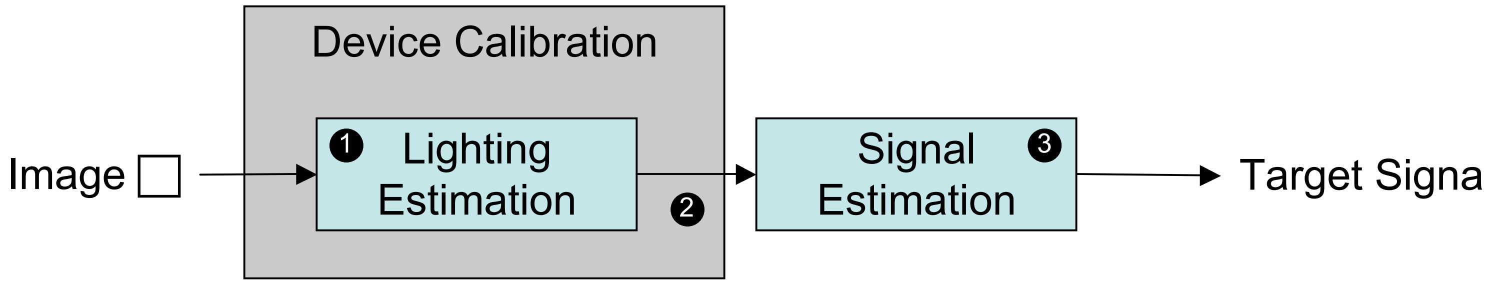
Problem Statement: Measuring Moss Photosynthesis

- Some natural phenomena can be measured without harming the environment:
  - Temperature
  - Rainfall
  - Humidity
- Others, require destructive instrumentation:
  - CO_2 flux from single plant, meadow, or soil

The site at James Reserve where mosscam is located

Process Overview



1. Estimate the incident illumination in the scene
2. Transform the image to be under a reference illuminant
3. Estimate the target signal

Device Calibration: Physical Model of Image Formation

$$r_k = \int_w E(\lambda)S(\lambda)R_k(\lambda)d\lambda$$

- r_k = response of the kth sensor
- w = bandwidth of device
- $E(\lambda)$ = incident spectral power distribution
- $S(\lambda)$ = subject's relative spectral reflectance
- $R_k(\lambda)$ = the sensitivity of the kth sensor

Device Calibration: Modeled Image Formation

$$r \approx \hat{E}(\lambda)\hat{S}(\lambda)^T R(\lambda)$$

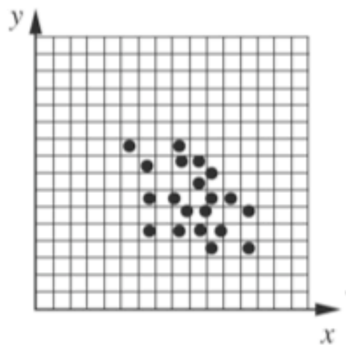
$$r \approx (\mathbf{B_e} w_e)(\mathbf{B_s} w_s)^T \mathbf{R}$$

- Discretize the bandwidth and rewrite in matrix notation
- Model E(λ) and S(λ) using functional PCA
- Results in 6 unknowns (w_e and w_s)

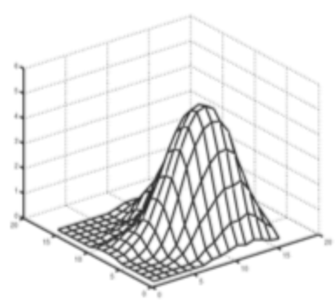
This system is under-constrained.
Estimate the spectra in sequence.

Device Calibration: Estimating Incident Illumination

Color By Correlation (Finlayson et. al.)



(a)



(b)

	ill 1	ill 2	ill 3	ill 4	ill 5	ill 6	ill 7	ill 8
x1, y1	0.1	0.0	0.7	0.1	0.0	0.0	0.0	0.9
x1, y2	0.2	0.1	0.6	0.2	0.0	0.4	0.1	0.9
x1, y3	0.2	0.1	0.5	0.4	0.0	0.4	0.1	0.7
	:	:	:	:	:	:	:	:
	:	:	:	:	:	:	:	:
	:	:	:	:	:	:	:	:
x1, yn	0.6	0.3	0.3	0.9	0.2	0.6	0.1	0.0
x2, y1	0.9	0.3	0.1	0.9	0.4	0.7	0.1	0.0
x2, y2	0.4	0.3	0.1	0.7	0.2	0.5	0.2	0.0
	:	:	:	:	:	:	:	:
	:	:	:	:	:	:	:	:
	:	:	:	:	:	:	:	:
	:	:	:	:	:	:	:	:
	:	:	:	:	:	:	:	:
	:	:	:	:	:	:	:	:
xn, yn	0.0	0.1	0.0	0.1	0.5	0.1	0.6	0.0

(c)

Device Calibration: Lighting Transformation

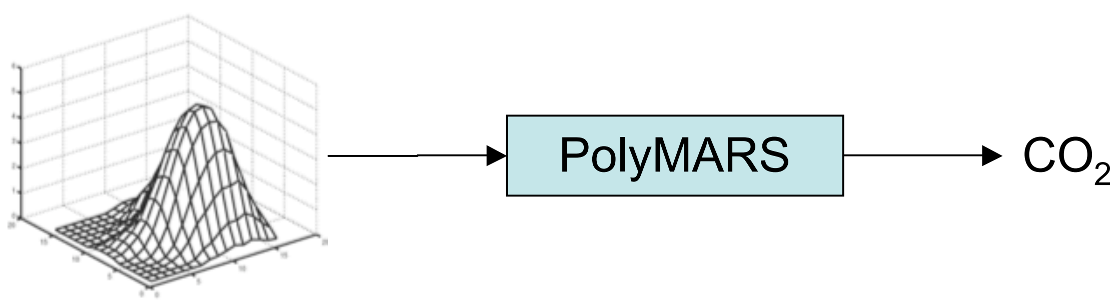
$$\begin{bmatrix} E_1(\lambda_R)S(\lambda_R) \\ E_1(\lambda_G)S(\lambda_G) \\ E_1(\lambda_B)S(\lambda_B) \end{bmatrix} = T_{light} \begin{bmatrix} E_2(\lambda_R)S(\lambda_R) \\ E_2(\lambda_G)S(\lambda_G) \\ E_2(\lambda_B)S(\lambda_B) \end{bmatrix}$$

$$T_{light} = \begin{bmatrix} E_1(\lambda_R)/E_2(\lambda_R) & 0 & 0 \\ 0 & E_1(\lambda_G)/E_2(\lambda_G) & 0 \\ 0 & 0 & E_1(\lambda_B)/E_2(\lambda_B) \end{bmatrix}$$

- Given some $E(\lambda)$ found previously, we can compute T_{light}
- This assumes that $R(\lambda) = \delta_k \quad k = \{R, G, B\}$
- Though unrealistic, this assumption has been shown to hold for cameras presented with “reasonable” light sources (like daylight)

Device Calibration: Estimating Spectral Reflectance

- Unlike lighting estimation, we have less insight into the relationship between CO_2 model and the image's color coordinates.
- Estimate the CO_2 using non-linear regression
- Use multiple time-shifted versions of chromaticity coordinates as input



Application: Measuring Moss Photosynthesis

Ecologists want to determine the effect of short summer rain events on the moss' ability to survive

- There are no available sensors
- Methods suggested by previously ecological studies have insufficient temporal resolution

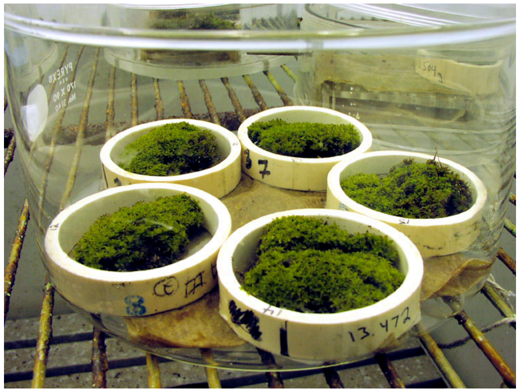
Tortula princeps

Photosynthesis begins to occur 5 minutes after being hydrated

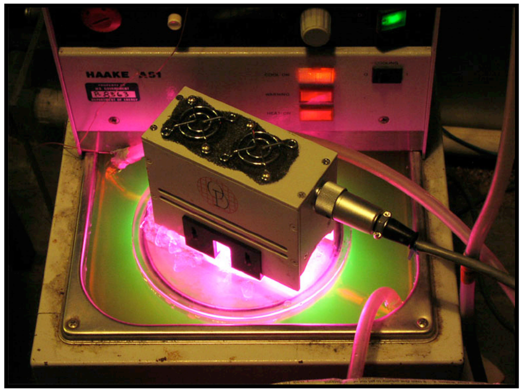
Application: Measuring Moss Photosynthesis

Lab Experimental Setup:

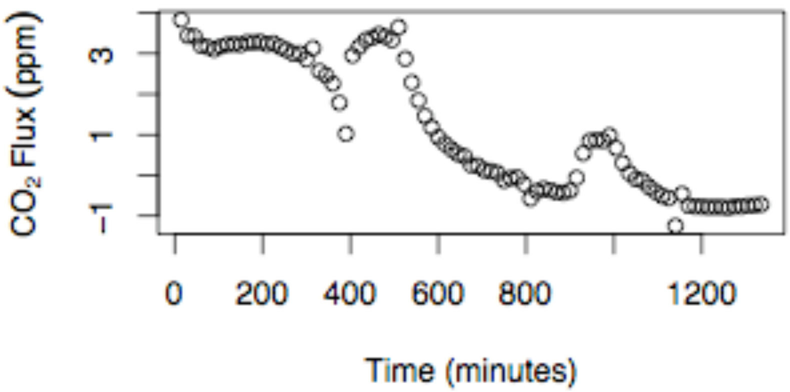
- Measured CO_2 flux of the moss as it dries down over time
- Use these measurements to train our models



Moss in a temperature controlled chamber

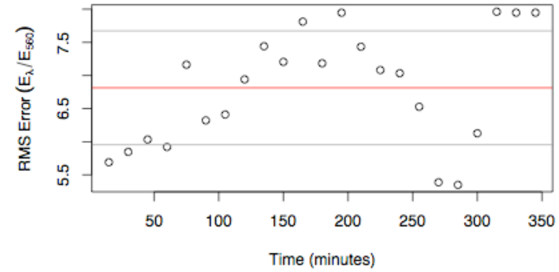


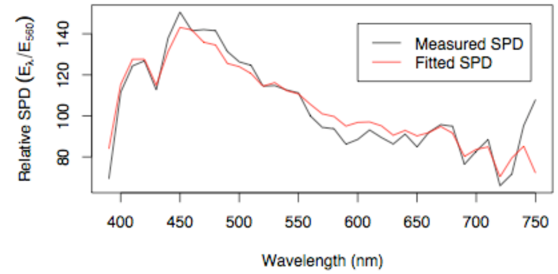
Infrared gas analyzer

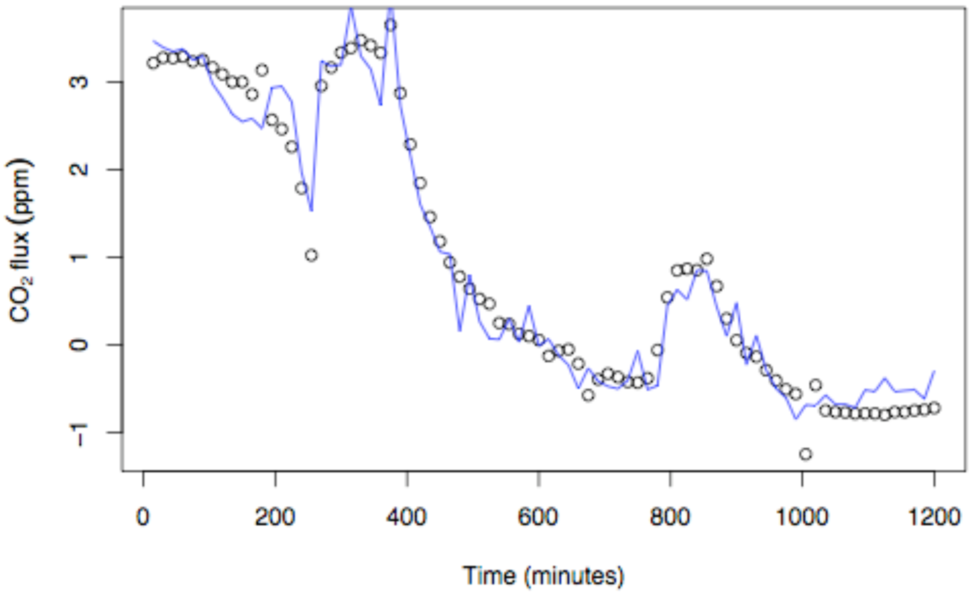


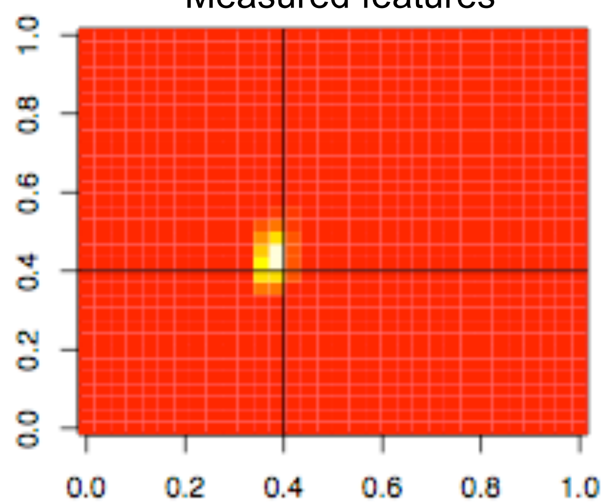
Application: Measuring Moss Photosynthesis

- Predict incident lighting
- “Register” images
- Use “registered” images to predict CO_2 (below)





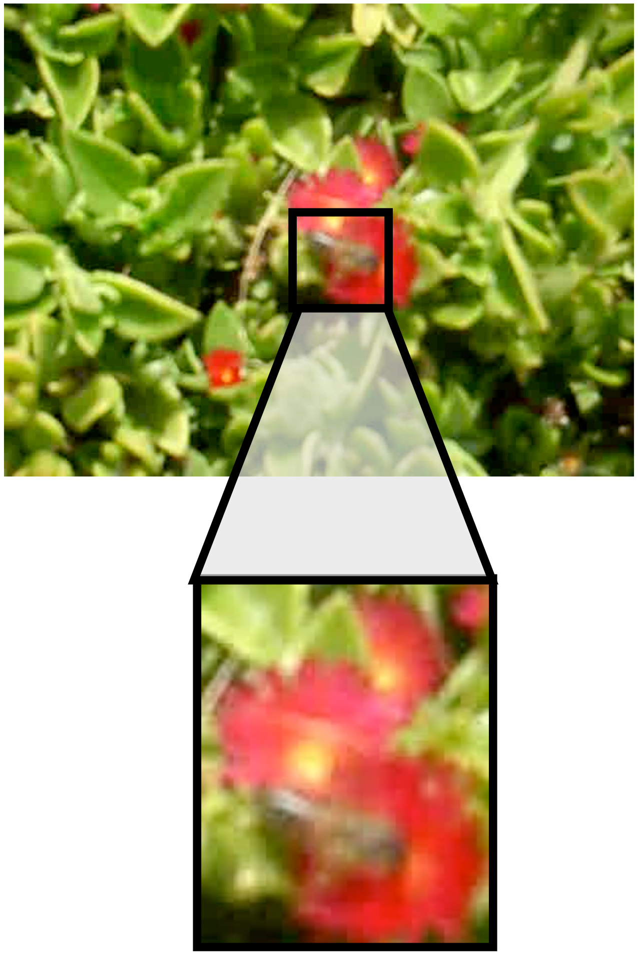




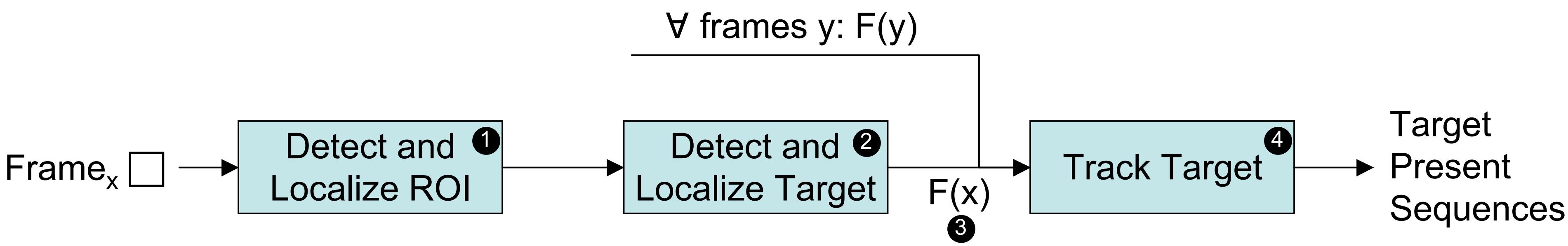
Problem Statement: Tracking Pollinators

Biologists want to perform studies about pollinator behavior over lengthy periods of time

- There are no available sensors
- Currently data is acquired by physically watching flowers and counting pollinators



Process Overview



1. Crop the image, leaving only the region of interest (ROI) remaining
2. Model the background to detect novel foreground objects
3. Locate most likely target, emit F(x): target location and likelihood
4. Track target through a sequence of frames

Application: Tracking Pollinators

- Step 1: Automatically "register" the images using template matching

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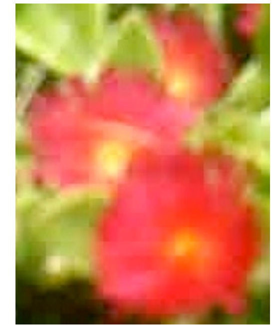
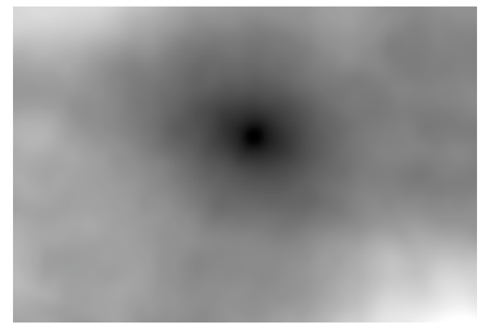


Convolve the template image with the target image:

$$J(r,c)=[I*h](r,c)=\sum_{\rho=-\infty}^{\infty}\sum_{\kappa=-\infty}^{\infty} I(r-\rho,c-\kappa)h(\rho,\kappa)$$

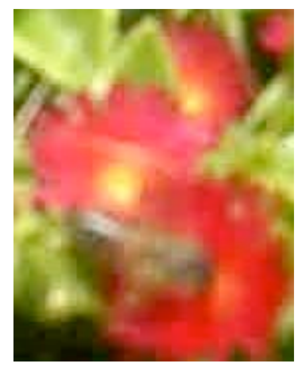
=



Instead of inner product, measure normalized L2 Distance:

$$R(x,y)=\frac{\sum_{x',y'}(T(x',y')-I(x+x',y+y'))^2}{\sqrt{\sum_{x',y'}T(x',y')^2\cdot\sum_{x',y'}I(x+x',y+y')^2}}$$

Find minimum value, and extract that as the best match $\Longrightarrow$



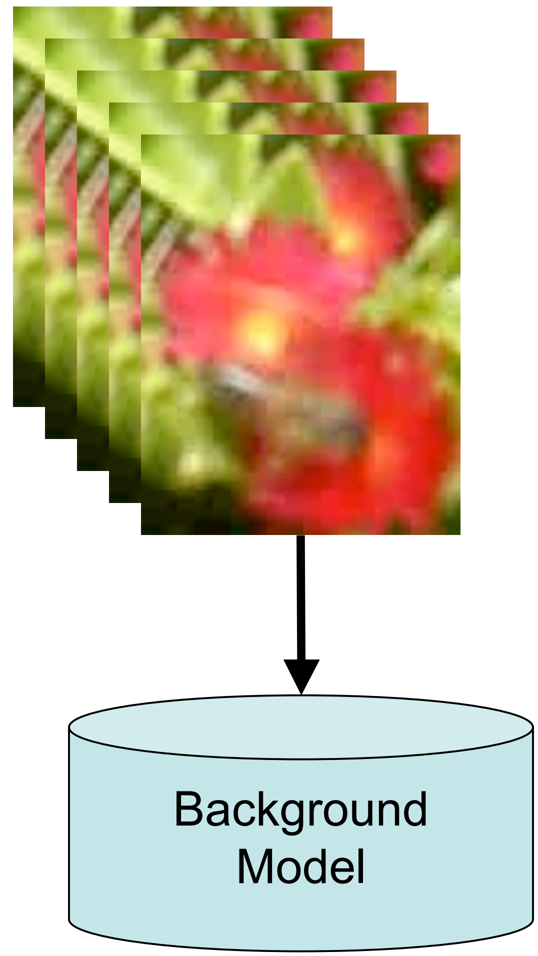
Application: Tracking Pollinators

- Step 2: “Learn” what the background looks like

Build a density estimate of color values:

$$p_{ij}(x) = \frac{1}{|S|}\sum_{s\in S}\delta(s-x)$$

$$S = \{x_t(a,b) \mid |a-i| < c, |b-j| < c, 0 \leq t < T\}$$



Application: Tracking Pollinators

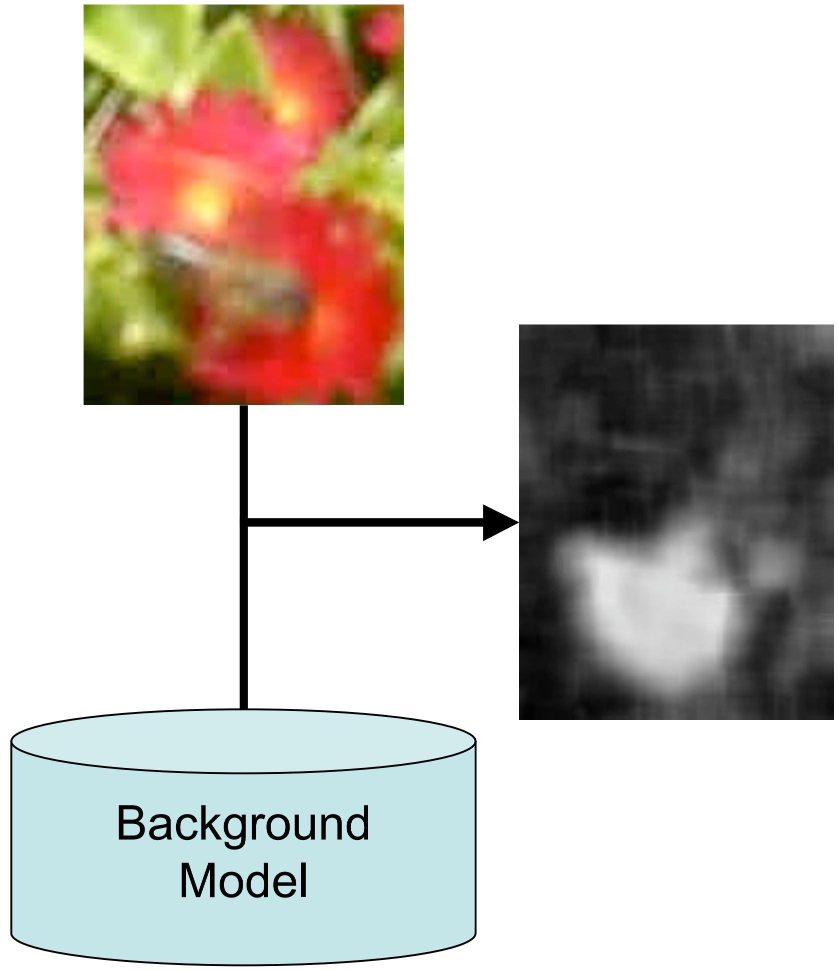
- Step 3a: Subtract the background

Compute the distance between a new image and the background model.

$$BC(p,q) = \sum_{x \in X} \sqrt{p(x)q(x)}$$

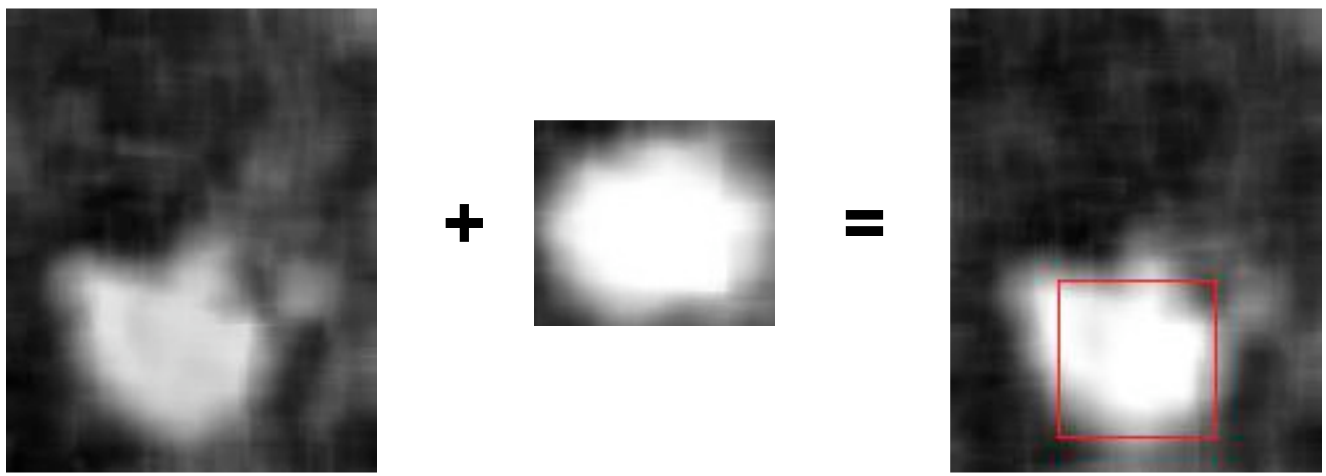
$$D_B(p,q) = -\ln\left(BC(p,q)\right)$$

Produces a difference image



Application: Tracking Pollinators

- Step 3b: Reapply template matching to detect target



Application: Tracking Pollinators

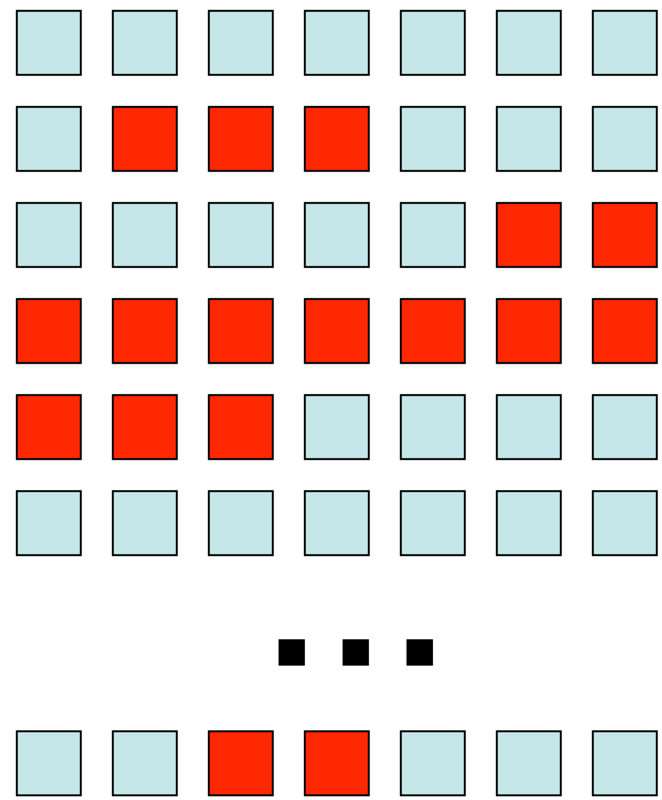
- Step 4: Look for sequential frames containing the target

$$R(x,y) = \frac{\sum_{x',y'} (T(x',y') - I(x+x',y+y'))^2}{\sqrt{\sum_{x',y'} T(x',y')^2 \cdot \sum_{x',y'} I(x+x',y+y')^2}}$$

match(S_i) = argmin(x_i,y_i) R(x_i,y_i))

Constraints for a sequence S:

- max(match(S_i)) < M_1
- mean(match(S_i)) < M_2
- max(dist(S_i,S_j)) < D_1
- mean(dist(S_i, S_j) < D_2



Questions?