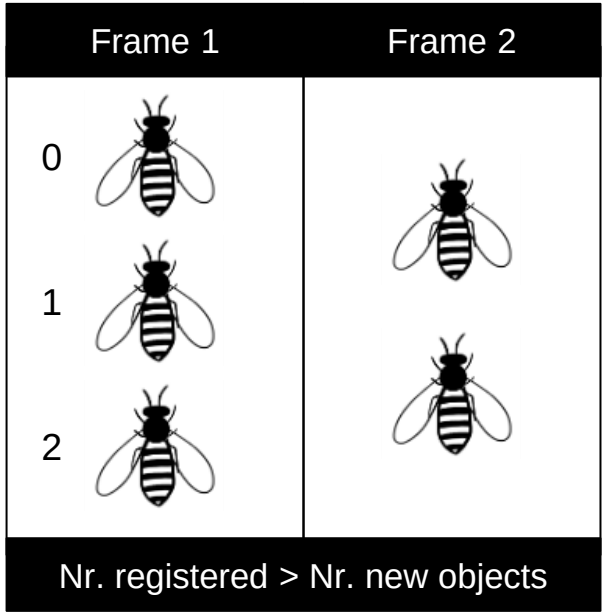
- Keep registered objects alive



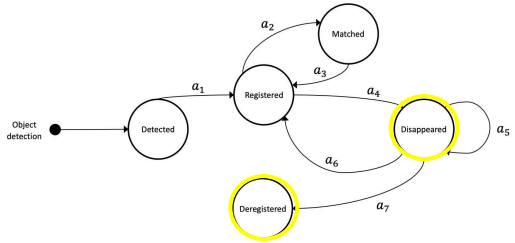
Missing Objects



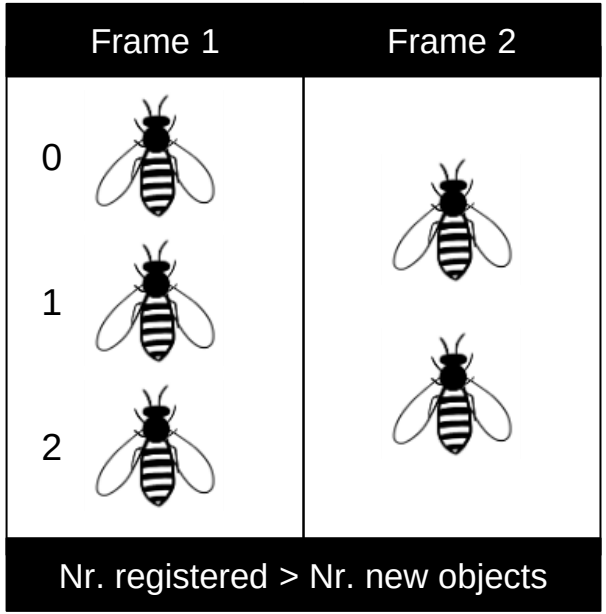
- Keep registered objects alive



Missing Objects

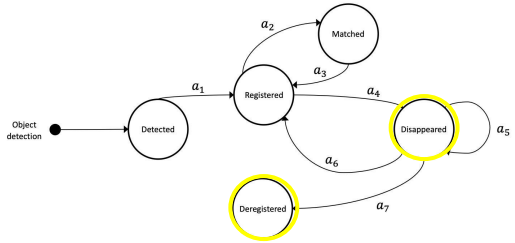


- Keep registered objects alive

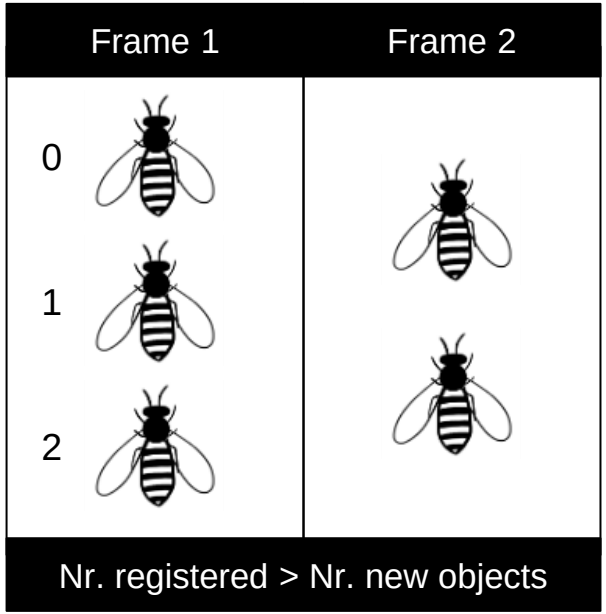


False Negative Detection

Missing Objects



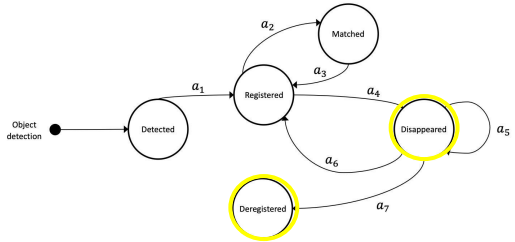
- Keep registered objects alive



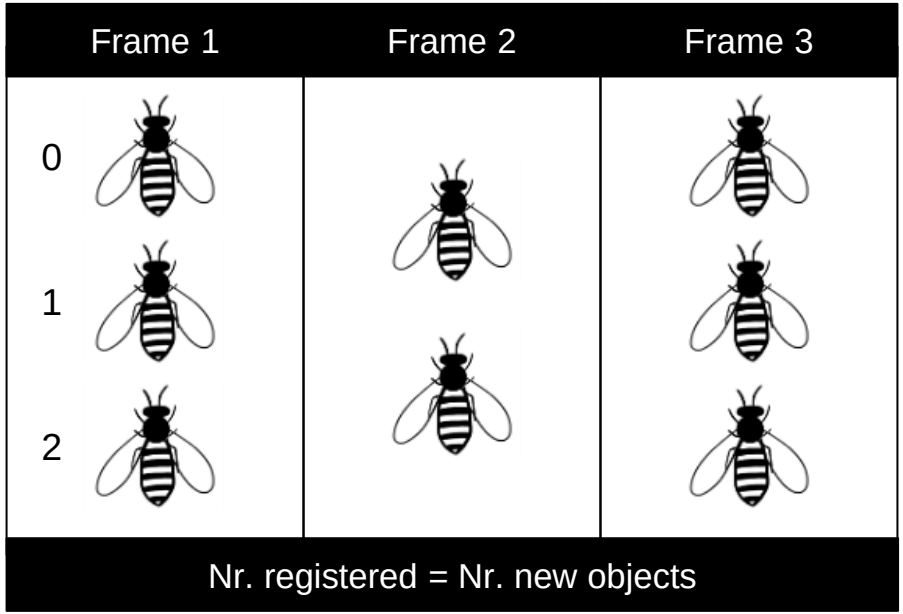
False Negative Detection

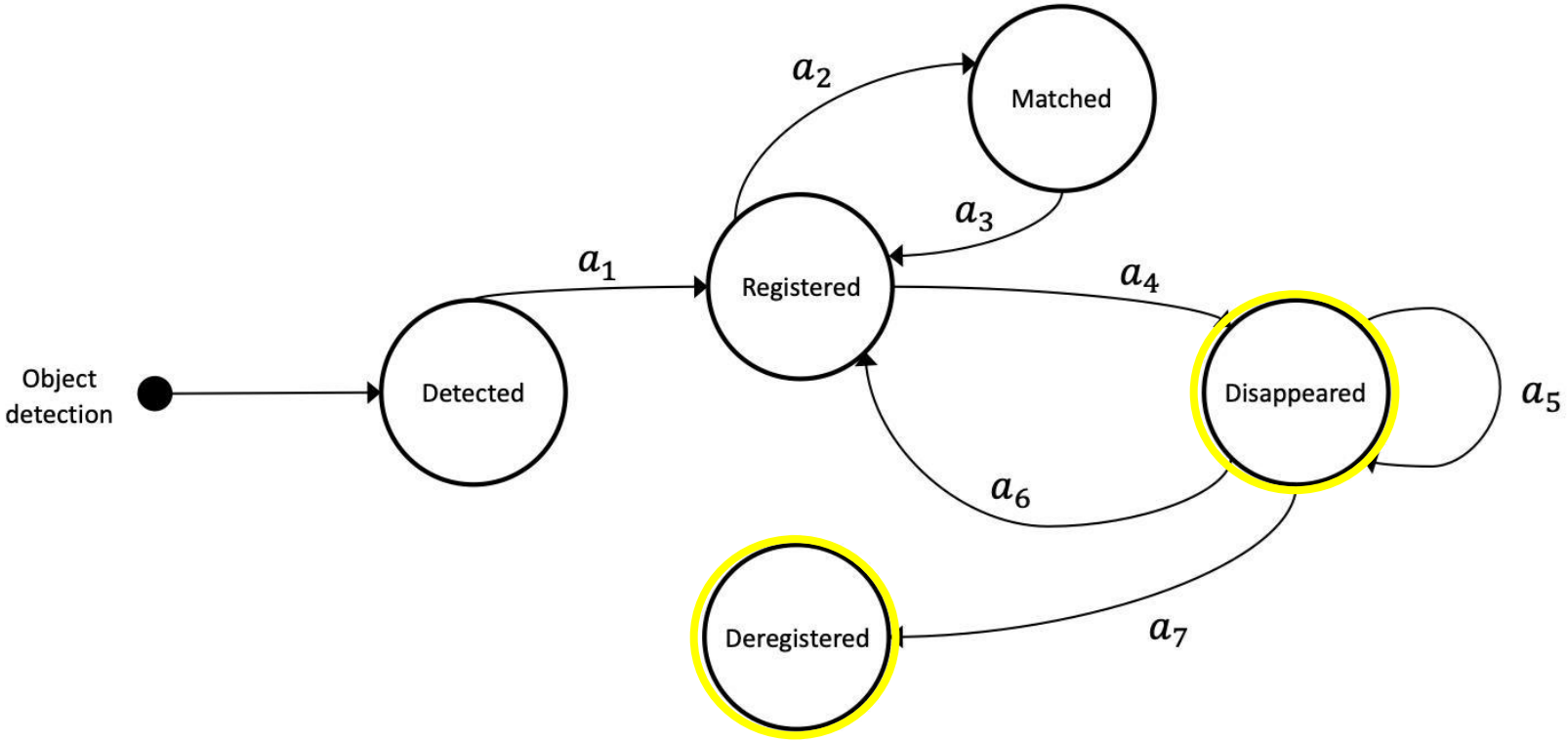
Bee flew out

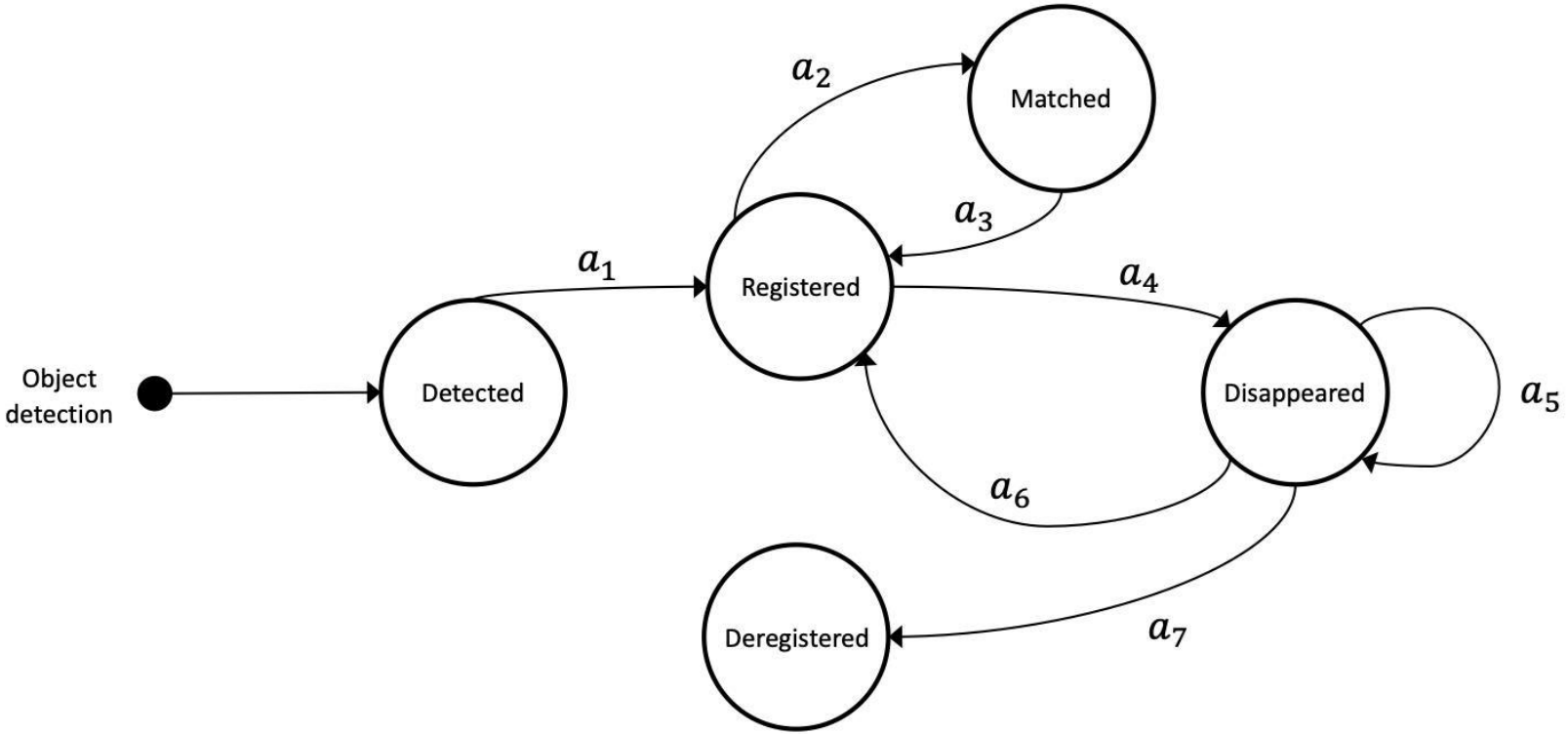
Missing Objects



- Keep registered objects alive




Object detection
Detected
Registered
Matched
Disappeared
Deregistered
a_1
a_2
a_3
a_4
a_5
a_6
a_7


Object detection
Detected
Registered
Matched
Deregistered
Disappeared
a_1
a_2
a_3
a_4
a_5
a_6
a_7

Bee Counting

Bee Counting

- Policy for outgoing bee

Bee Counting

- Policy for outgoing bee:
  - Starts in the hive entrance
  - Has multiple detections outside of the entrance
  - Ends outside of the entrance


In: 0
Out: 0
Nr of Bees: 23
Last activity:
FPS: 29.98
Frame: 57

Bee Counting

- Policy for outgoing bee:
  - Starts in the hive entrance
  - Has multiple detections outside of the entrance
  - Ends outside of the entrance
- Policy for incoming bee:

Bee Counting

- Policy for outgoing bee:
  - Starts in the hive entrance
  - Has multiple detections outside of the entrance
  - Ends outside of the entrance
- Policy for incoming bee:
  - Starts outside of the entrance
  - Has multiple detections inside of the entrance
  - Ends inside of the entrance


20
15
13
34
10
12
35
16
7
6
5
9
36
2
39
38
In: 0
Out: 3
Nr of Bees: 21
Last activity: Bee 19 flew out
FPS: 29.97
Frame: 302

Counting System Output

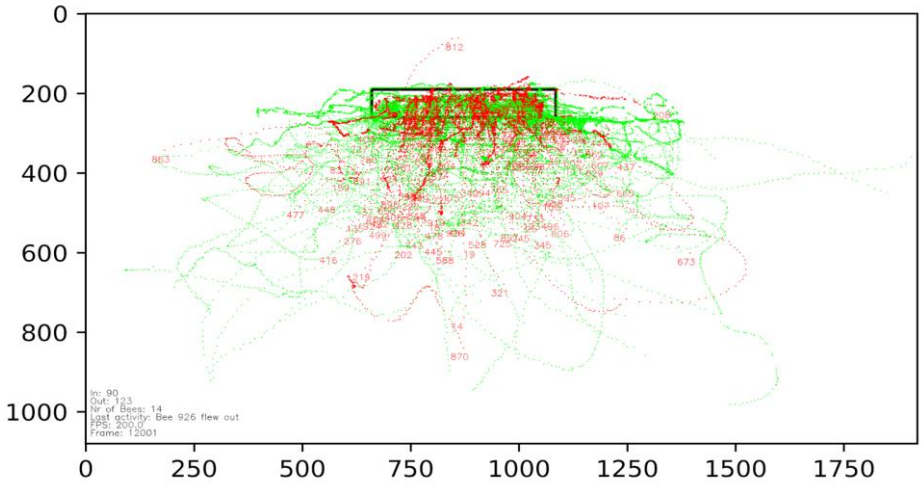
- Video file

Counting System Output

- Video file
- Traffic visualization

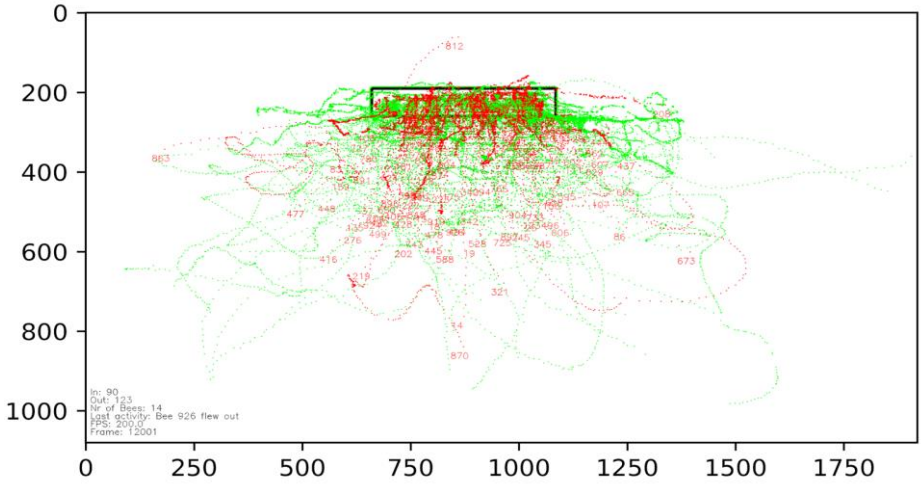
Counting System Output

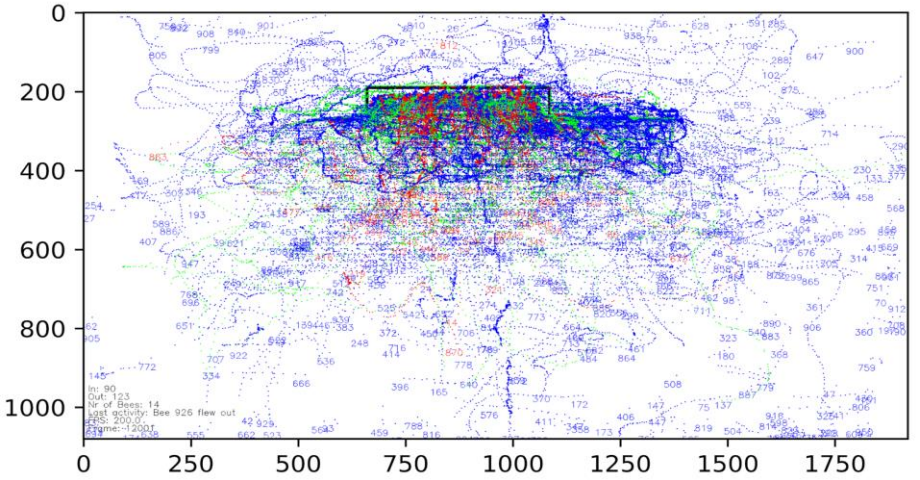
- Video file
- Traffic visualization



Counting System Output

- Video file
- Traffic visualization





Conclusions

- Object Detection
  - 80 images are enough to reach F2-score > 0.9
  - Cross-validation of models with defined data set
  - (Staged) Clustered training might have better performance than individual (apply when F2 <0.9X)
  - Don’t over engineer, validate constantly
  - General model, might improve with increase of data for reducing variance… (try if staging < 0.9X)
- Tracking:
  - Only as good as object detection
  - The higher the frame rate the better the tracking

Future Work

- Object Detection:
  - Data augmentation techniques for complex backgrounds
  - FastYOLO for IoT devices
- Tracking:
  - Predictive target location (LSTM or Kalman Filter)
  - Stabilization of object detection

Thank you.