Big and Streaming Video Data in the Smart Factory

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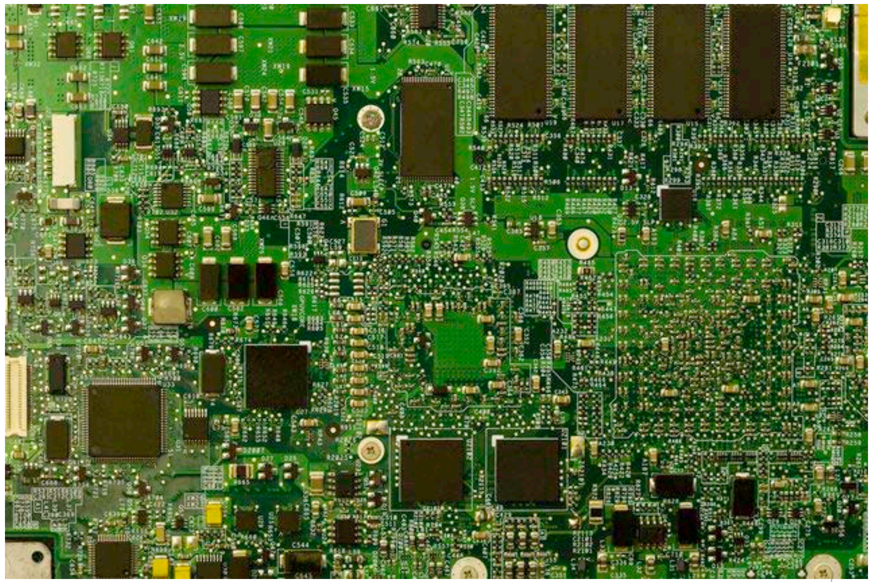
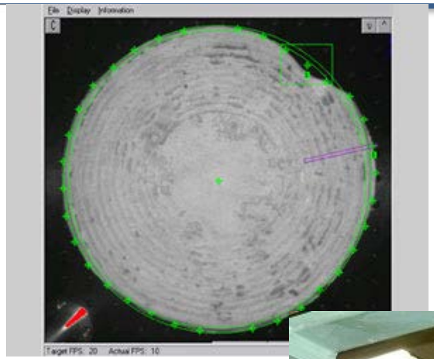
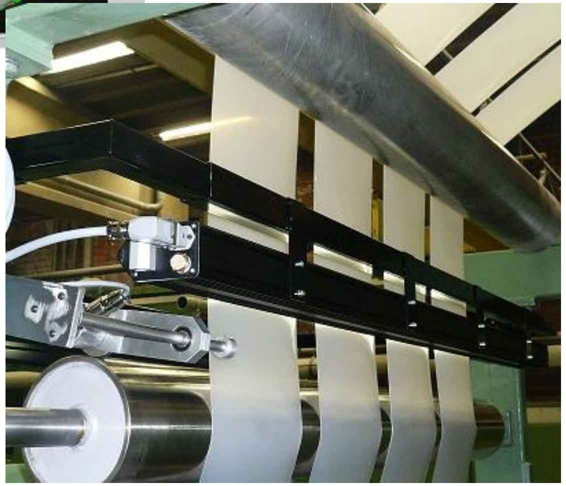
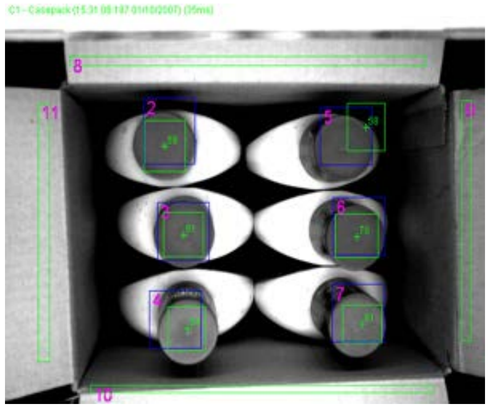
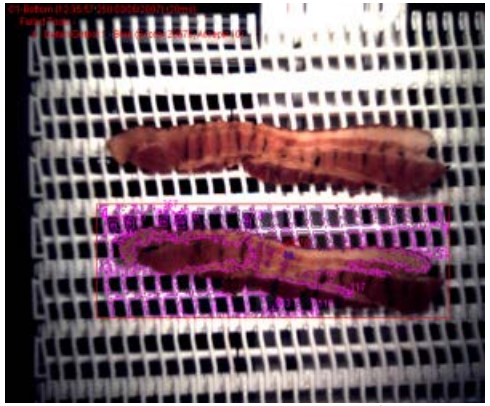
Machine Vision in the Factory





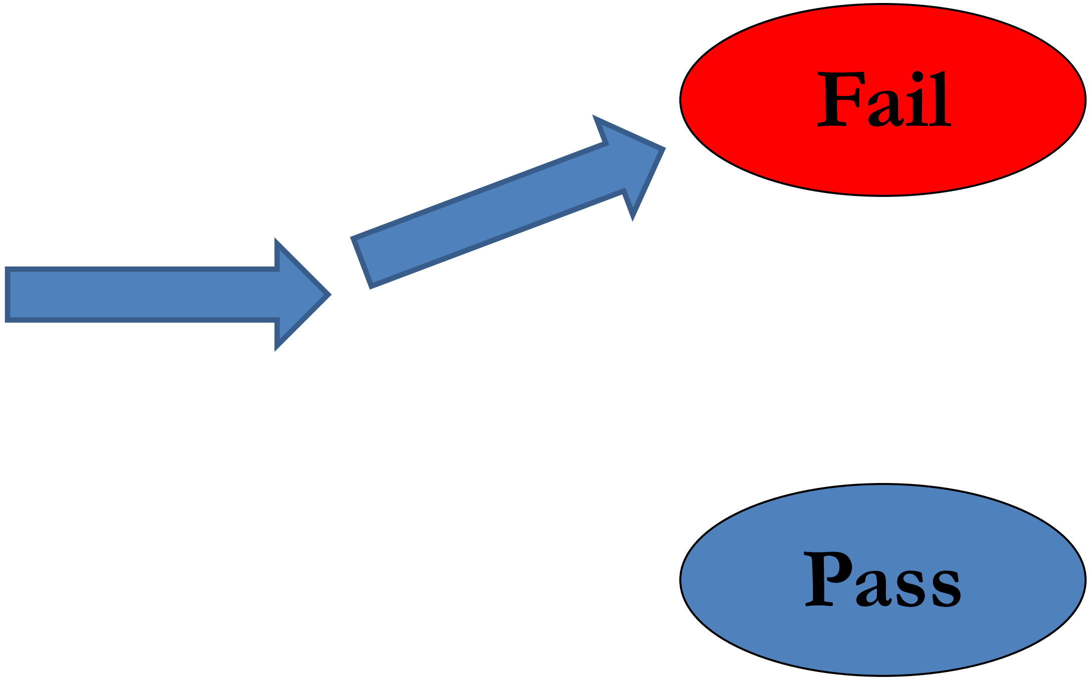




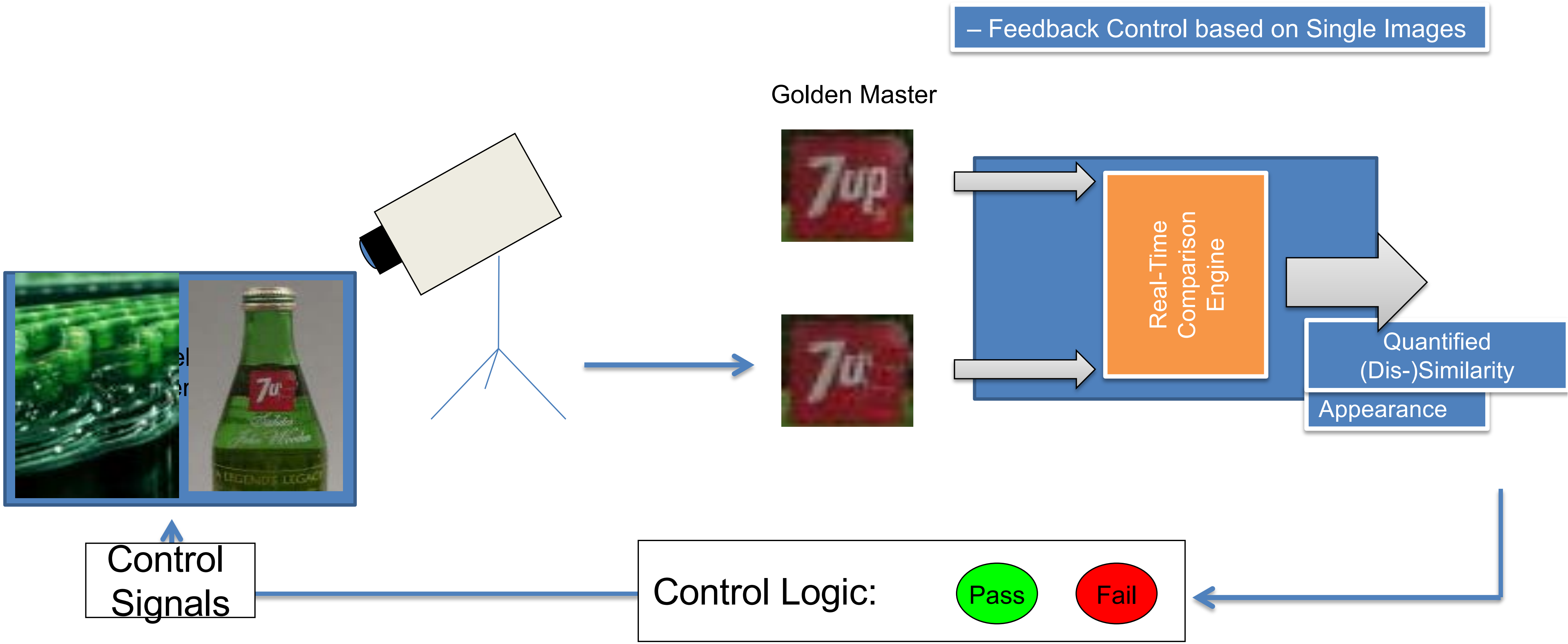


What is Machine Vision?

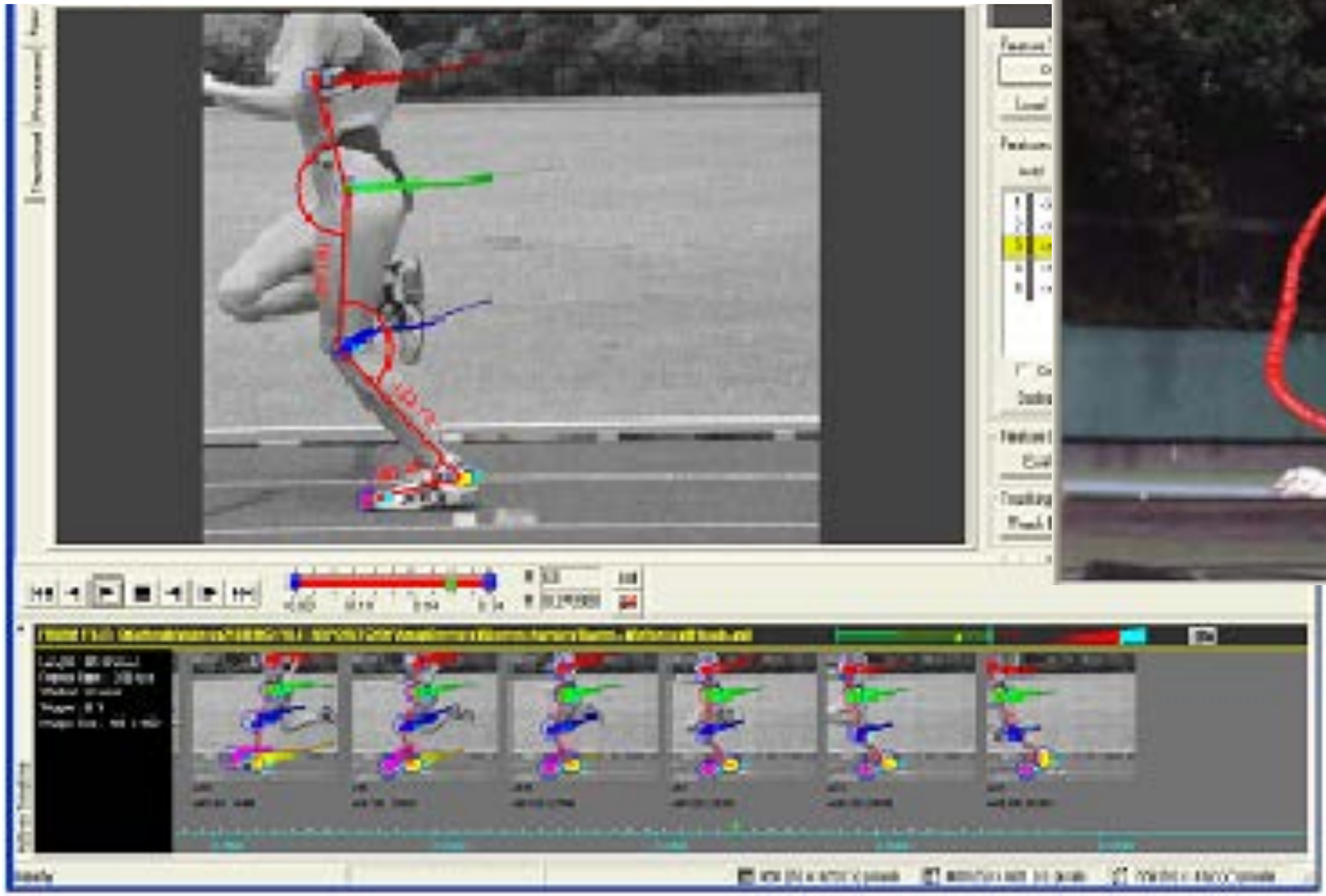
❑ Extracting Measurements from Images for Decision Making

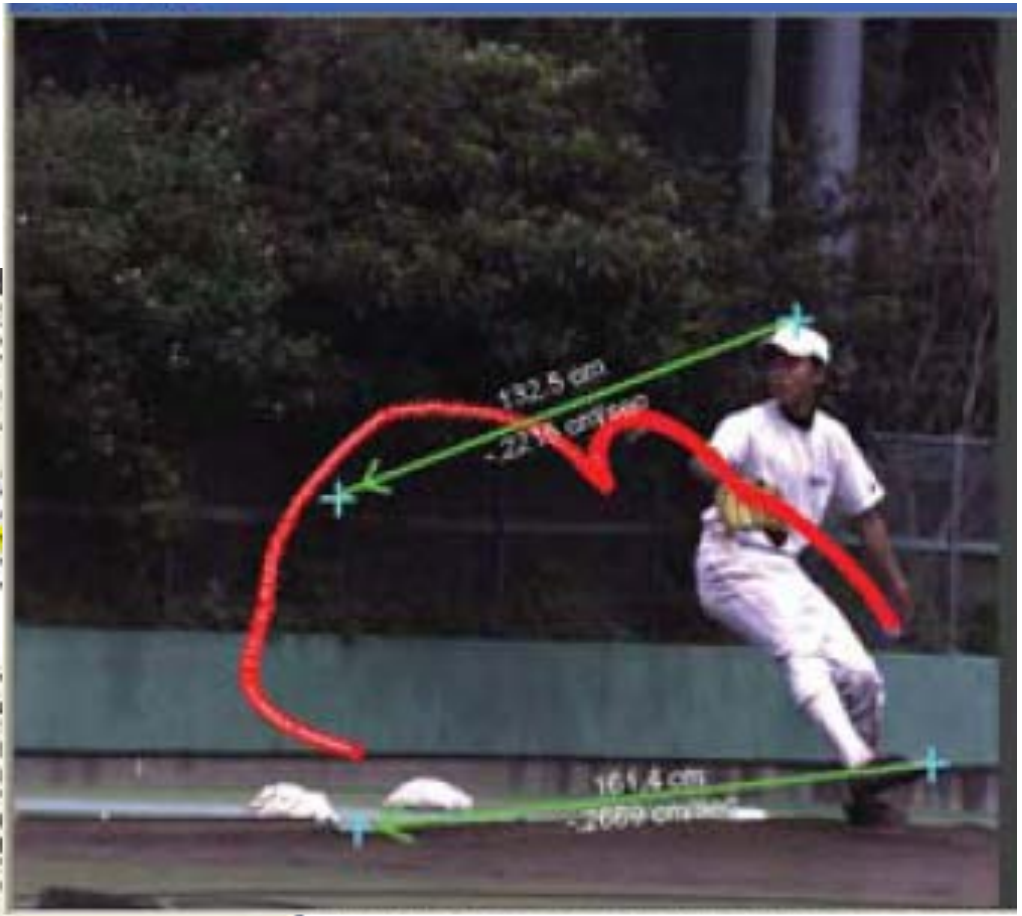


Industrial Machine Vision

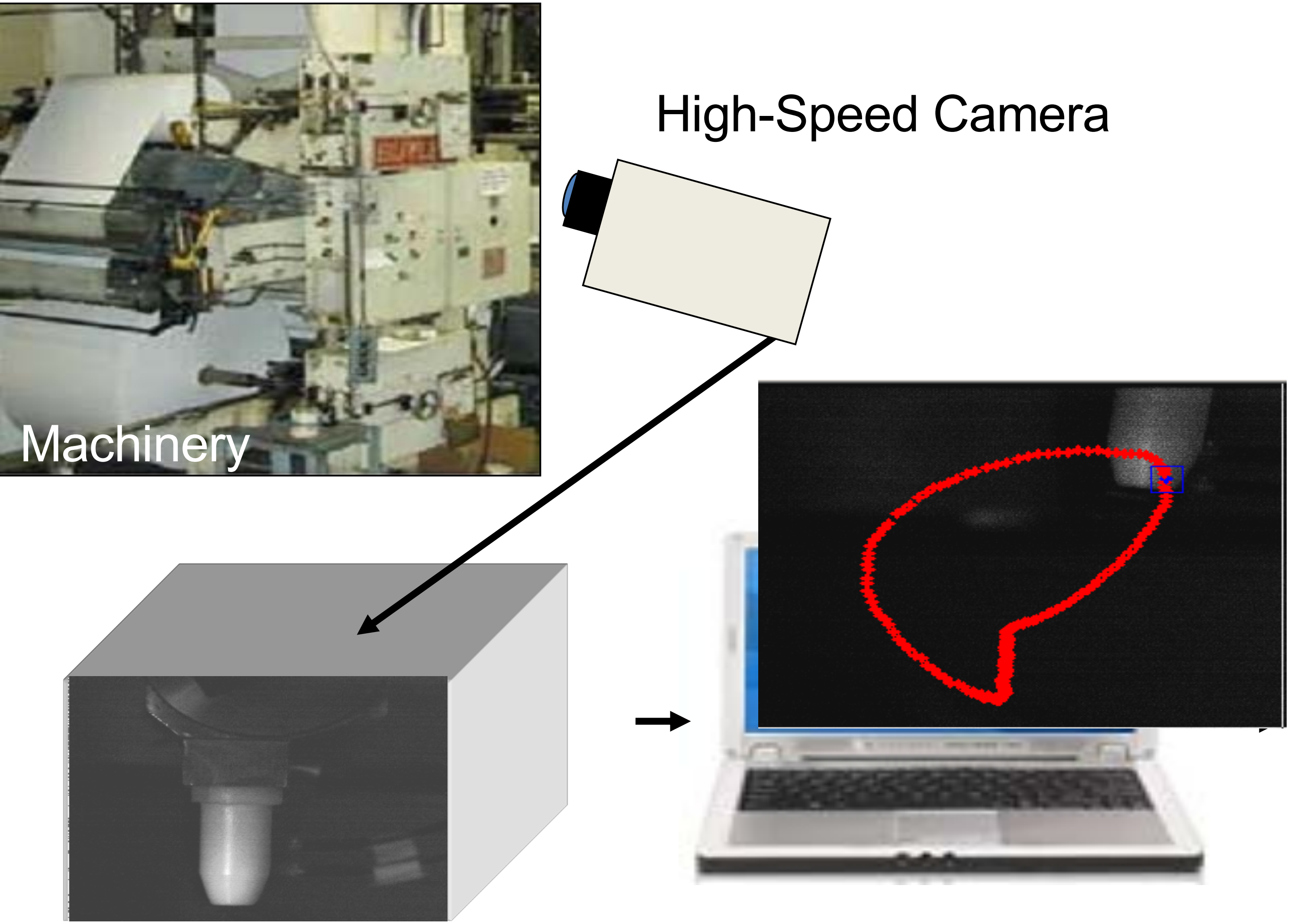


Motion Analysis



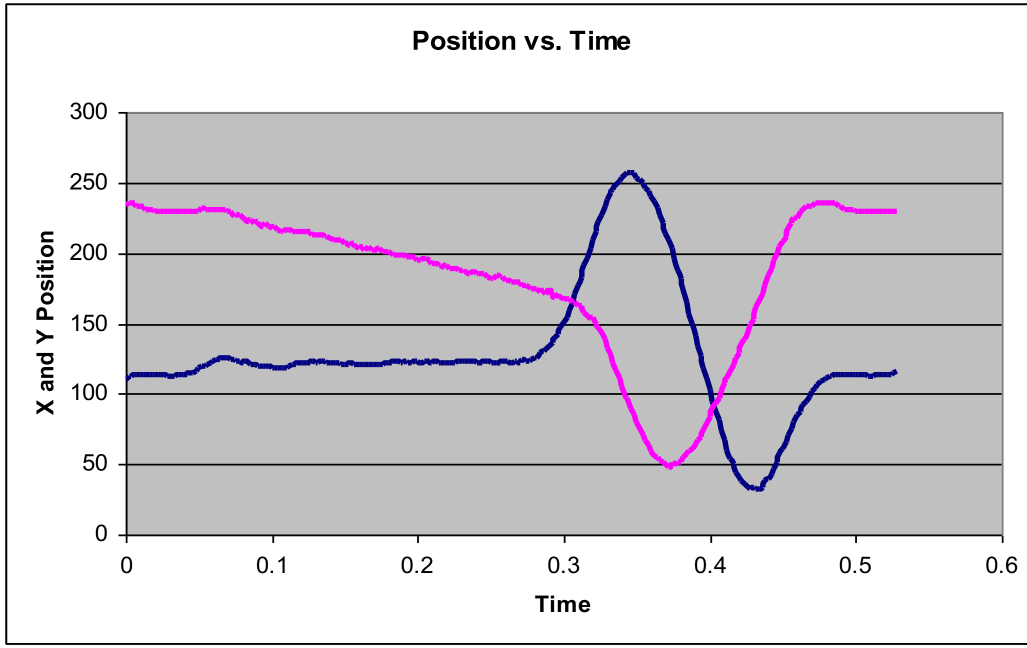


Motion Analysis



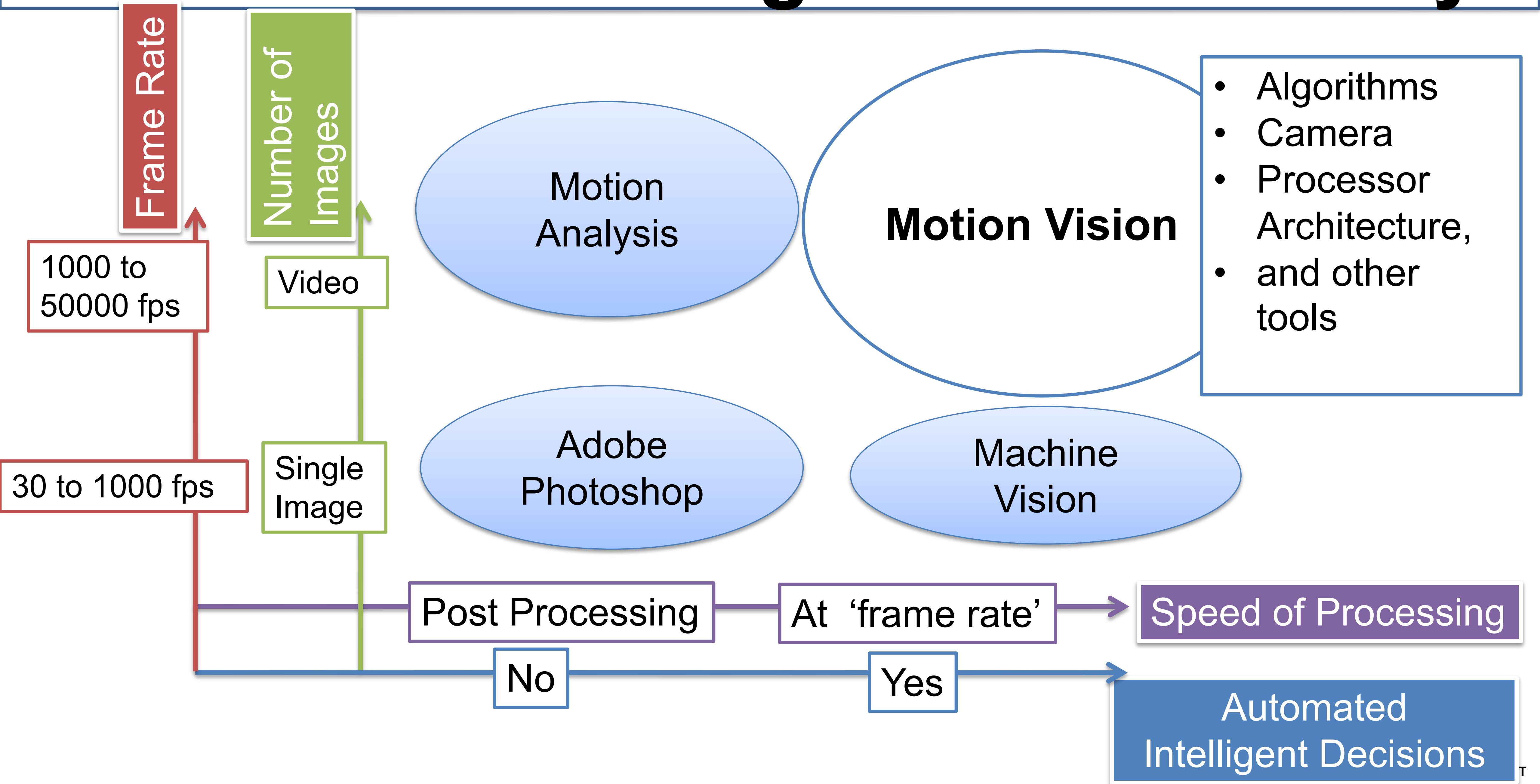
Gigabyte Video

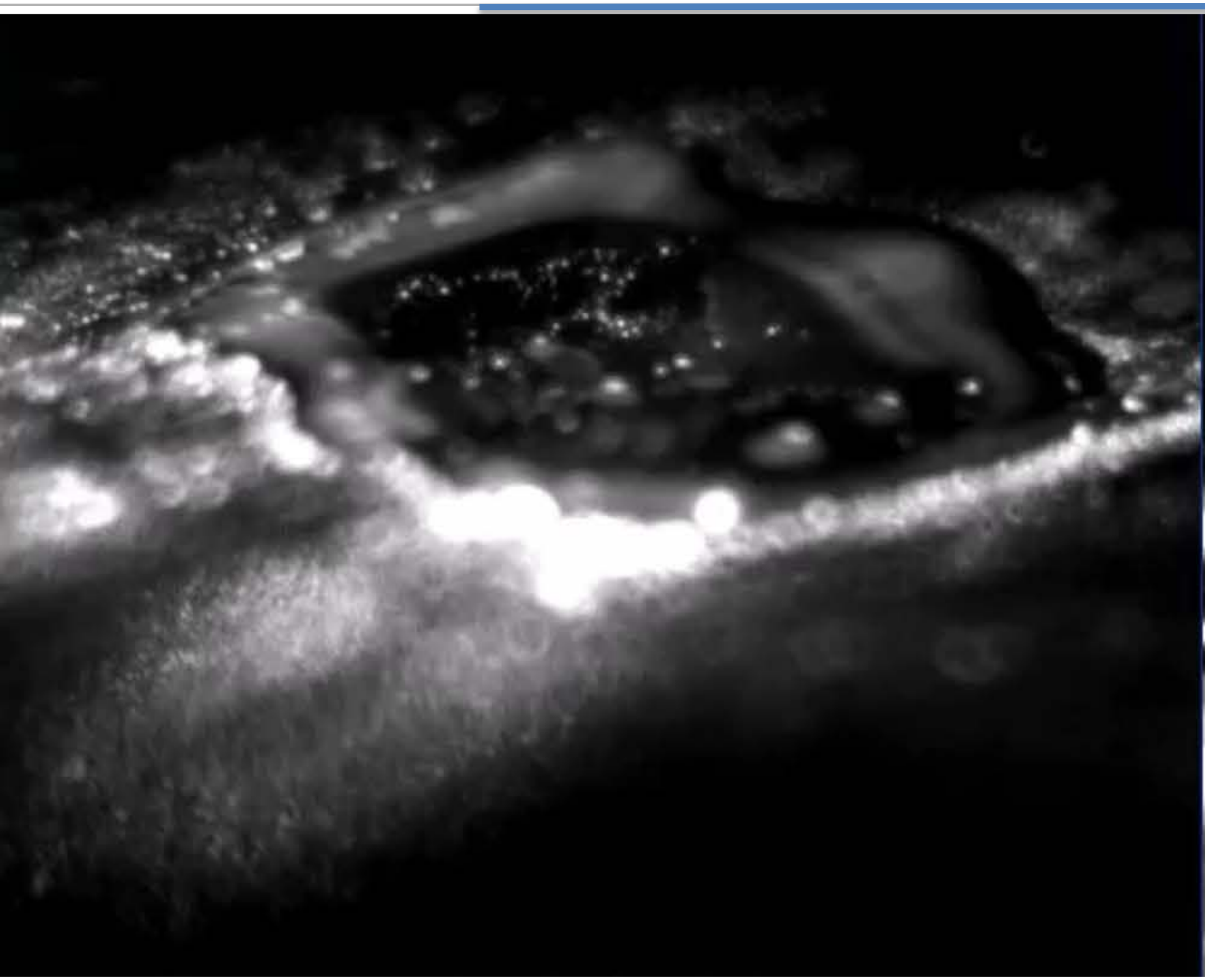
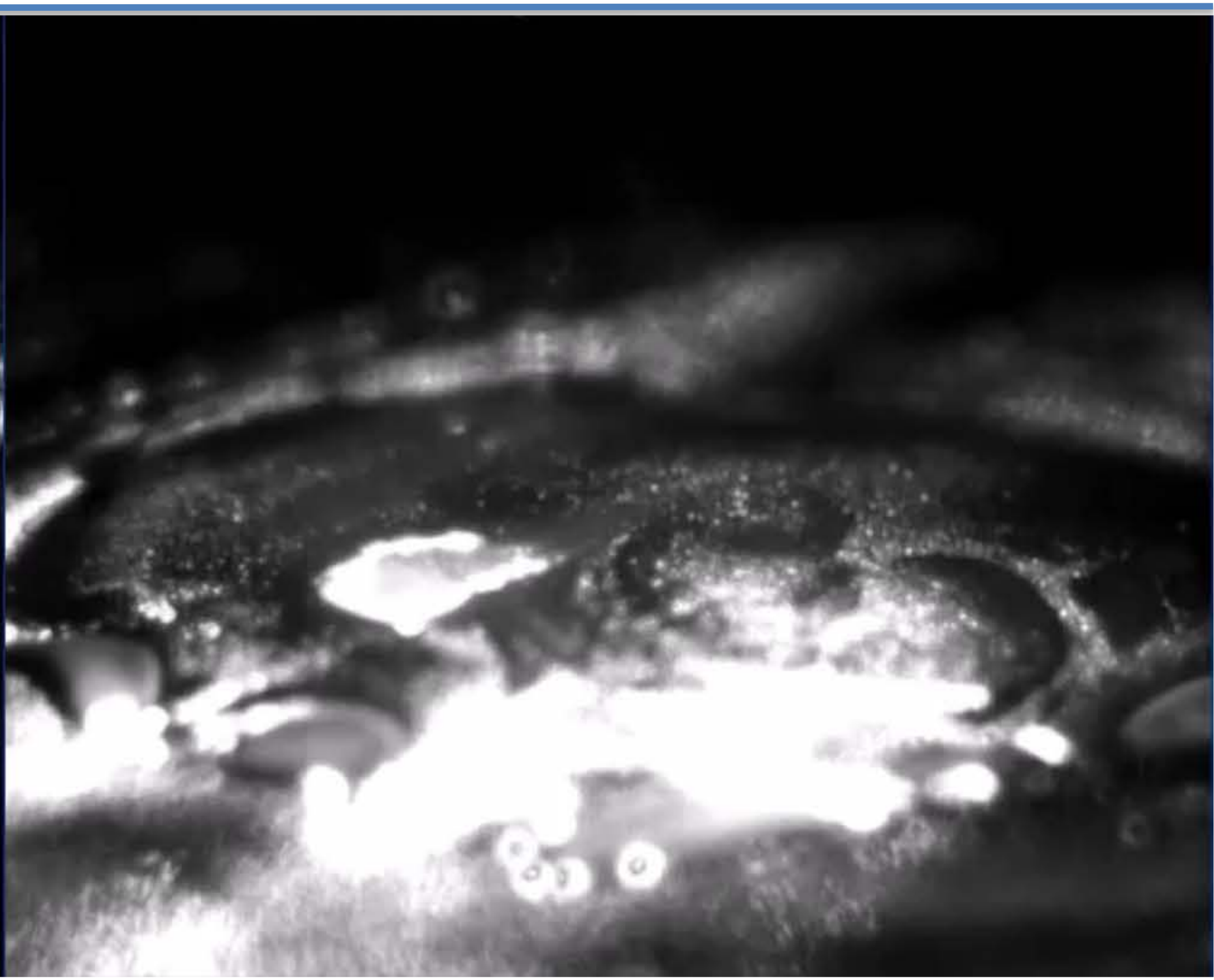
Analyzed Video – Human-in-the-Loop



Analysis Results for Human Interpretation

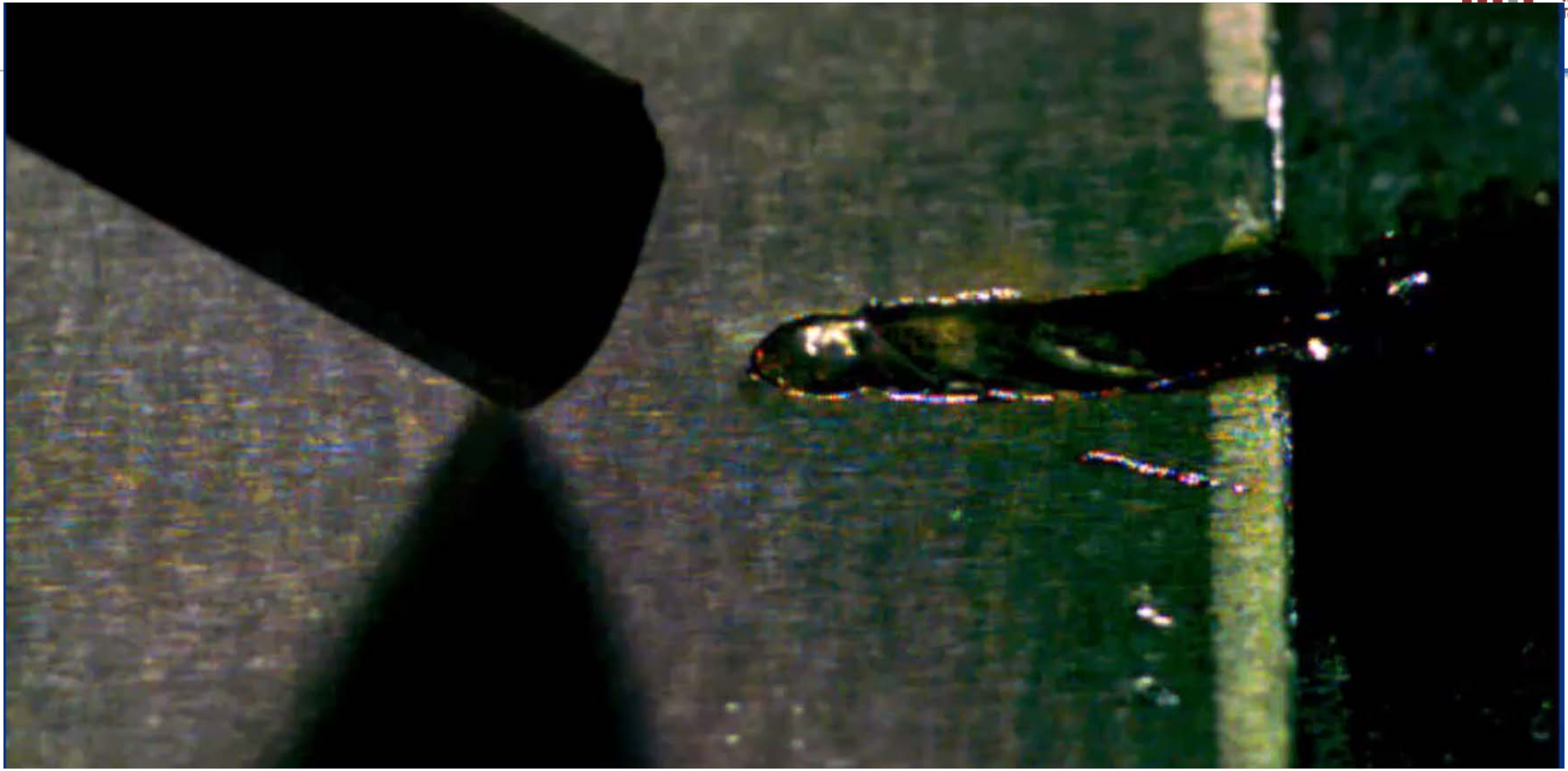
Cameras and Images in the Factory



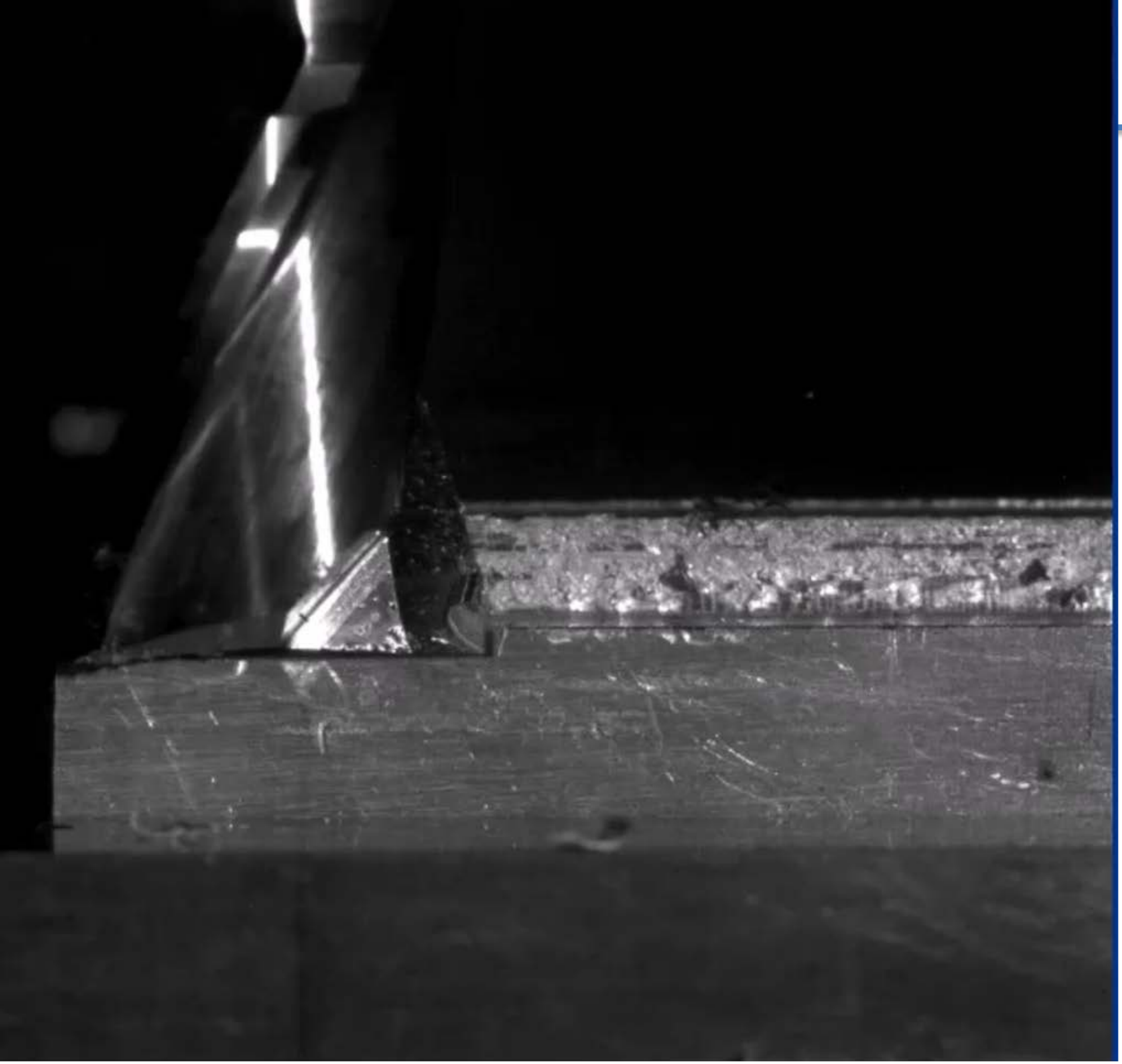
Laser Weld Melt Pool
10000 fps
1/1000000 sec

512x512 mono
Data Rate: 4x data rate of full color 4K
Data Rate: 4600x data rate of HD Netflix



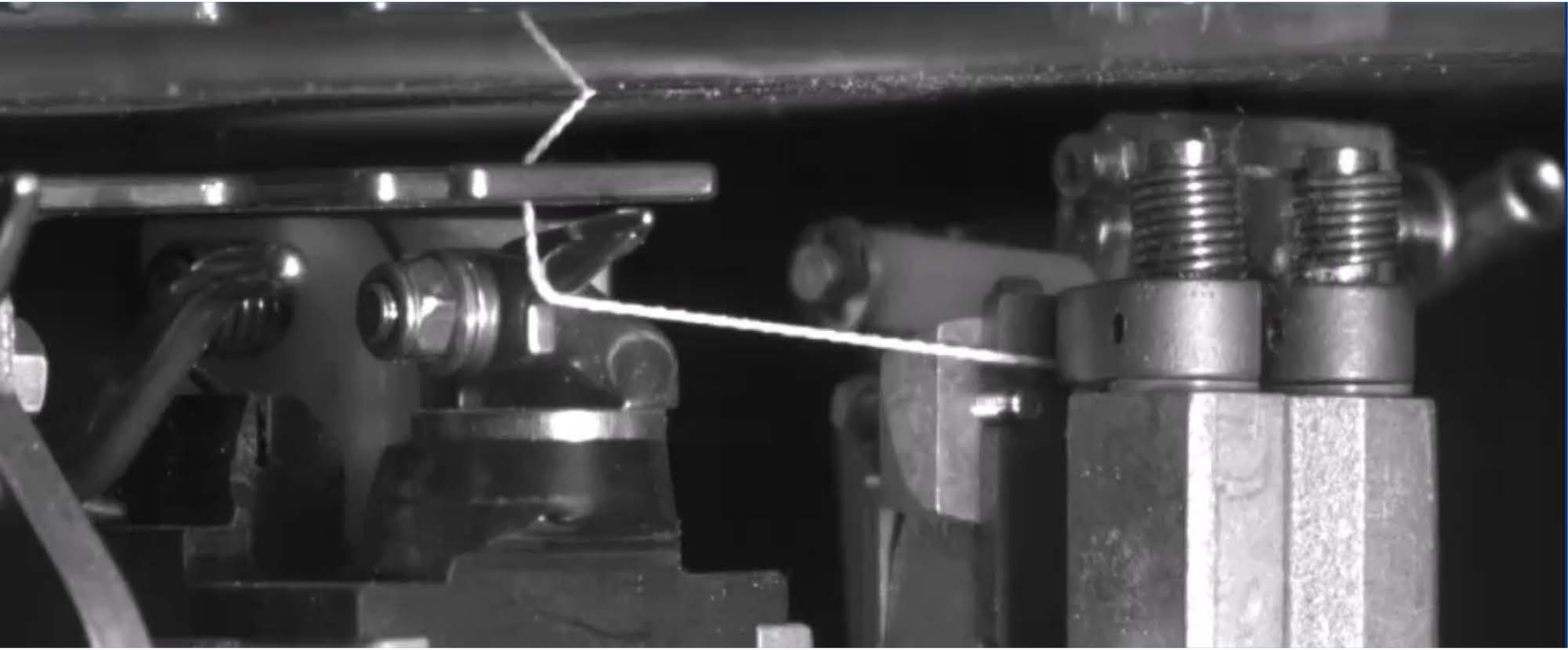
Laser cutting alum.
10000 fps
1/50000 sec

Wire Fed Plasma Welding
5000 fps
1/1000000 sec



Milling
2000 fps
1/10000 sec

Milling
6000 fps
1/50000 sec

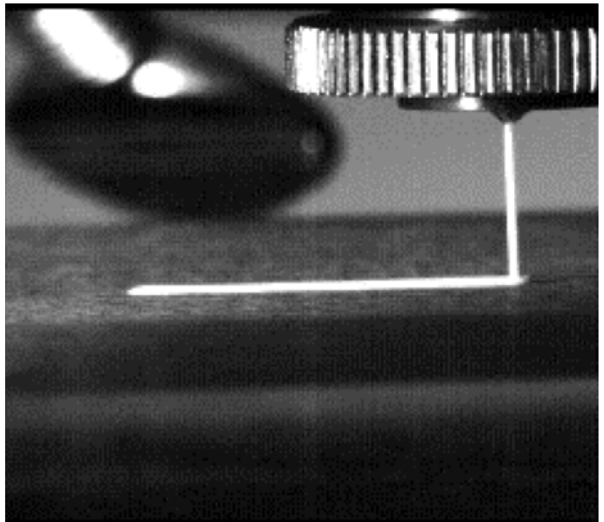


Binding Machine
2500 fps
1/10000 sec

Pill Packing
500 fps
1/4000 sec

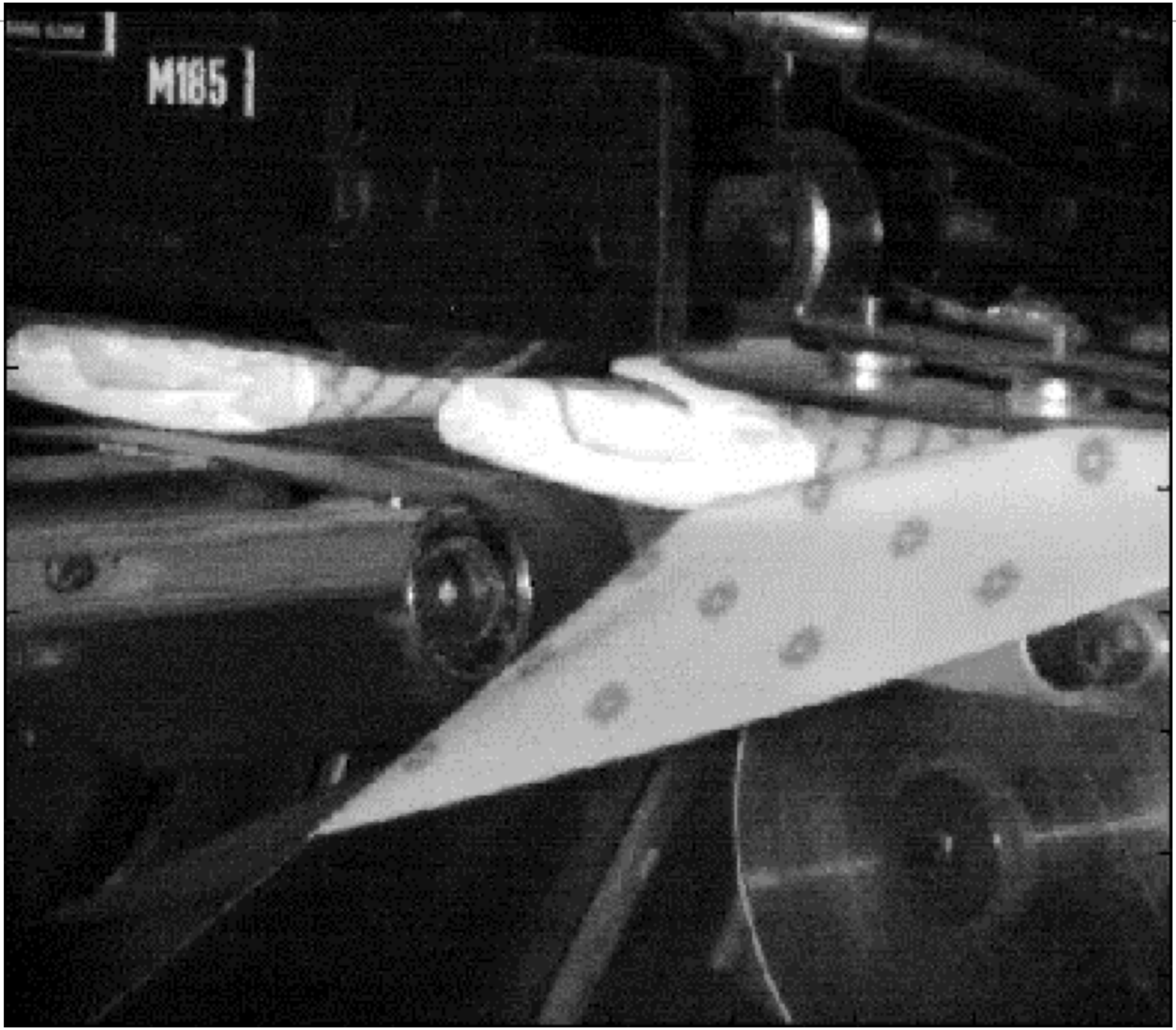
Sewing
6000 fps
1/20000 sec

Spray Coating
4000 fps
1/1000000 sec



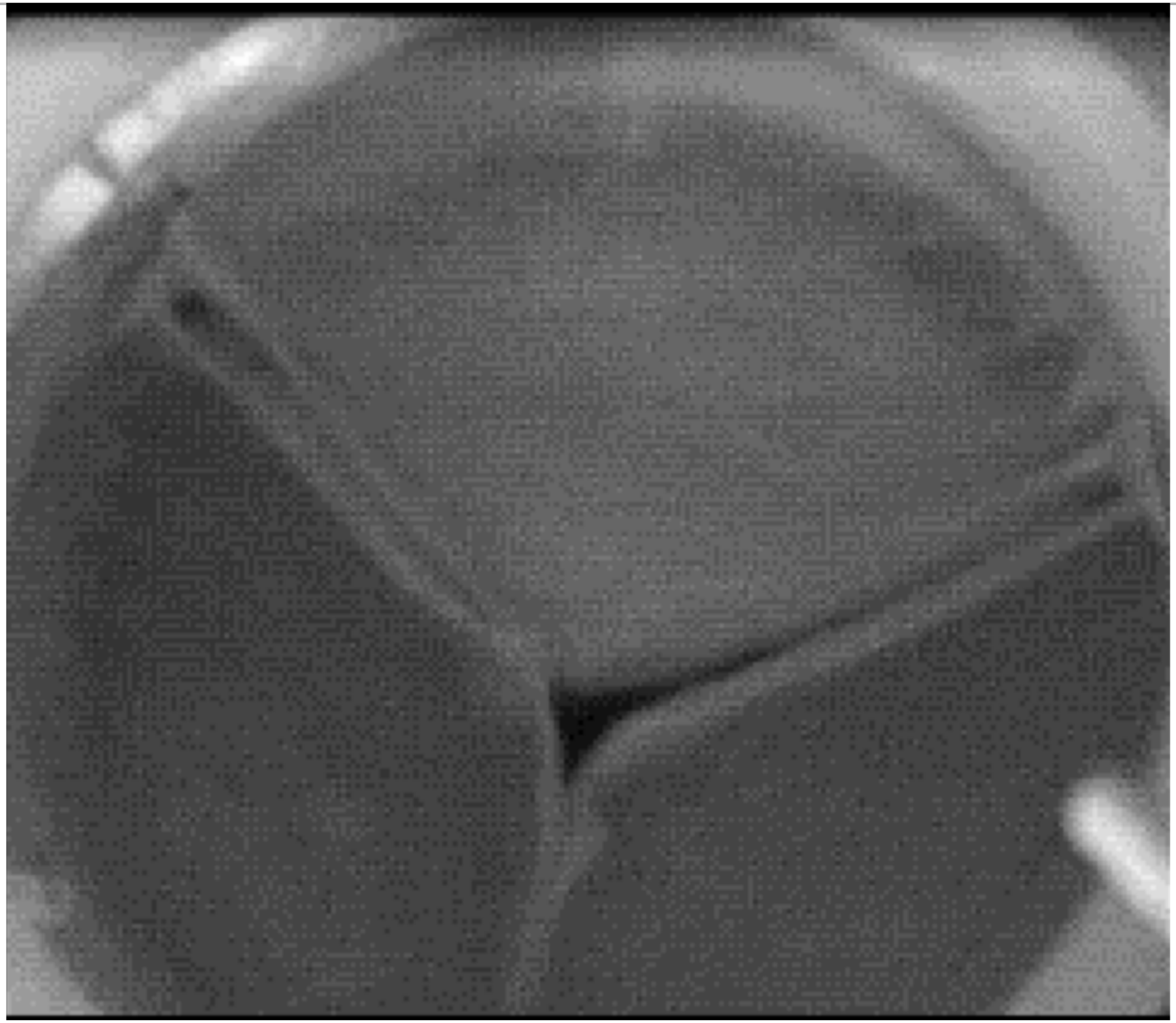
Ink Print
250000 fps
1/1000000 sec

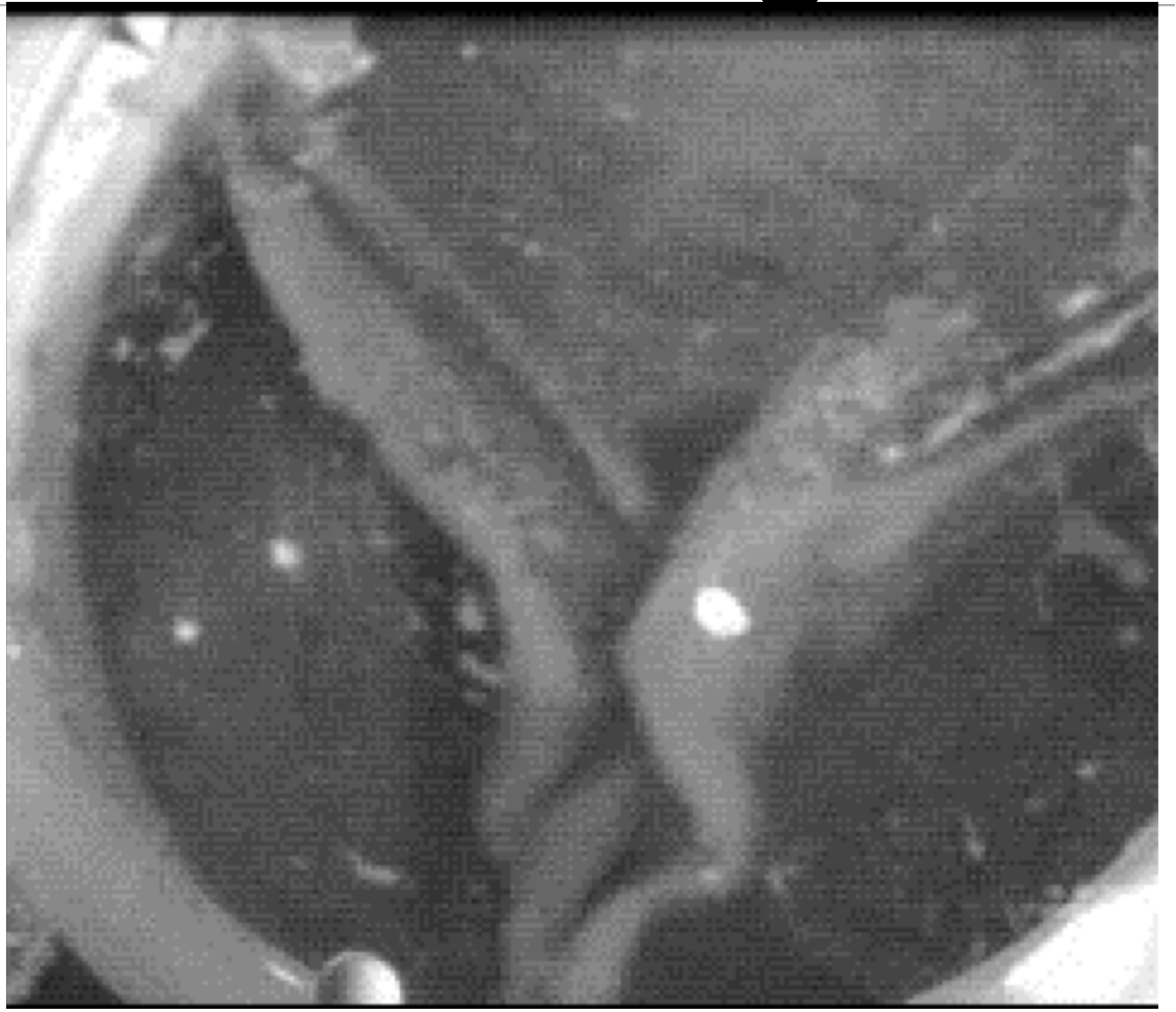
Automated Fault Detection



Anthony BW, Chua F. "*Computationally Efficient Optimal Video Comparison for Machine Monitoring and Process Control*". J Manuf Sci Eng. 2017 Aug 24;139(10):101007.

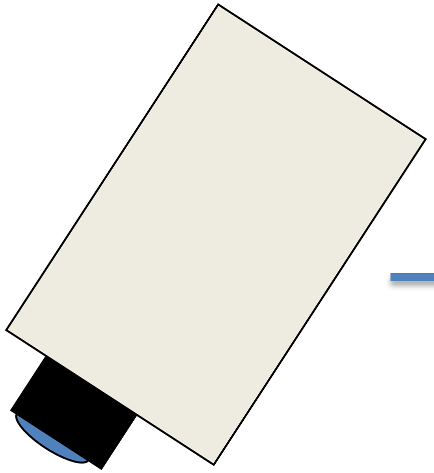
Automated Product Testing

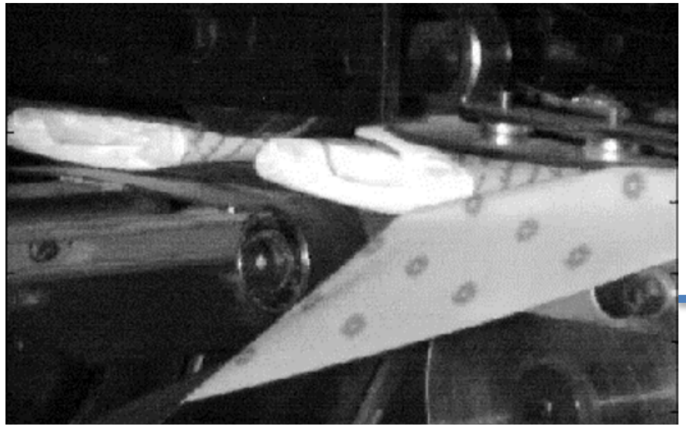




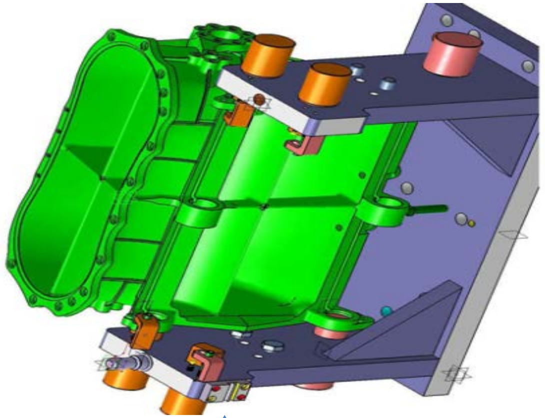
Anthony BW, Chua F. "*Computationally Efficient Optimal Video Comparison for Machine Monitoring and Process Control*". Journal Manufacturing Science Engineering. 2017 Aug 24;139(10):101007.

Video Instrument





Compare

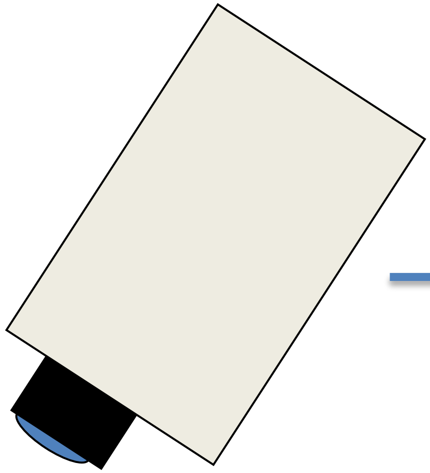


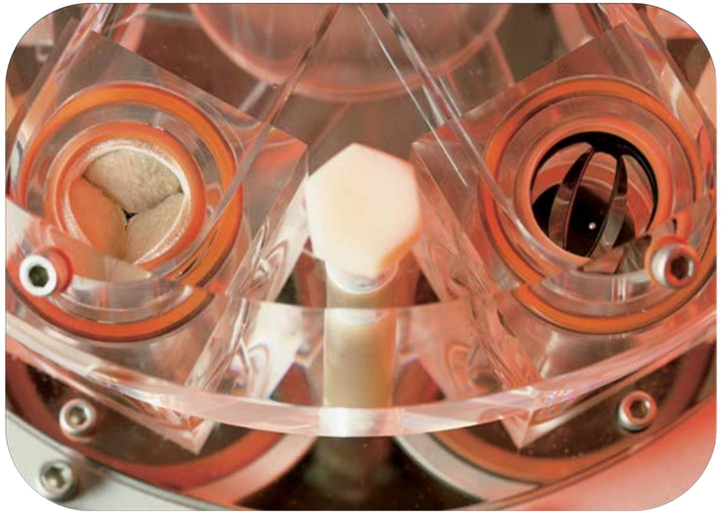
Control Signals

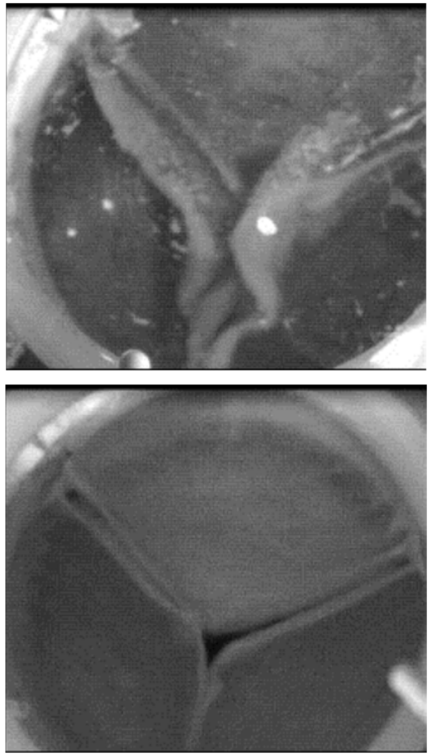
Control Logic

– Feedback Control based on Video Sequences

Video Instrument







Compare

Wear Monitor

Design/Repair Signals

– Design Decisions based on Video Sequences

Characteristics and Needs

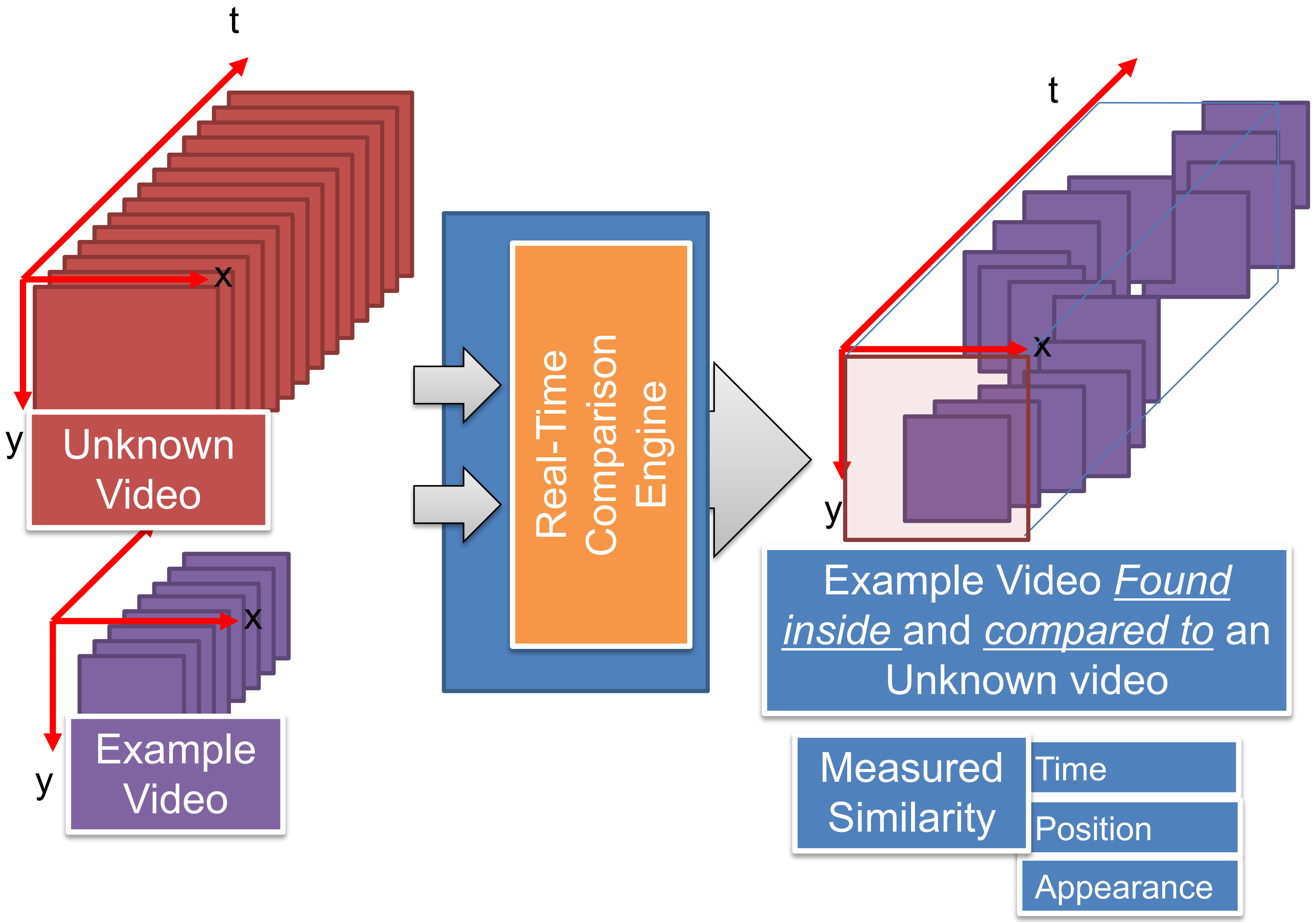
- General use, no Specific Models
  - paper, fluids, molten metals, and other amorphous and flexible objects
- Usable by Non-computer Scientist on the Factory Floor
  - easy to understand and modify
  - easy to configure and produce results
- Minimal Training Data
  - A single training example? The “golden master.”
- Computation Easily Scaled to Match Fast Production Rate
  - 1000’s of frames / second
  - Efficient Way to reduce Data Size

Data Size

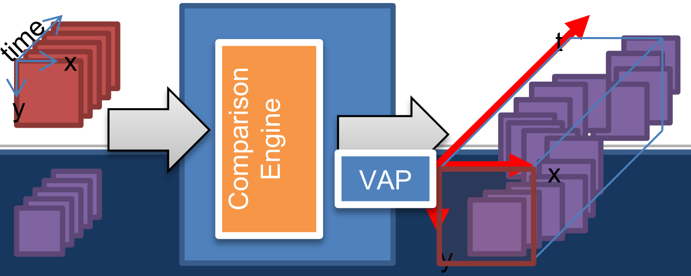
	x	Y	FPS	byte	MBytes/ sec	Relative to Color 4K	Relative to HD Netflix Streaming
4k at 24 fps	4096	2160	24	1	212	0.3	**373**
4k at 24 fps	4096	2160	24	3	637	1.0	**1118**
weld	512	512	10000	1	2621	**4.1**	**4599**
laser cut	768	384	10000	1	2949	**4.6**	**5174**
wire fed	1024	576	5000	1	2949	**4.6**	**5174**
mill	512	512	6000	1	1573	**2.5**	**2759**
mill	768	672	2000	1	1032	**1.6**	**1811**
binding machine	1024	352	2500	1	901	**1.4**	**1581**
blister	512	512	500	1	131	**0.2**	**230**
sewing	768	656	6000	1	3023	**4.7**	**5303**
beverage	1024	1024	2000	3	6291	**9.9**	**11038**
4k at 1000 fps	4096	2160	1000	3	26542	41.7	46565

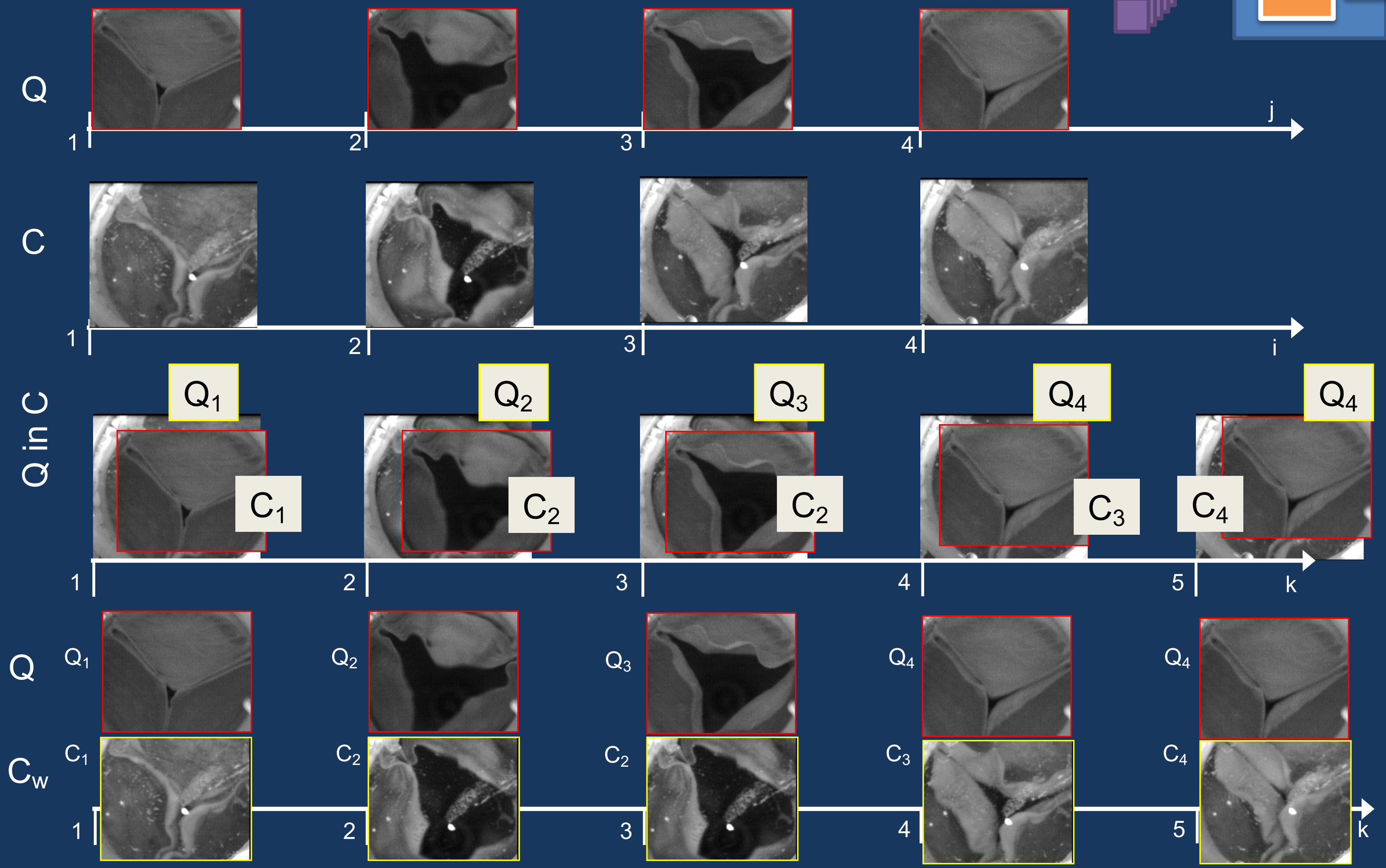
INTUITION FOR APPROACH

Video Alignment Path



Video Alignment Path (VAP)

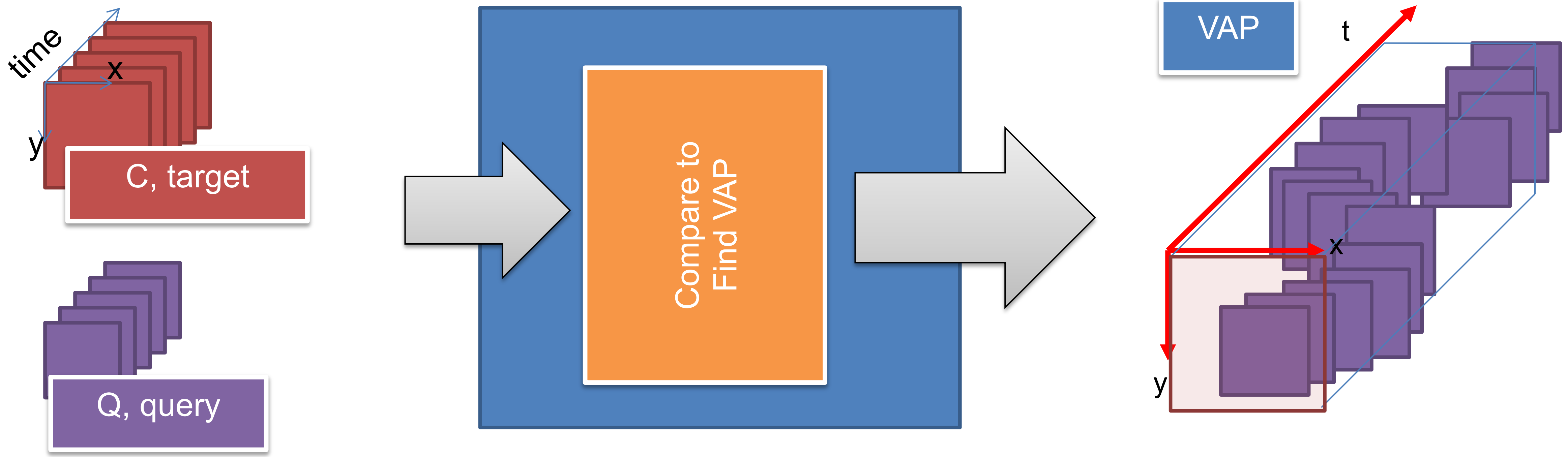




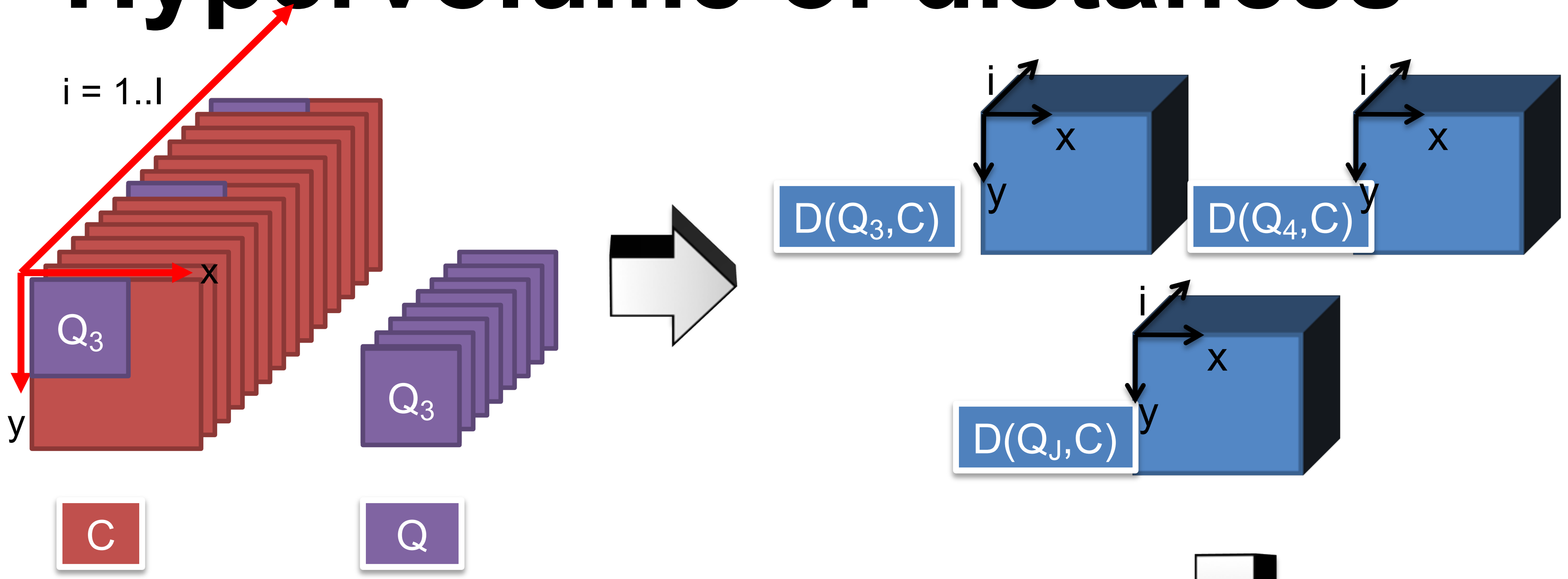
APPROACH

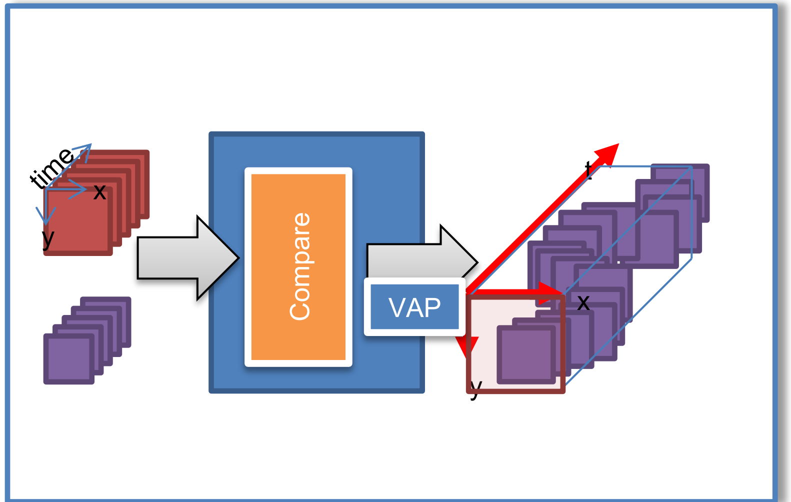
Finding VAP

- Find the optimal VAP of the query video, Q, through / in the target video, C, (distorting time and space) subject to natural constraints.



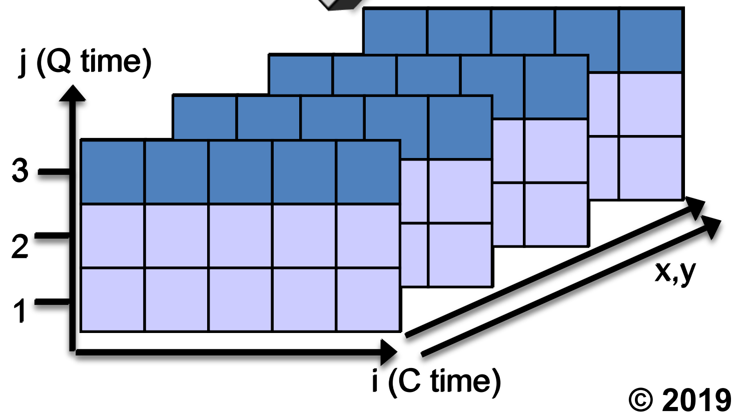
Approach – Shortest* Path through a Hypervolume of distances



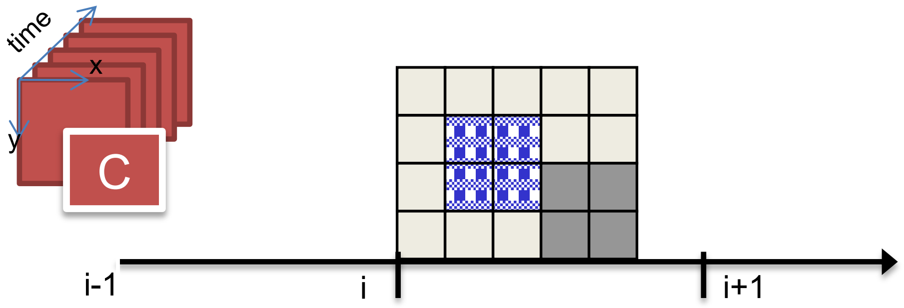


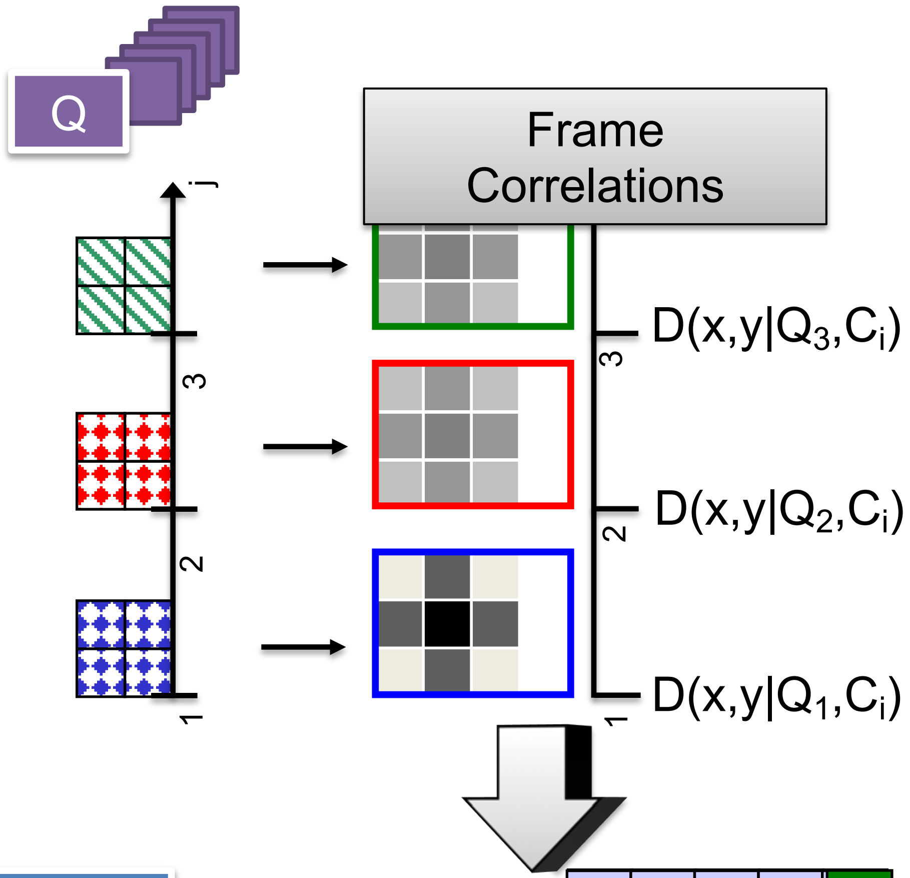
$D_L(Q_{1.J}, C_{1.I})$

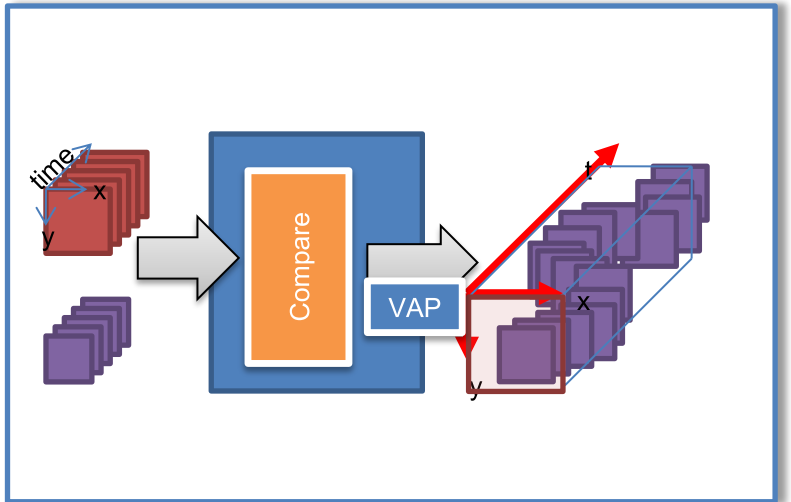
4 Dimensional Elemental Distances Hypervolume:



Query Frame Correlations

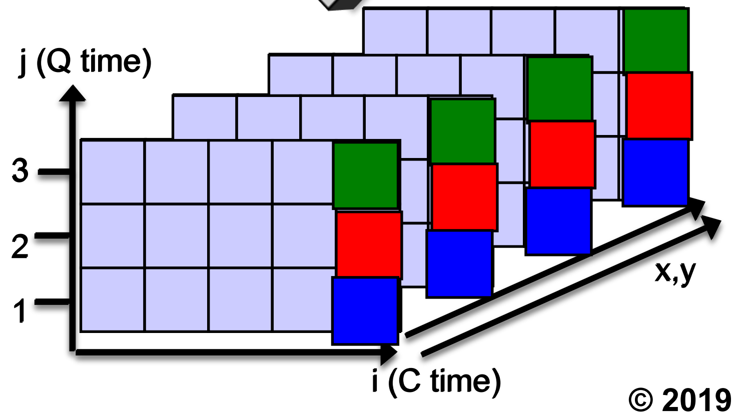






$D_L(Q_{1.J},C_{1.I})$

4 Dimensional Elemental Distances Hypervolume:

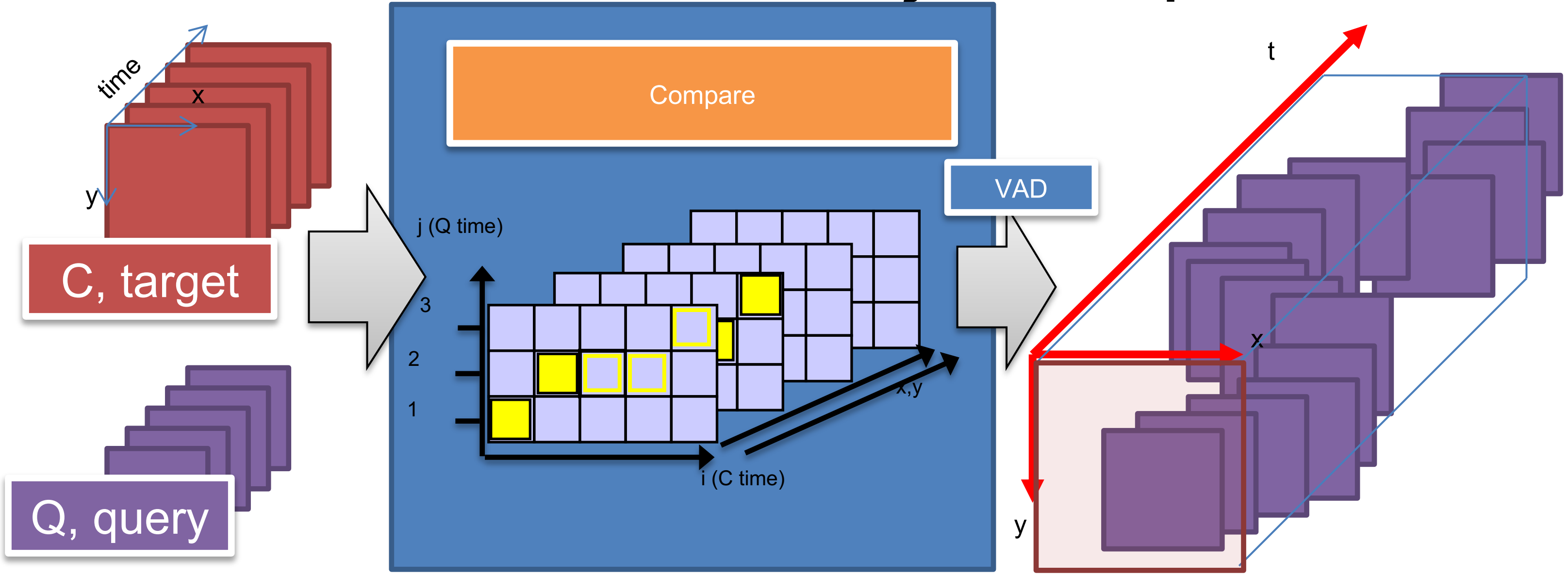


Constraints

APPROACH AND INTUITION

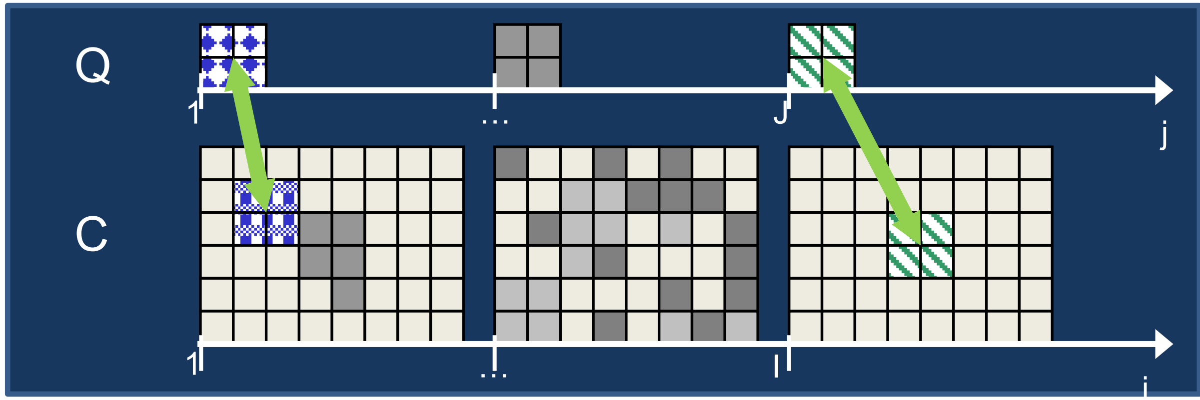
Natural Constraints

- Find the best match of the template video, Q, through the target video, C subject to alignment **constraints**.
- Find the minimum cost path through the elemental hypervolume of distances subject to path **constraints**.



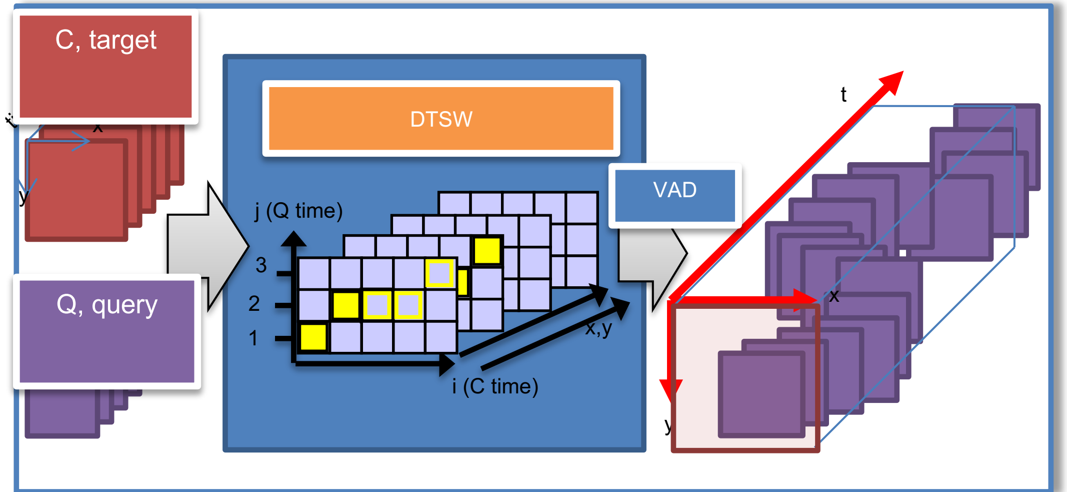
- **Endpoints**
- Temporal Continuity
- Bi-Temporal Causality
- Spatial Continuity
- Spatial Drift

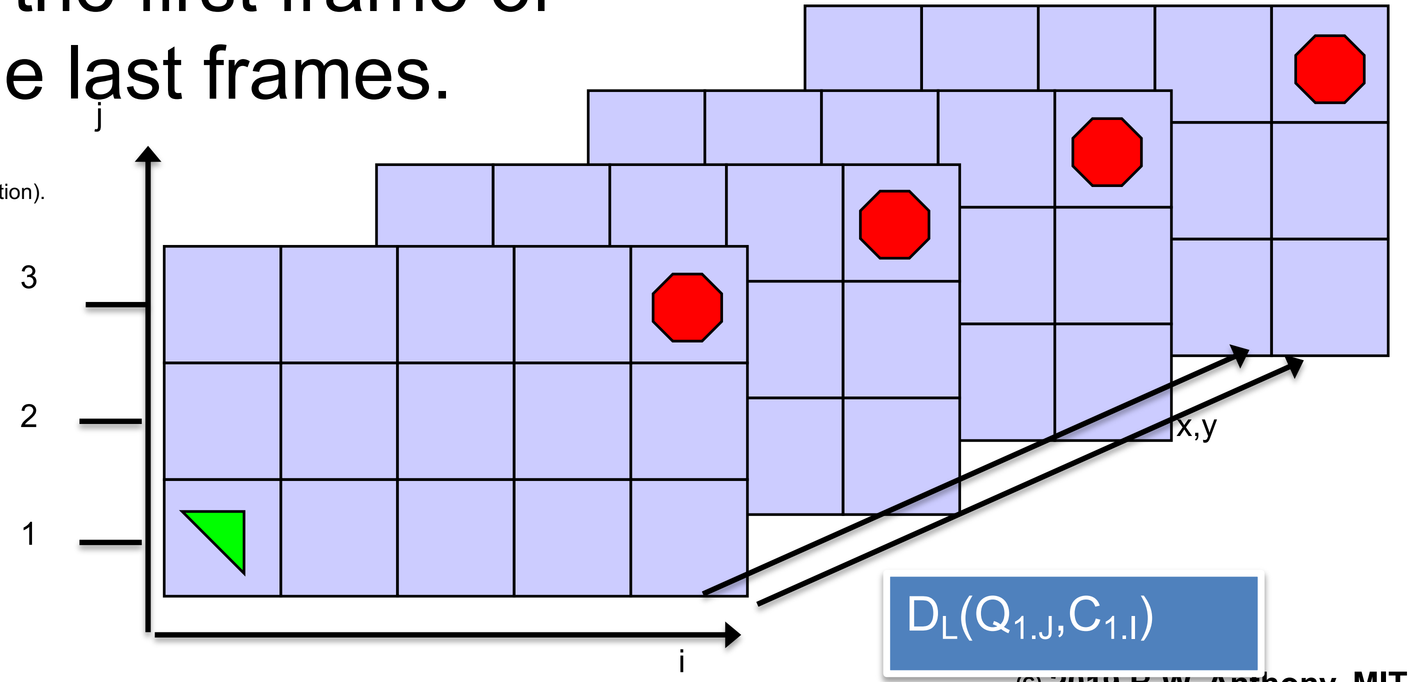
Natural Constraints



The **end frames constraint** ensures that the first frame of the query is matched to the first frame of the test video, and likewise for the last frames.

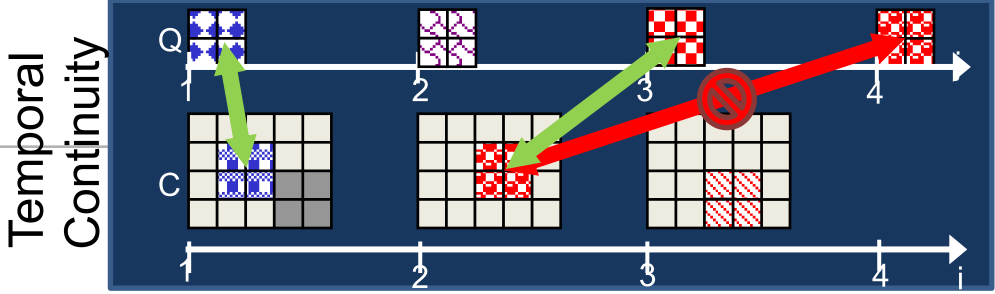
; this constraint is easily relaxed to accommodate imprecise temporal clipping, and to facilitate scanning (for detection).

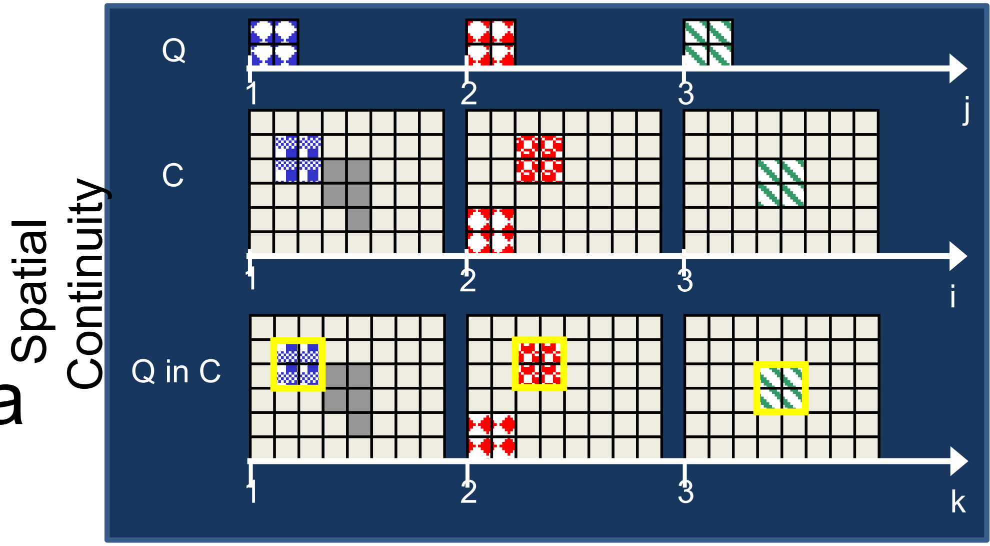




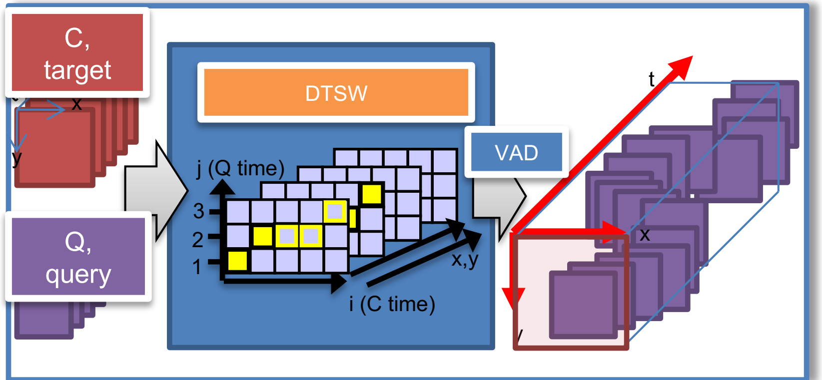
- Endpoints
- Temporal Continuity
- Bi-Temporal Causality
- Spatial Continuity
- Spatial Drift

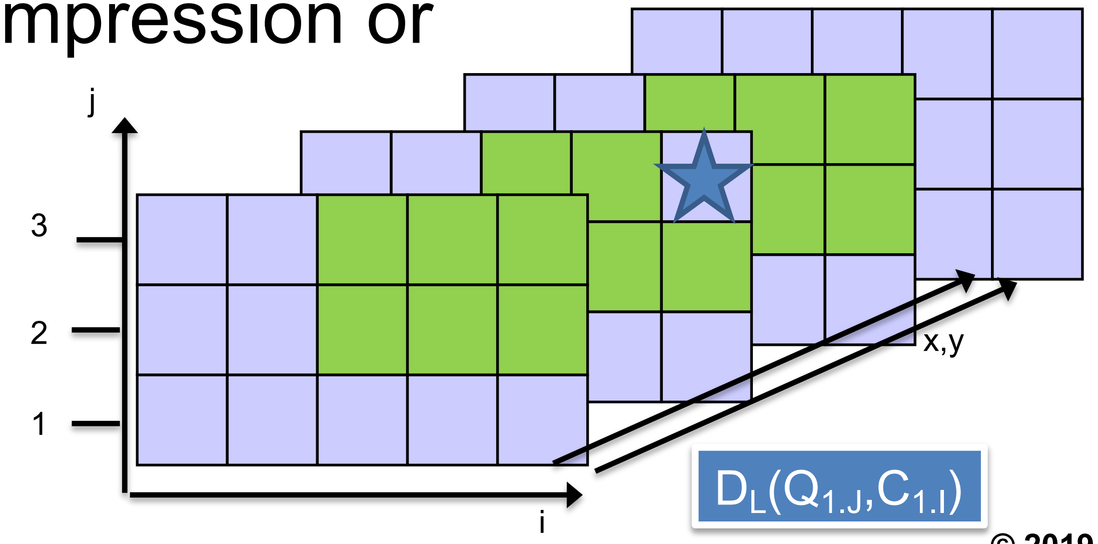
Natural Constraints





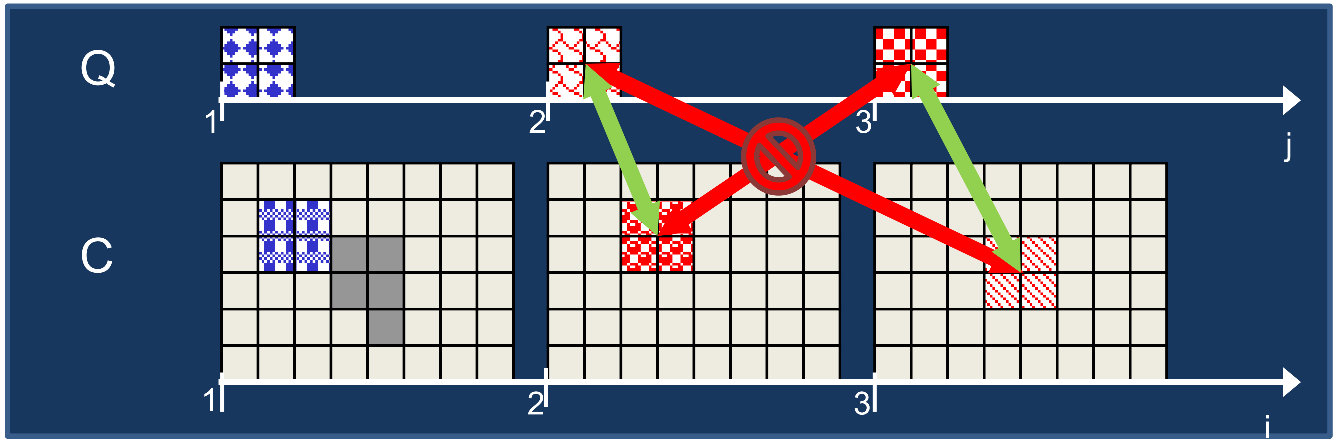
The **spatial continuity constraint** limits the VAP stay within a bounded spatial radius over a short period of time. The **temporal continuity constraint** limits local temporal compression or stretching of the time axes.



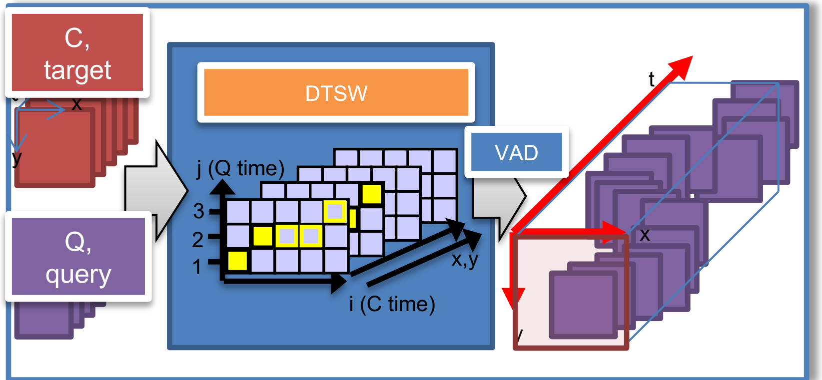


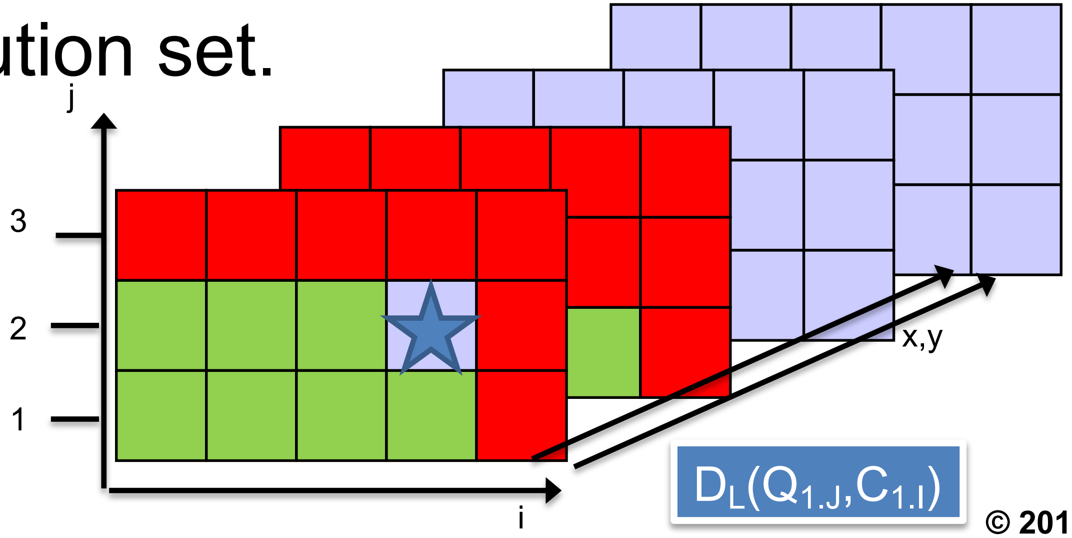
Natural Constraints

- Endpoints
- Temporal Continuity
- **Bi-Temporal Causality**
- Spatial Continuity
- Spatial Drift



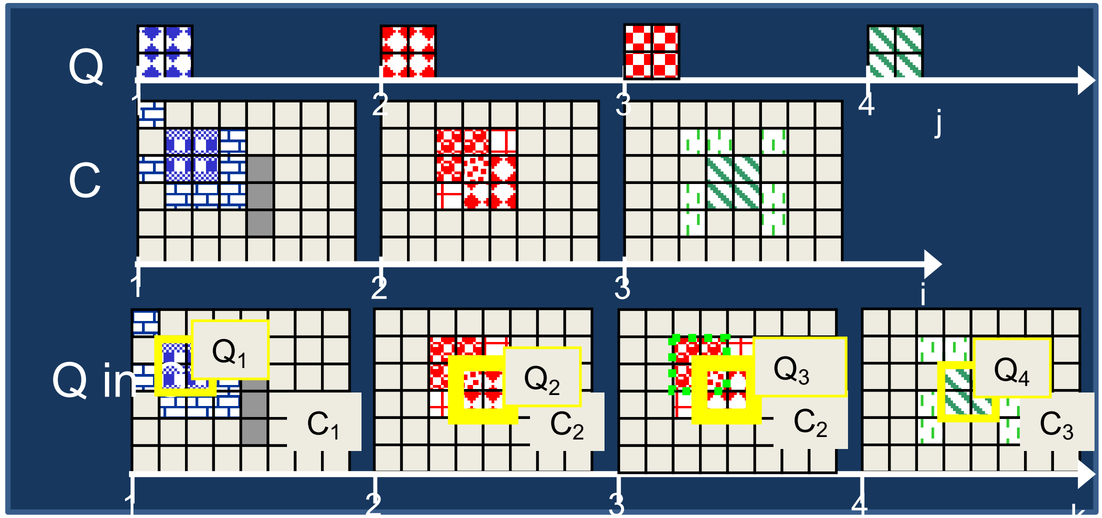
The **bi-temporal causality constraint** enforces the assumption that both Q and C are time-ordered sequential segments; this constraint also ensures a finite solution set.





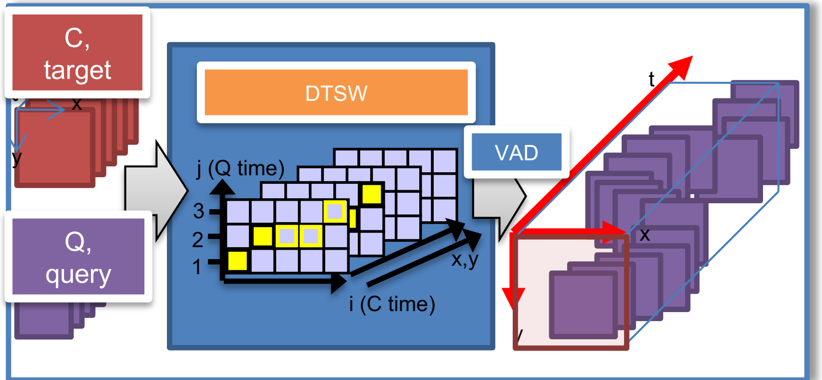
Natural Constraints

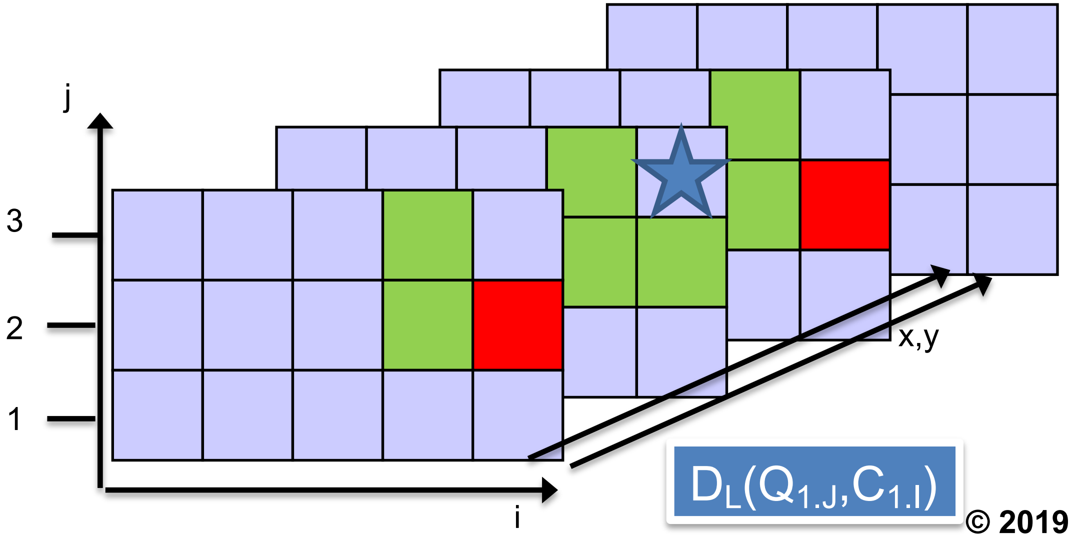
- Endpoints
- Temporal Continuity
- Bi-Temporal Causality
- Spatial Continuity
- **Spatial Drift**



The **spatial drift or blur constraint** enforces the assumption of a fast frame exposure, relative to observed motion. A frame contains an image of a scene at an instant in time.

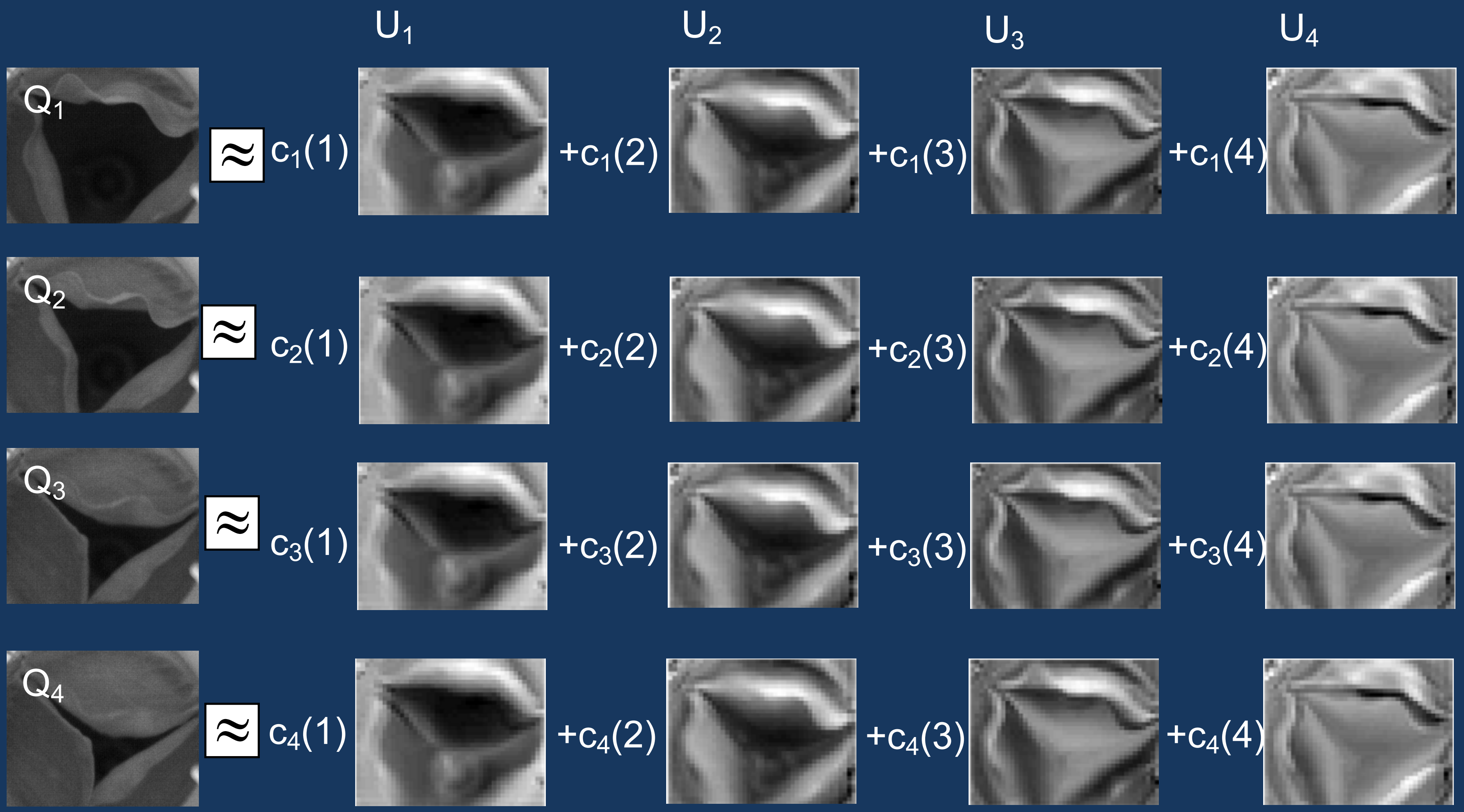
If a frame of Q must be replicated to match to two or more frames of C, then the frame-to-frame matching must occur at the same spatial location in the replicated frame of C. If frame exposures are long compared to the time scales of captured motion, then blurring or spatial drift would make physical sense, and this constraint would be relaxed



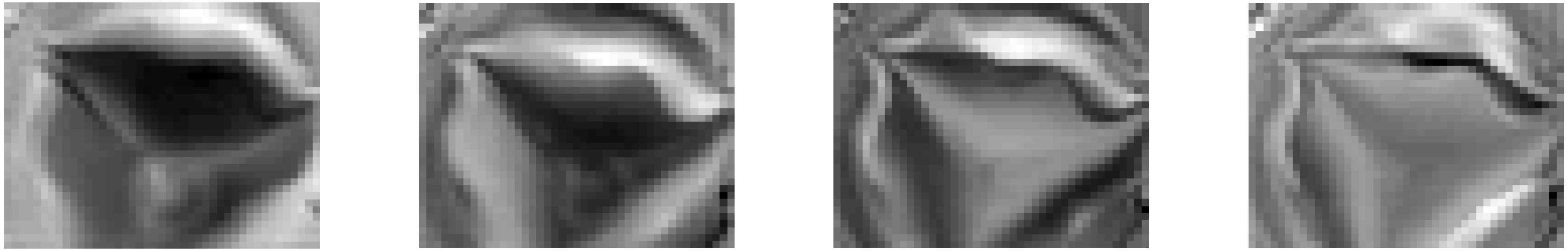


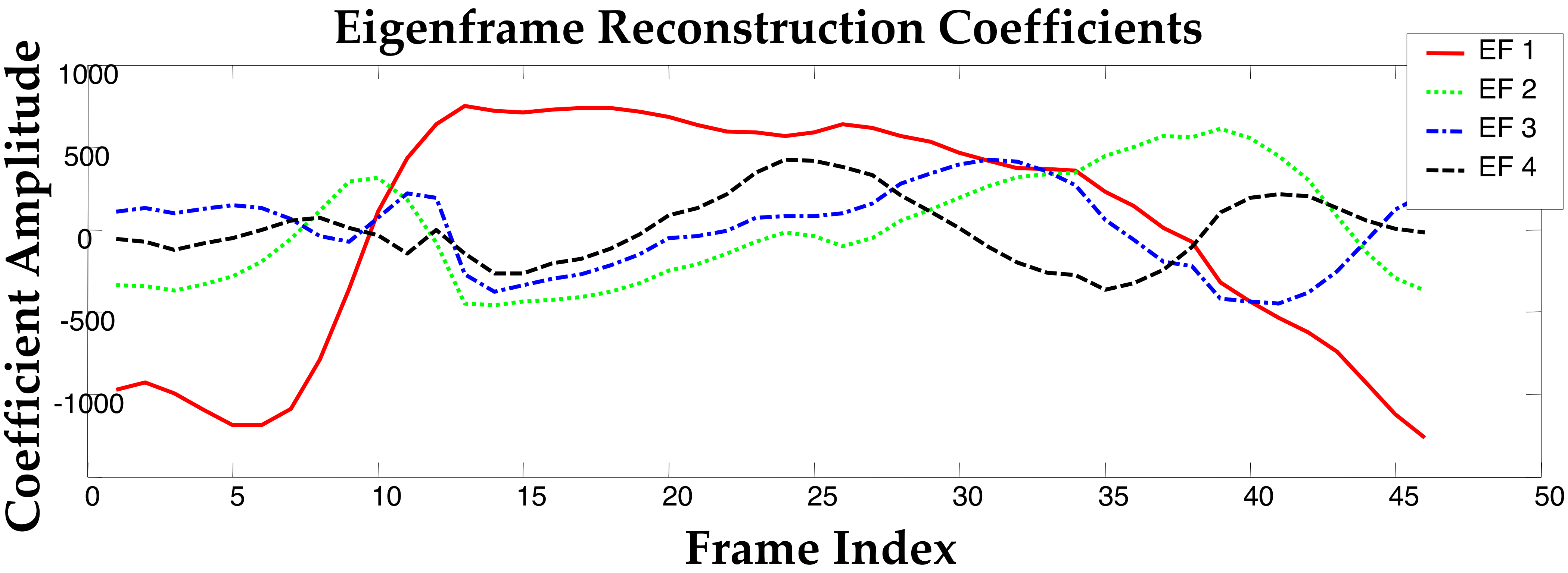
ACCELERATED PROCESSING

Eigenframes

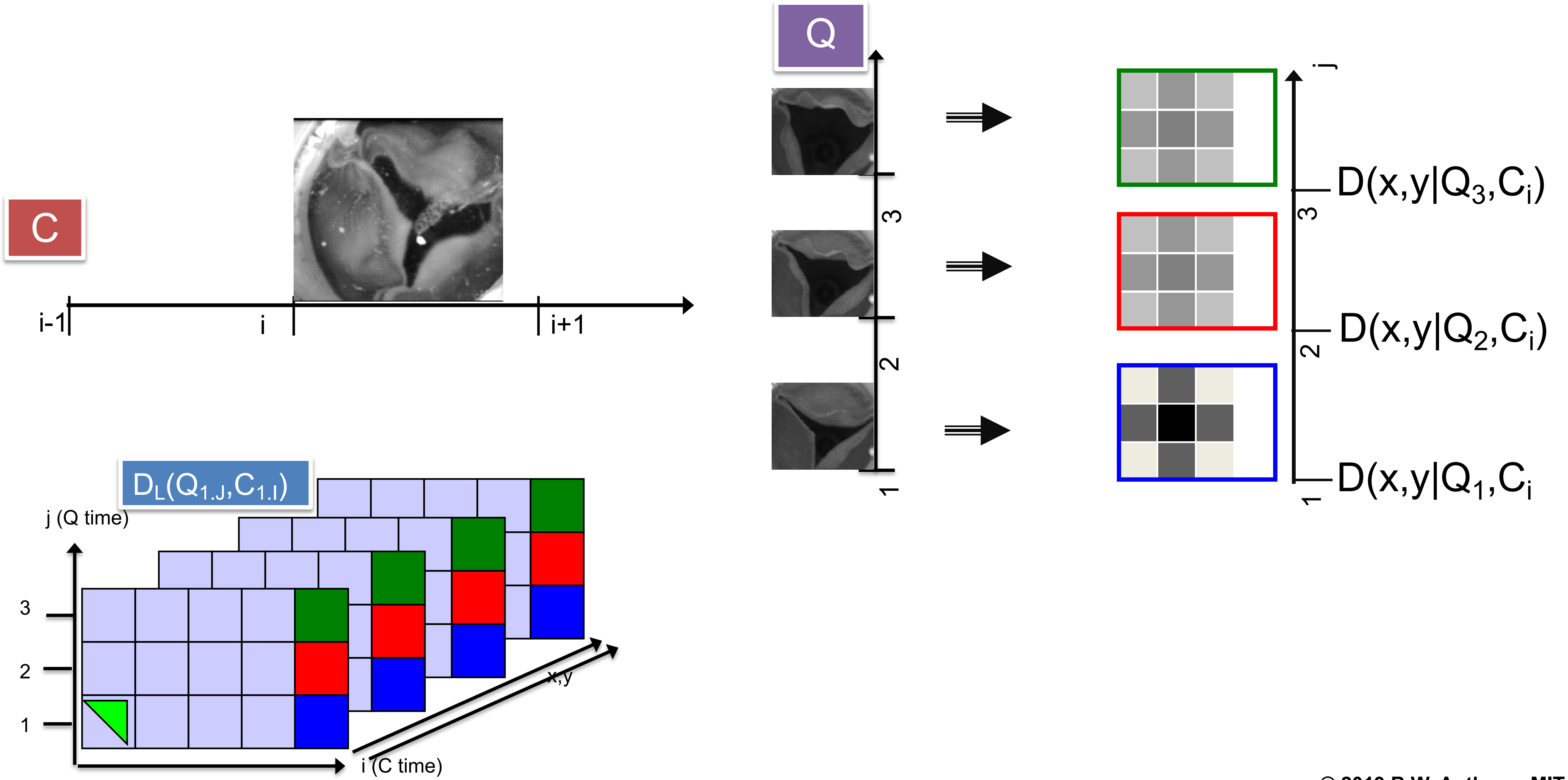


Eigenframes and Coefficients

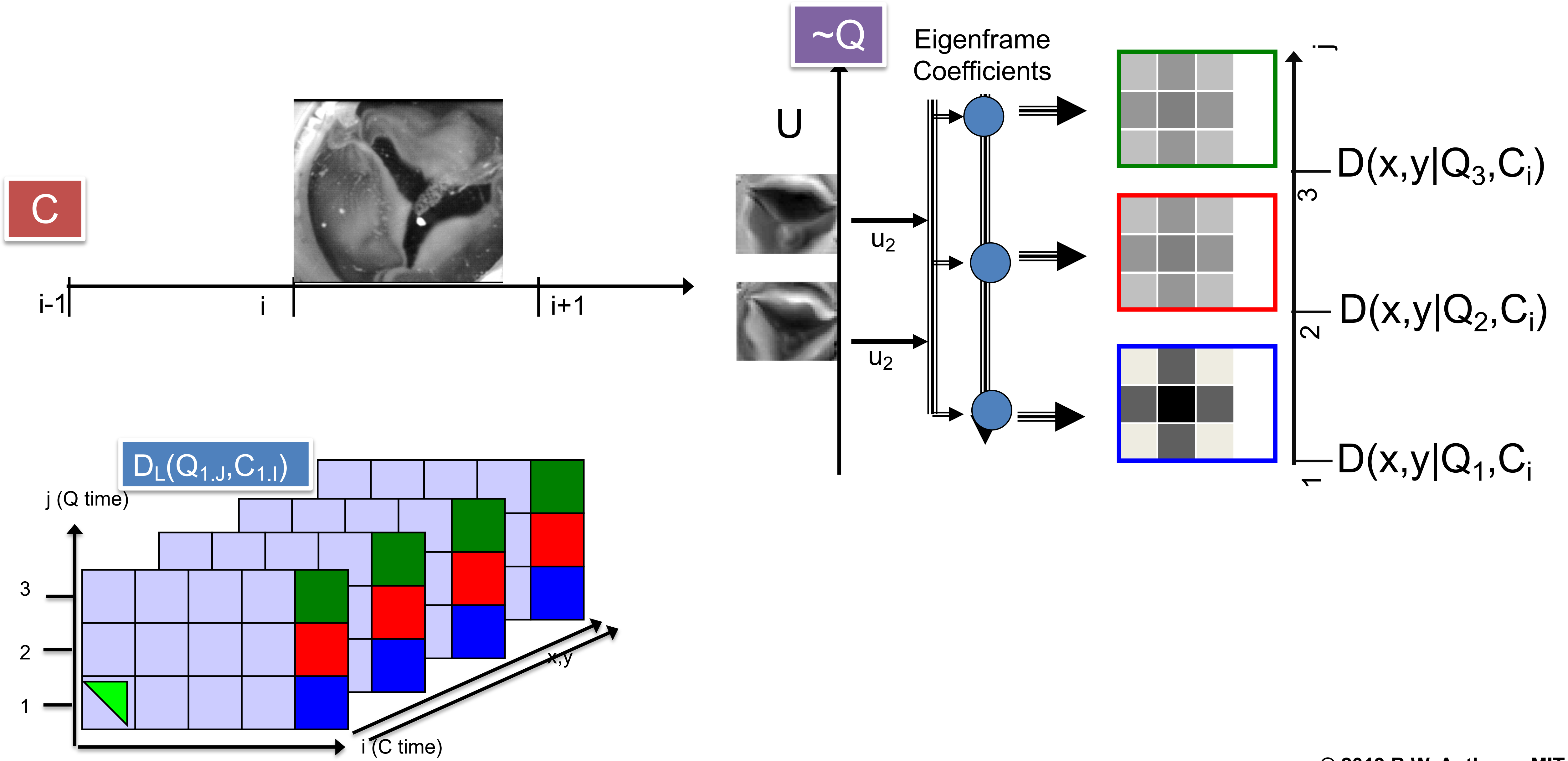




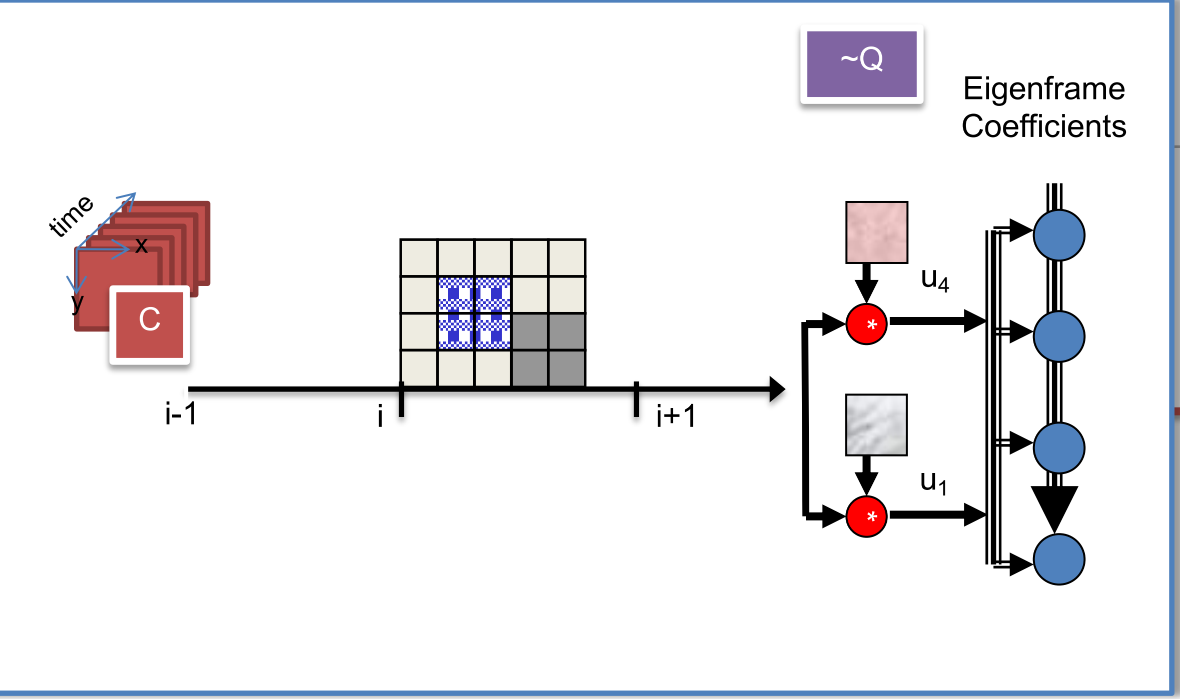
Query Frame Filterbank

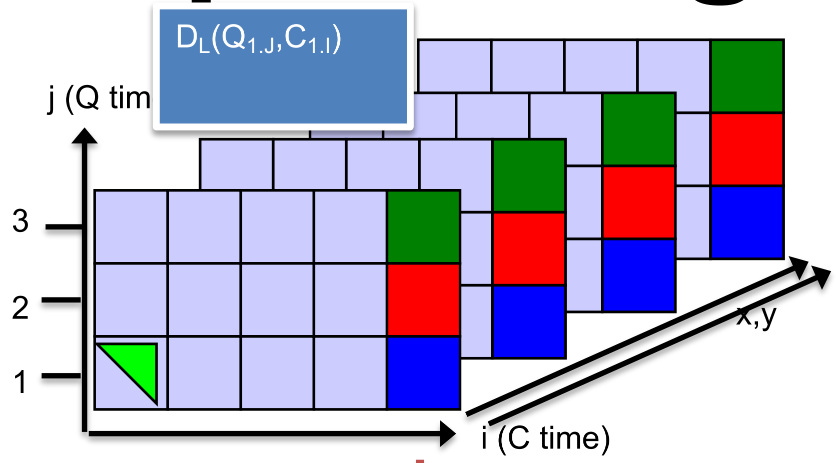


Eigen-Frame Filterbank

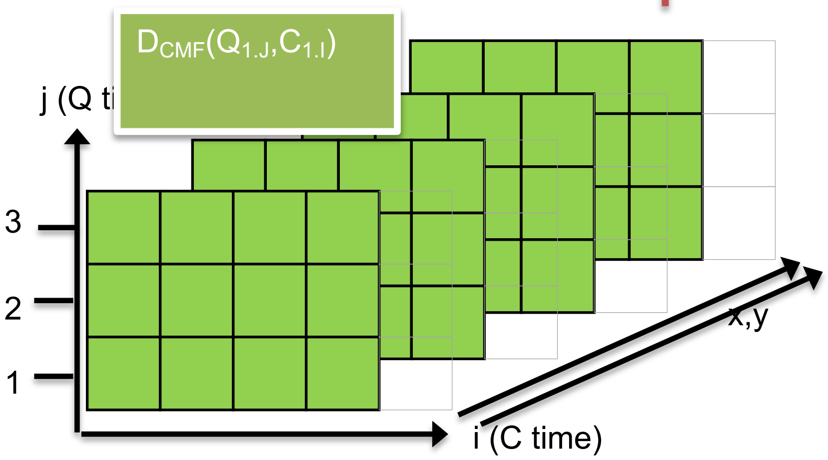


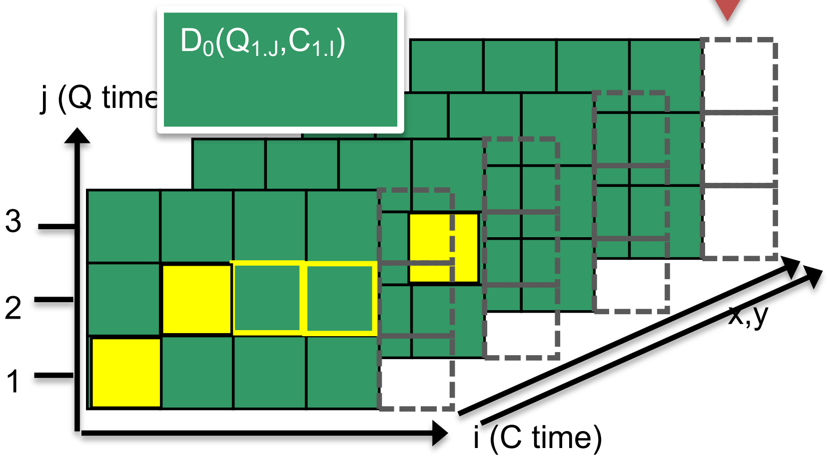
Complete Algorithm





“Minimum Accumulation Filter” on IJ planes ---- MA(*,H_{MA})



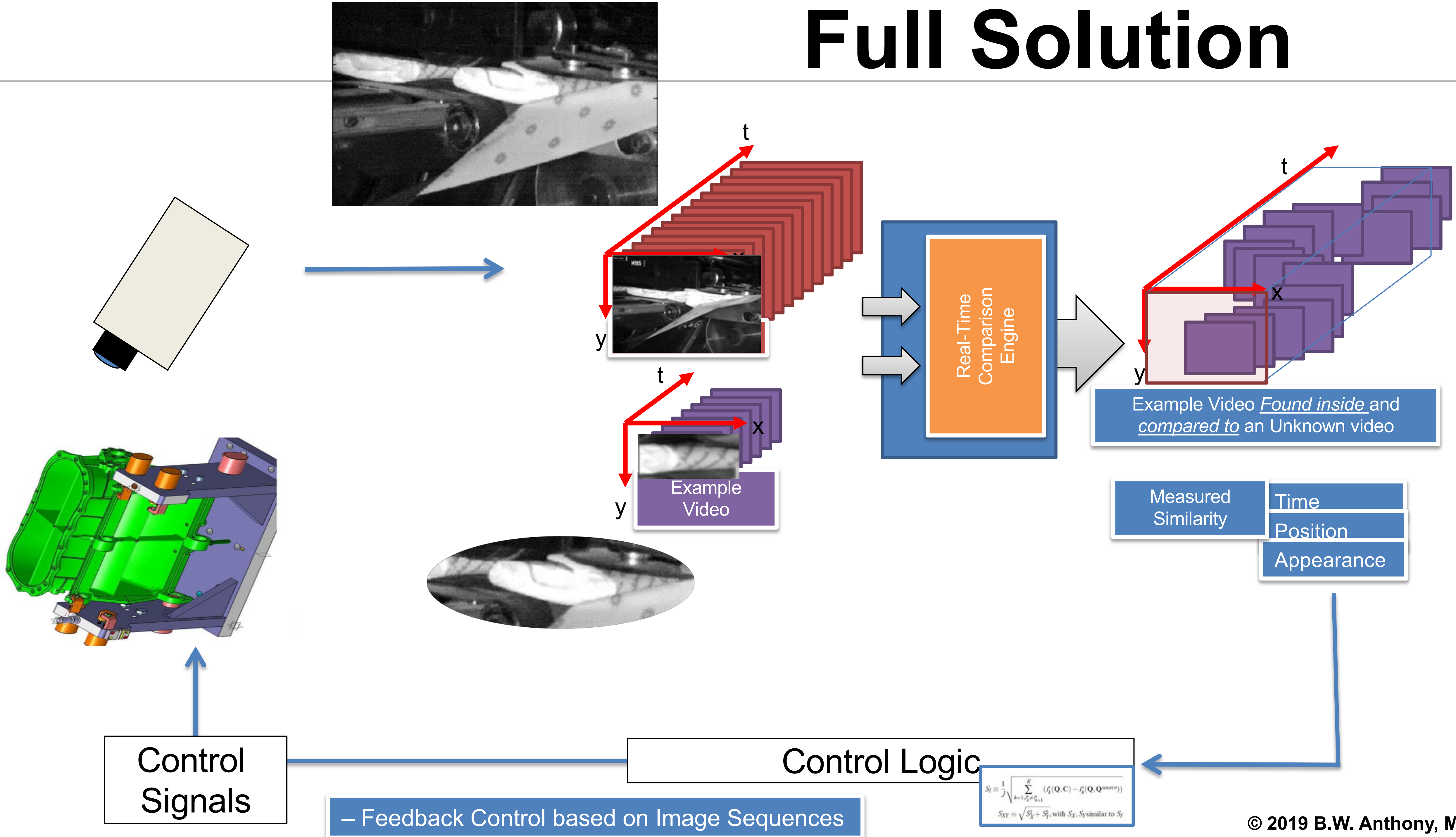


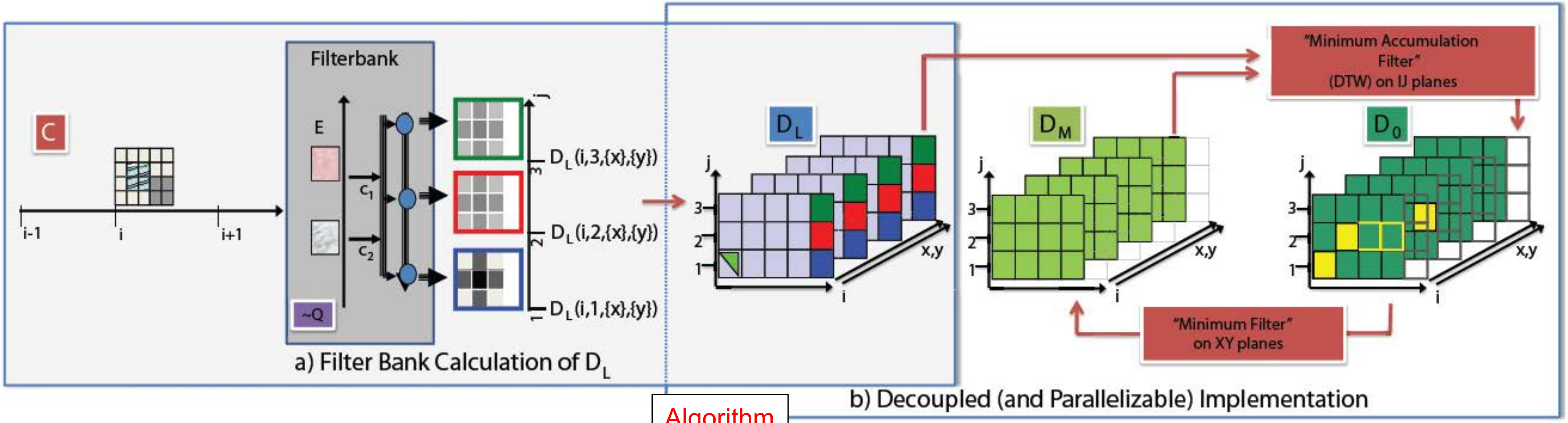
“Local Minimum Filter” on XY planes --- MF(*,H_{LM})

$$D_0(i,j,x,y) = \min \begin{cases} D_0(i-1, \ j, \ \mathbf{x_b},\mathbf{y_b}) + 1D_L(i,j,x,y) \\ D_0(i-1, j-1, \mathbf{x_b},\mathbf{y_b}) + 2D_L(i,j,x,y) \\ D_0(\ i, \ j-1, \ x, \ y) + 1D_L(i,j,x,y) \end{cases}$$

RESULTS

Full Solution

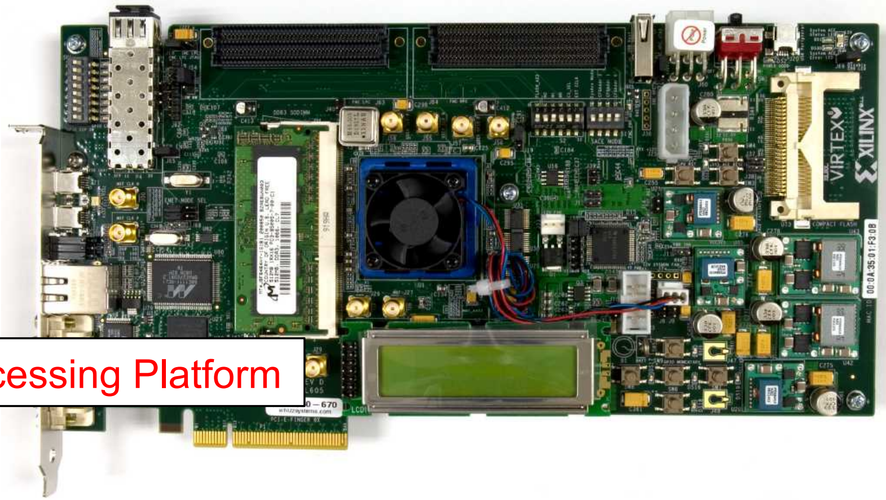




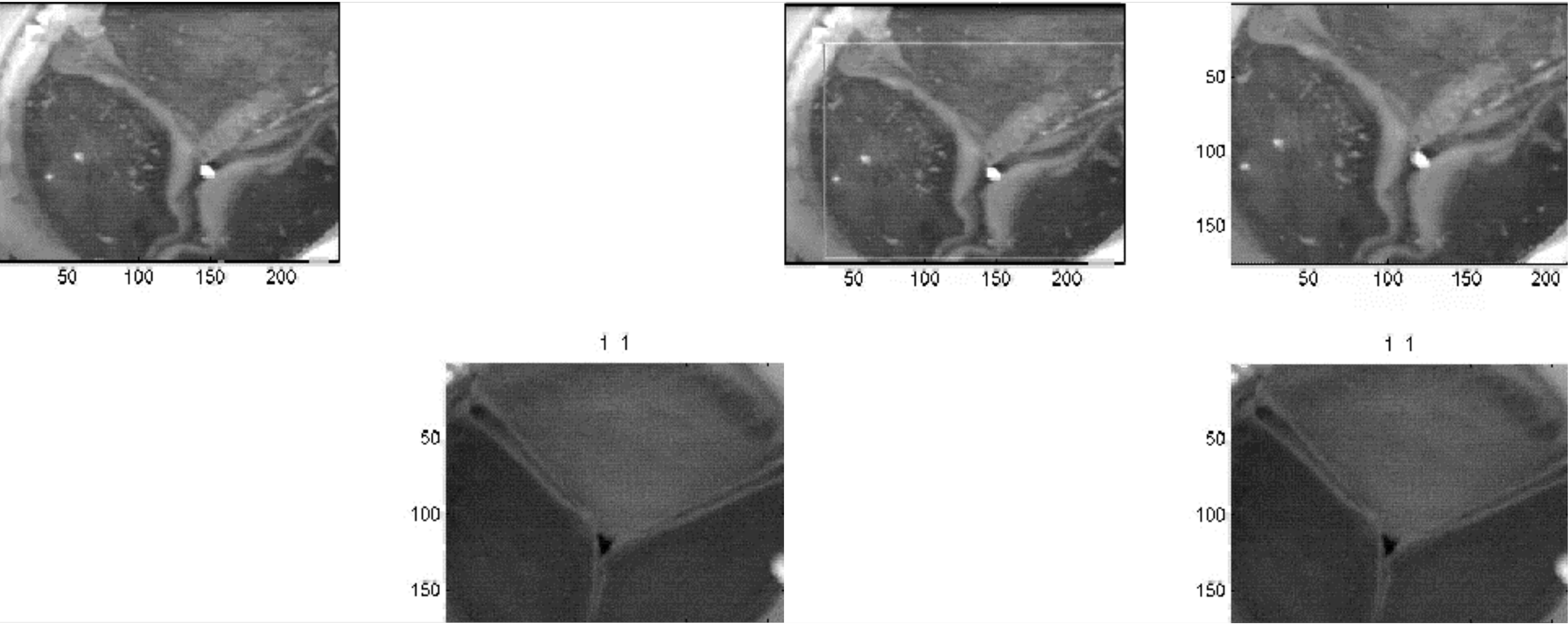
Algorithm

Camera

Processing Platform



Anthony, MIT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50 100 150
50 100 150 200
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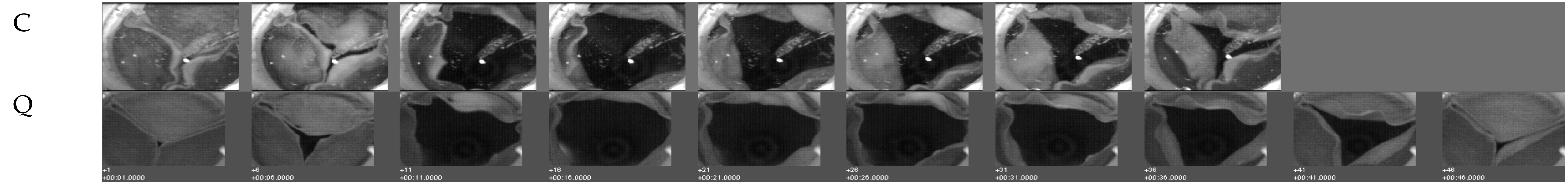
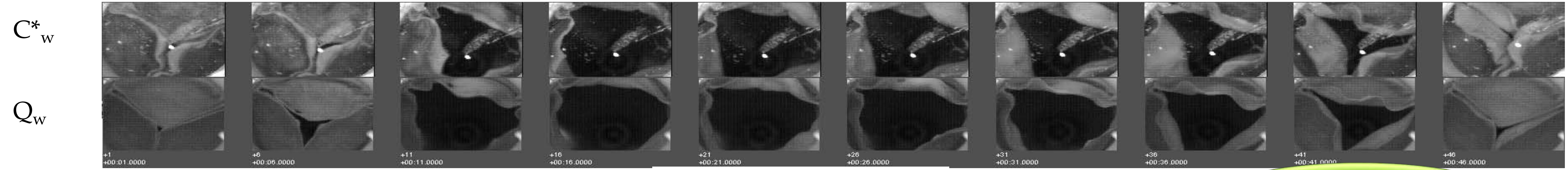
50 100 150
1 1
50 100 150

Automated Monitoring: Product Lifetime Test, Monitoring a synthetic heart valve

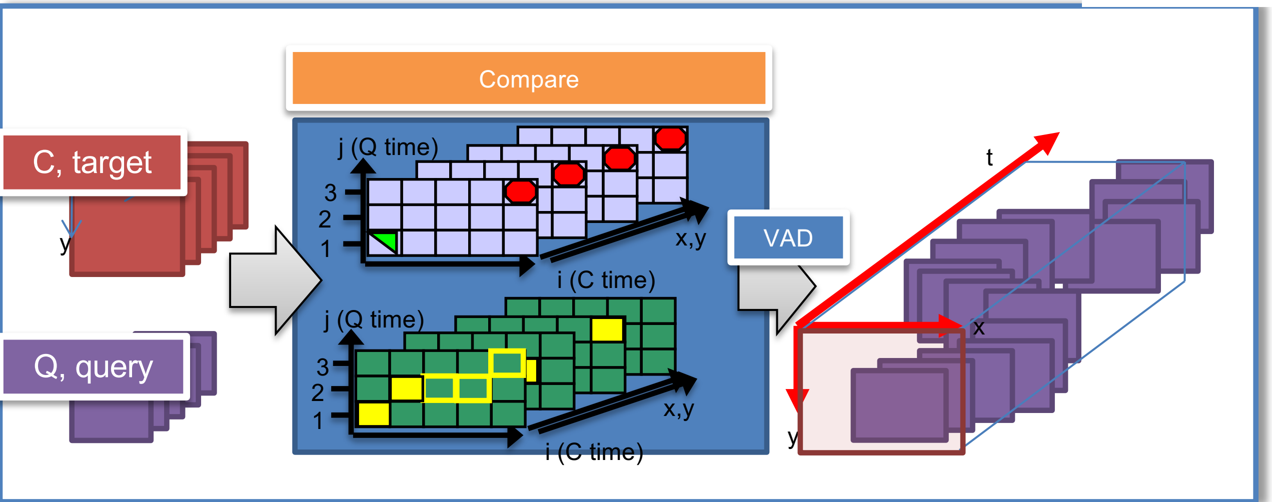
Input





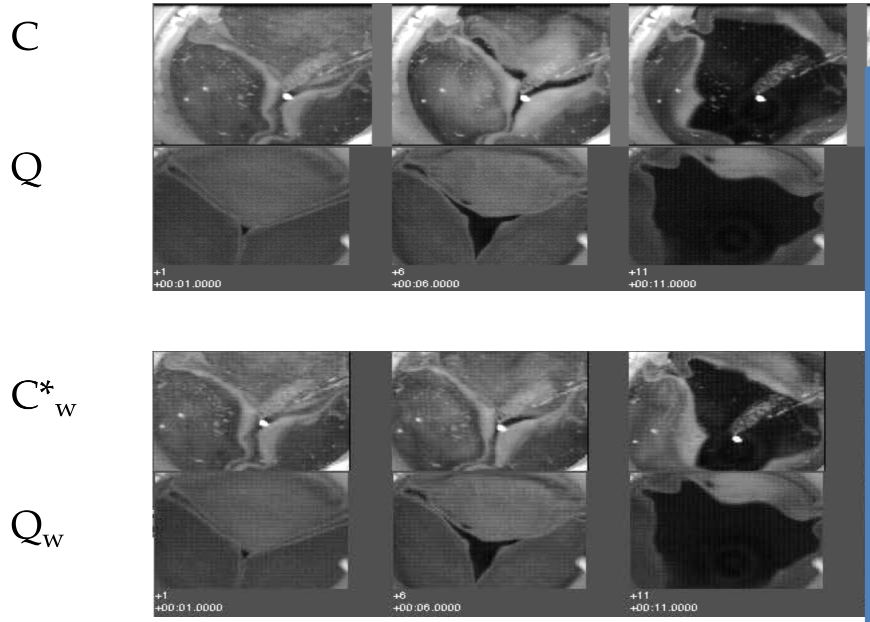
Output

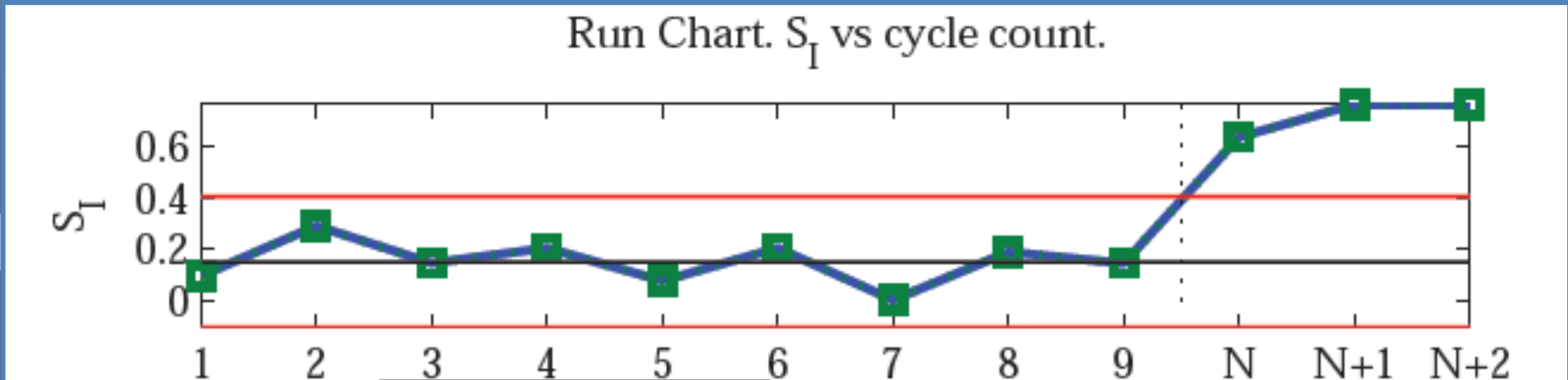
SHOW VIDEOS

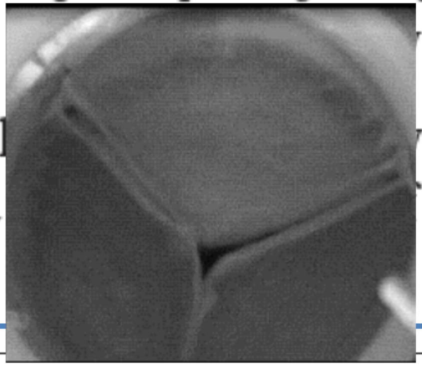


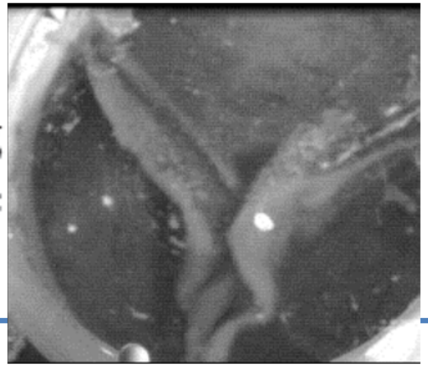
Automated Monitoring: Product Lifetime Test, Monitoring a synthetic heart valve

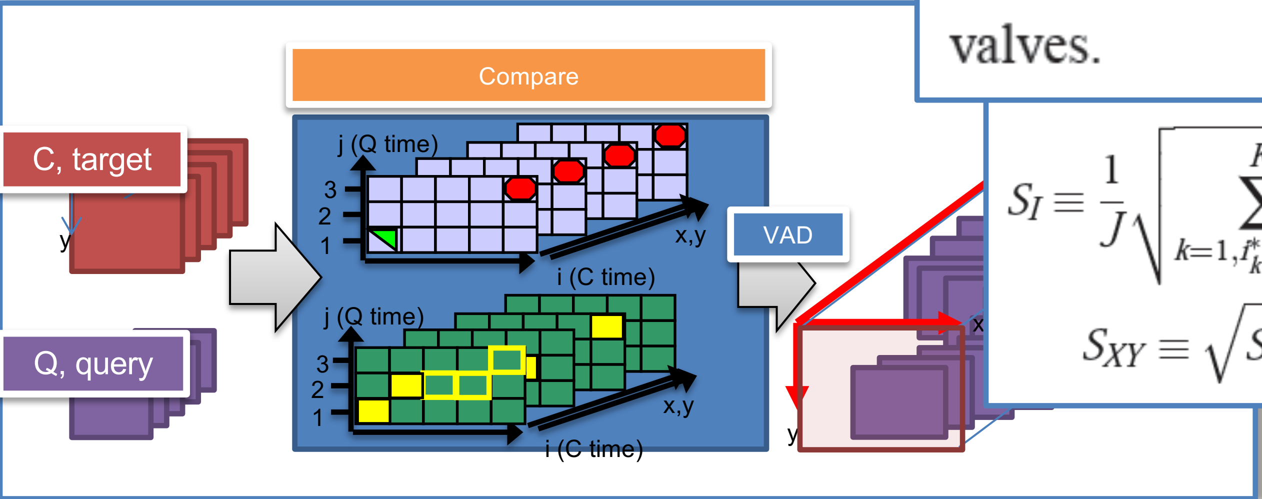
Input









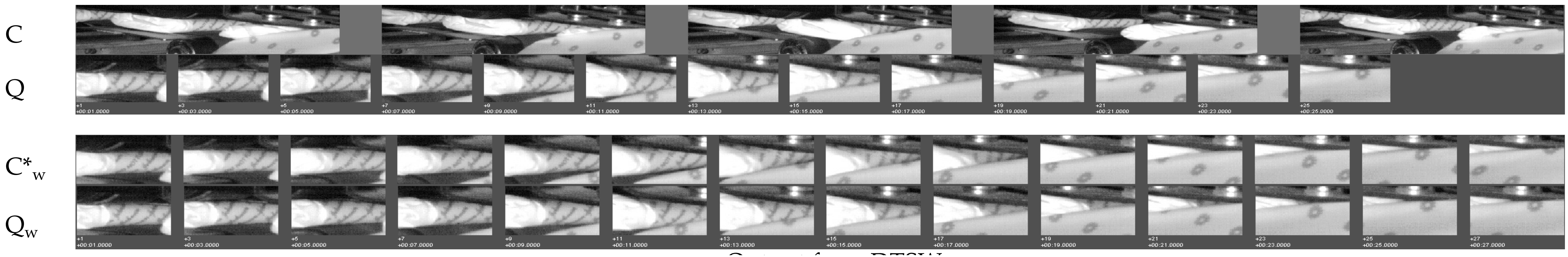


$$S_I \equiv \frac{1}{J}\sqrt{\sum_{k=1,\, i^*_k \neq i^*_{k+1}}^{K} \left(i^*_k(\mathbf{Q},\mathbf{C}) - i^*_k(\mathbf{Q},\mathbf{Q}^{source})\right)}$$

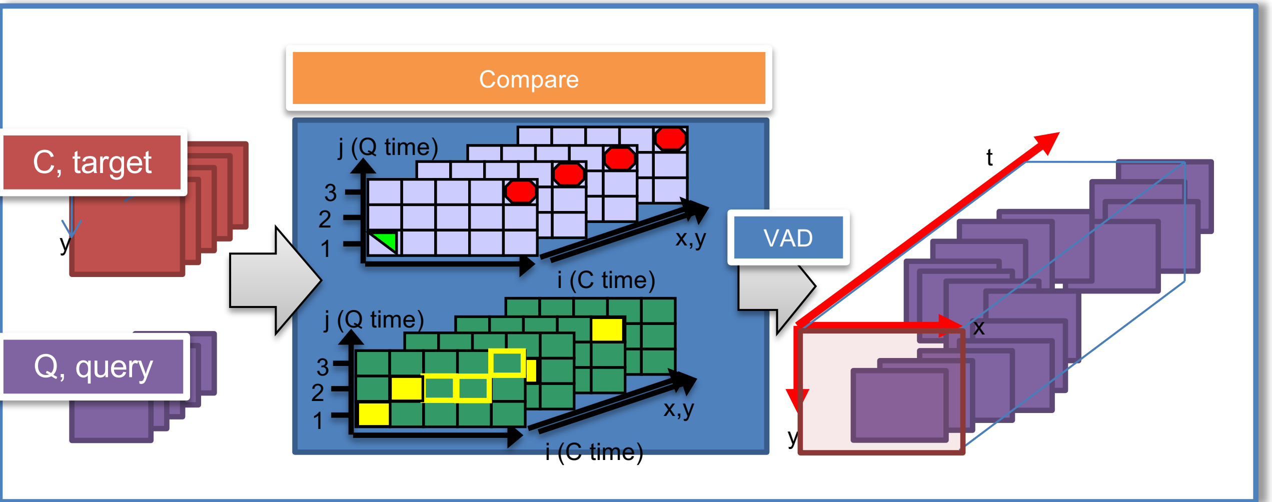
$$S_{XY} \equiv \sqrt{S_X^2 + S_Y^2}, \text{with } S_X, S_Y \text{similar to } S_I$$

Automated Monitoring:
Production Faults, Monitoring a Diaper Packaging Line

Input



Output



Automated Monitoring:
Production Faults, Monitoring a

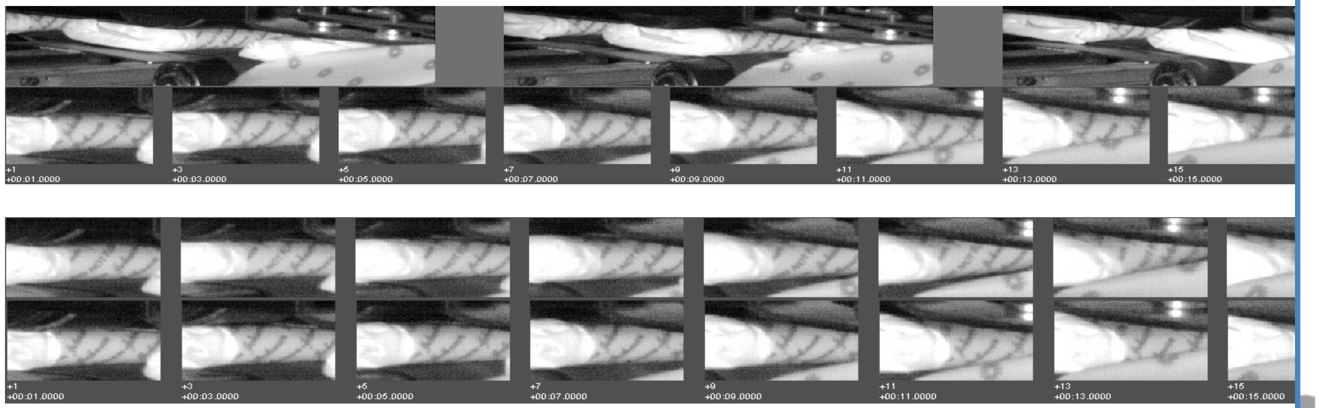
Input to D

C

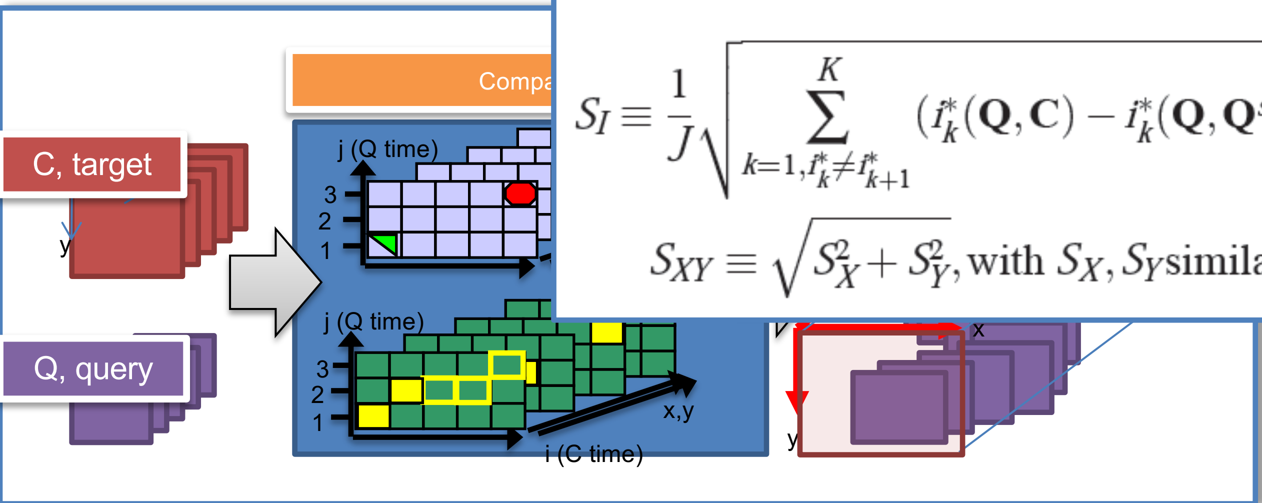
Q

C*w

Qw



Output from



$$S_I \equiv \frac{1}{J}\sqrt{\sum_{k=1, i_k^* \neq i_{k+1}^*}^{K} \left(i_k^*(\mathbf{Q},\mathbf{C}) - i_k^*(\mathbf{Q},\mathbf{Q}^{source})\right)}$$

$$S_{XY} \equiv \sqrt{S_X^2 + S_Y^2}, \text{with } S_X, S_Y \text{similar to } S_I$$

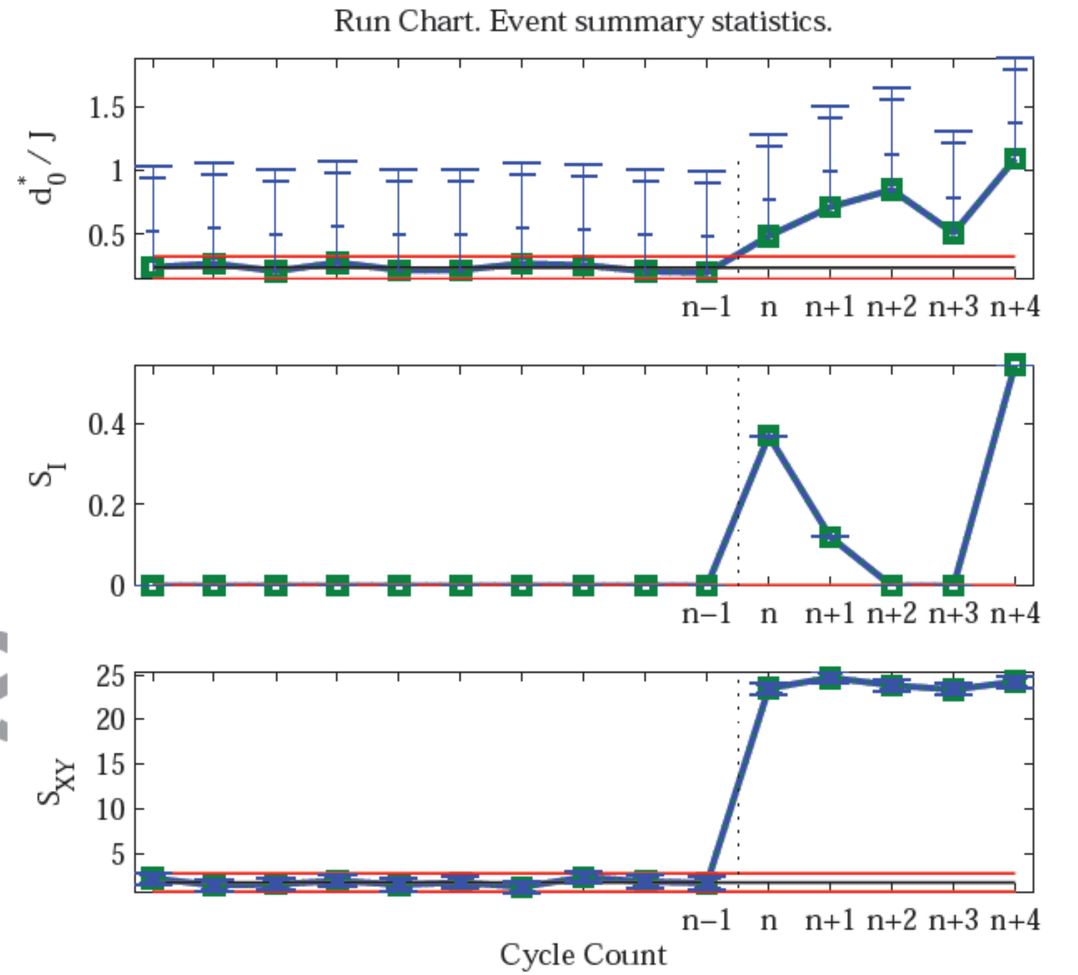
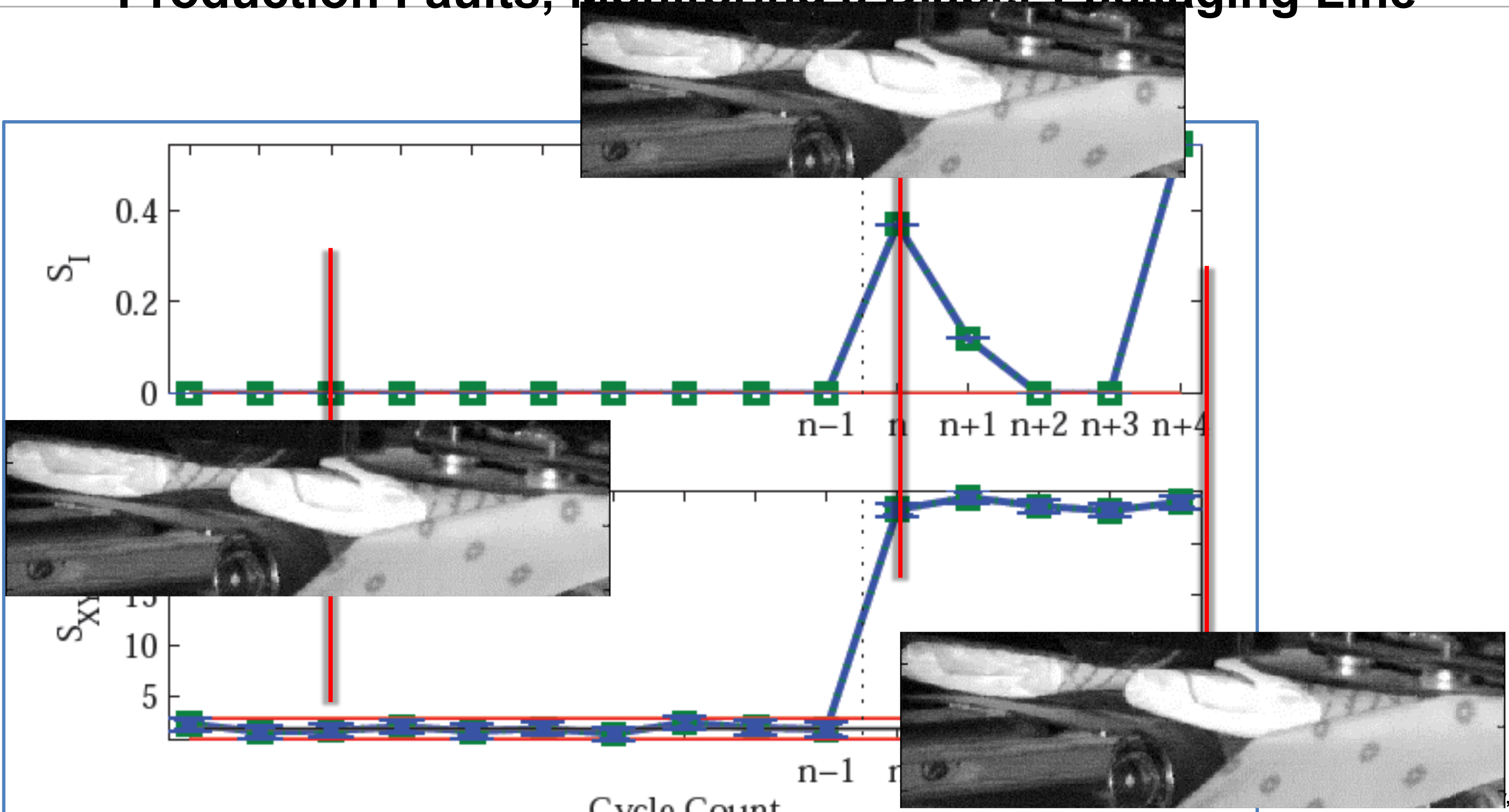


Fig. 13 Diaper wrapping event summary statistics: d_0^*/J - normalized DTSW distance, S_I - L_2 time error, S_{XY} - L_2 position error, prior to, including, and after the first glitch at **Event n** are plotted. In order to autonomously monitor and detect faults, we would first set a threshold during normal operation and then detect when that threshold is exceeded. We see that it would be easy to select thresholds that detect a problem starting at **Event n** and through **Event n+4**. The error bars

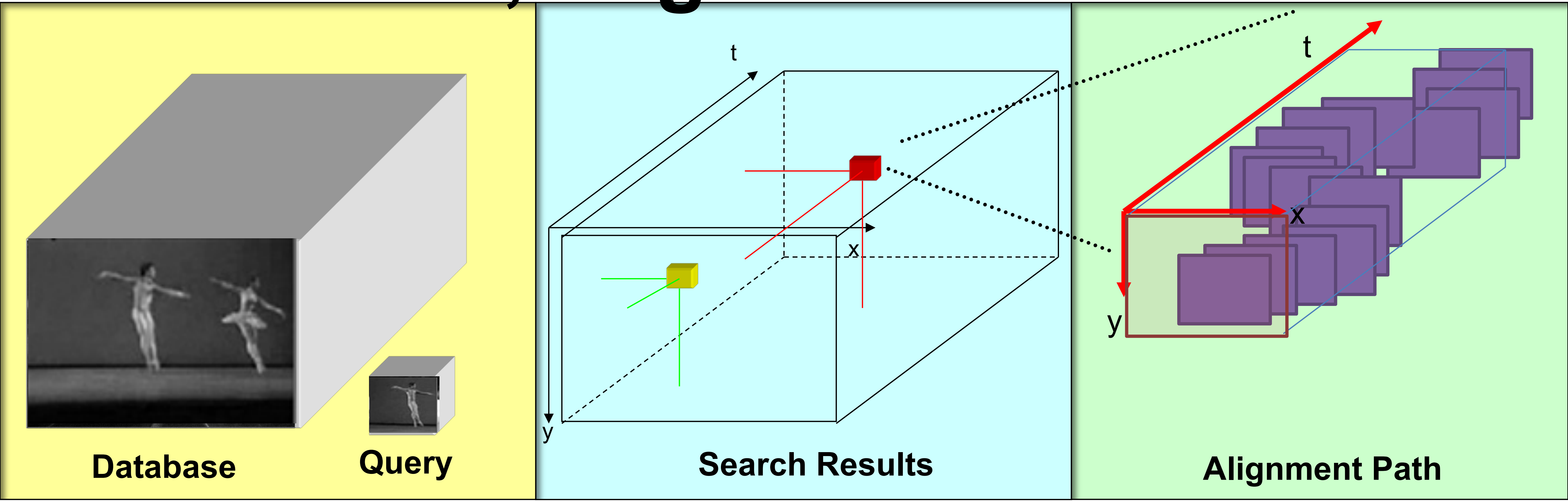
Automated Monitoring:
Production Faults, Monitoring a Diaper Packaging Line



New direction…

VIDEO SEARCH

Detection, Alignment Information

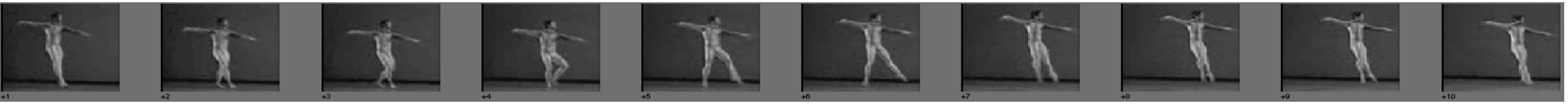


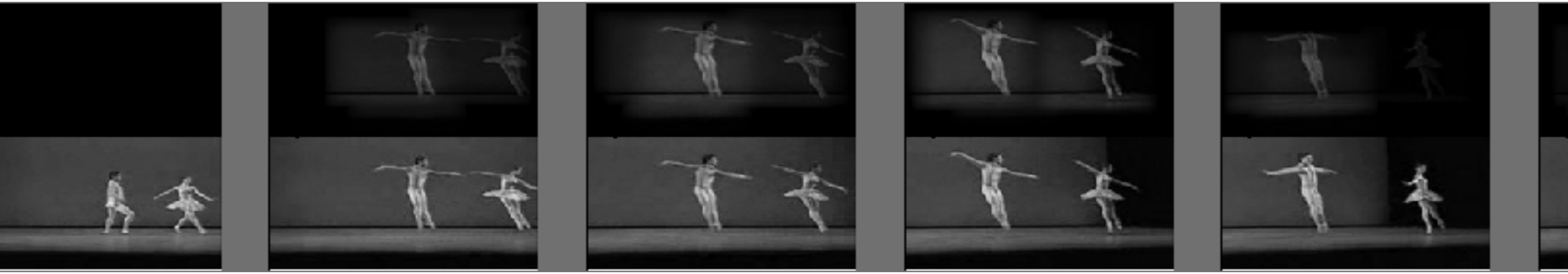
thony, MIT

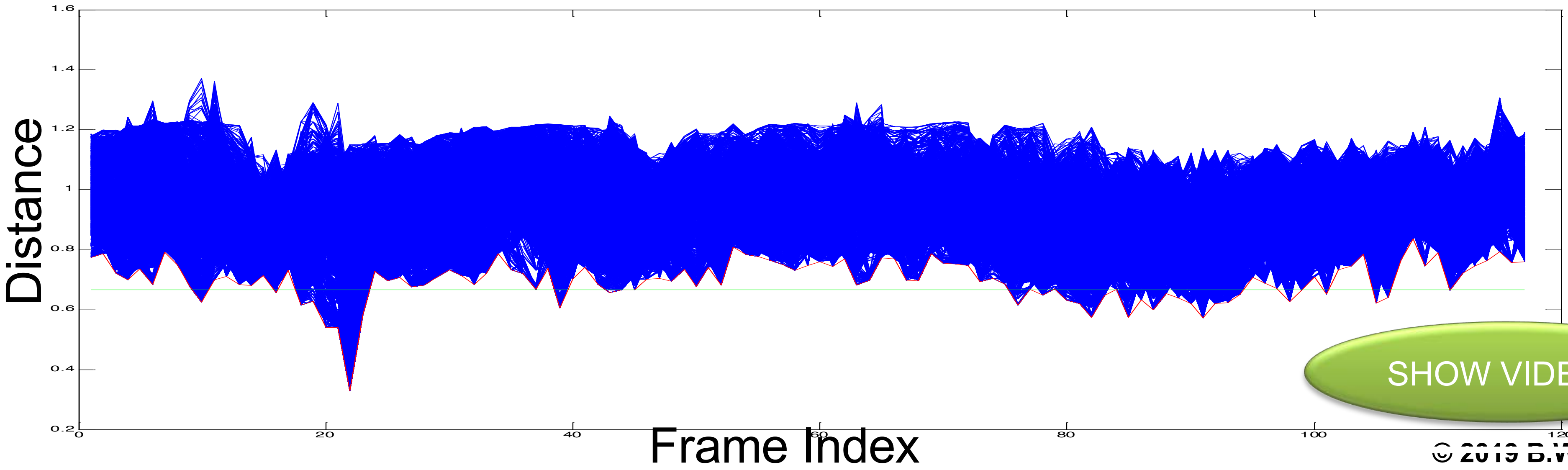
Detection

thony, MIT

Example: Video Event Detection







SHOW VIDEOS

Example: Karate

Input

C

Q

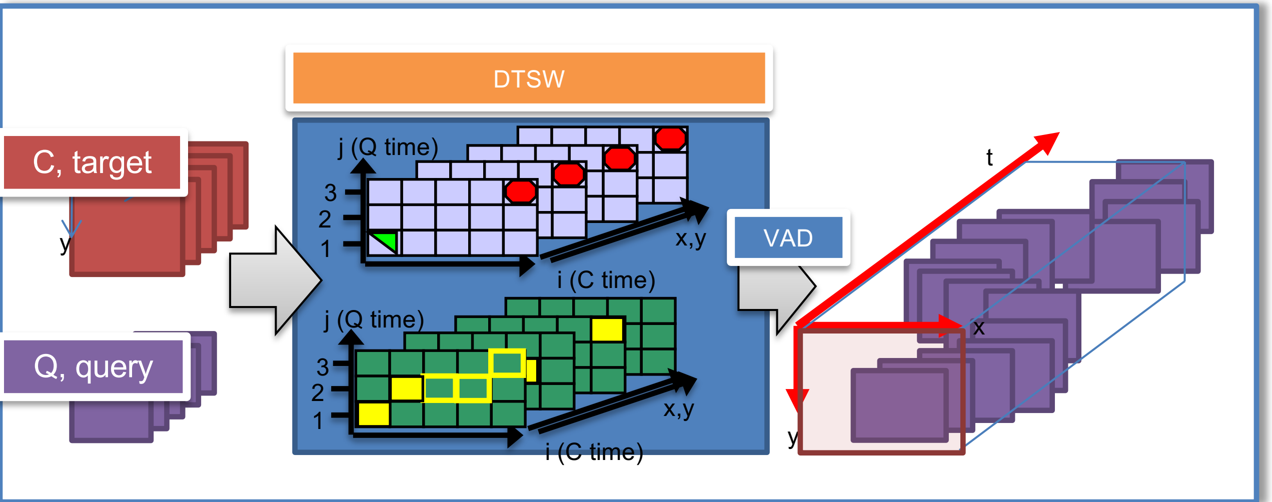
C*$_W$

Q_W

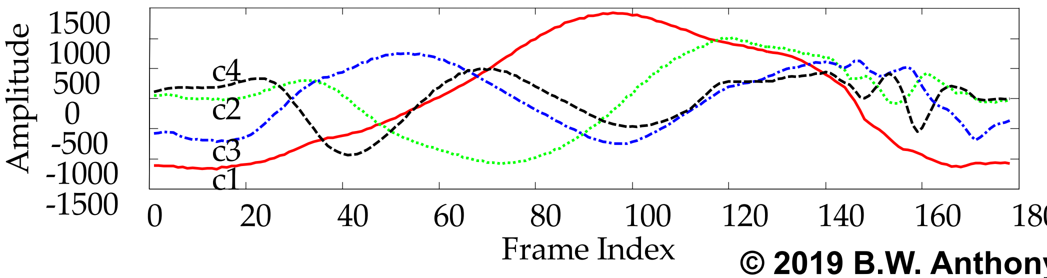
Output

SHOW VIDEOS

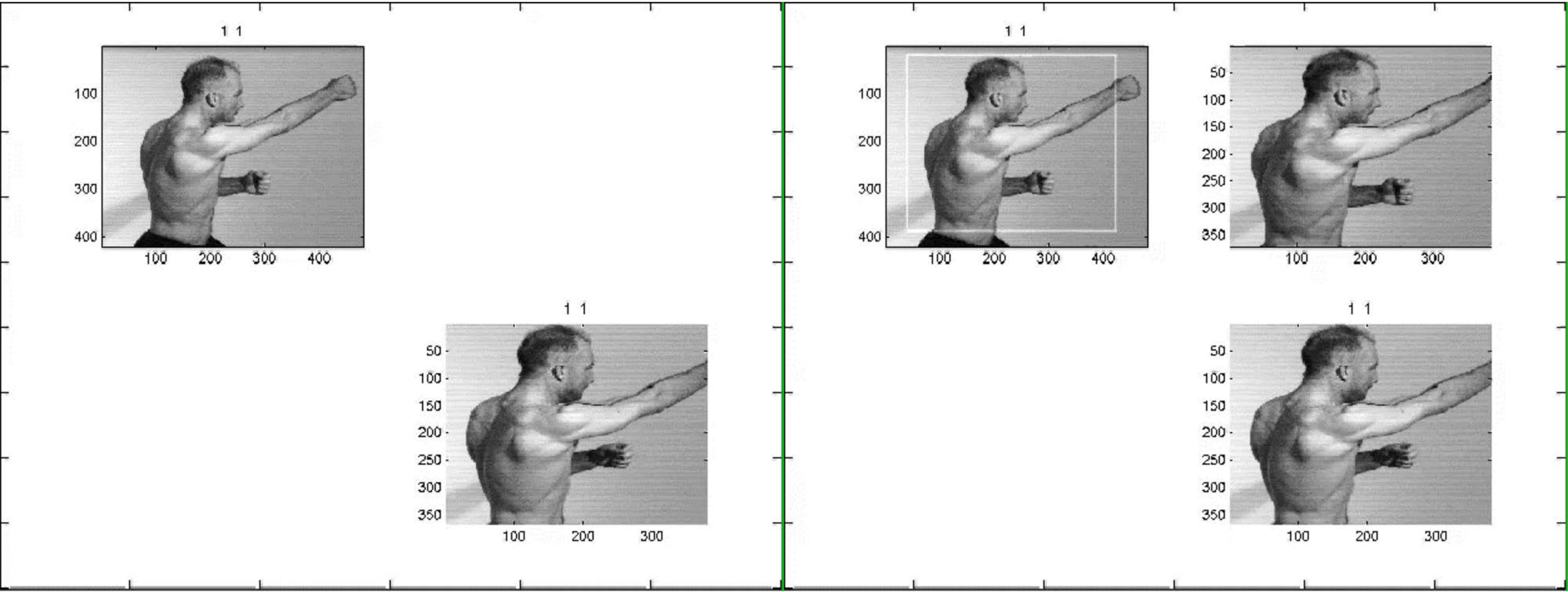
Eigenframes 1 through 4



Reconstruction Coefficients



Alignment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100 200 300

Dubai World Cup: The richest race day returns with $35 million prize purse

By Ben Church, CNN

Updated 1250 GMT (2050 HKT) March 27, 2019

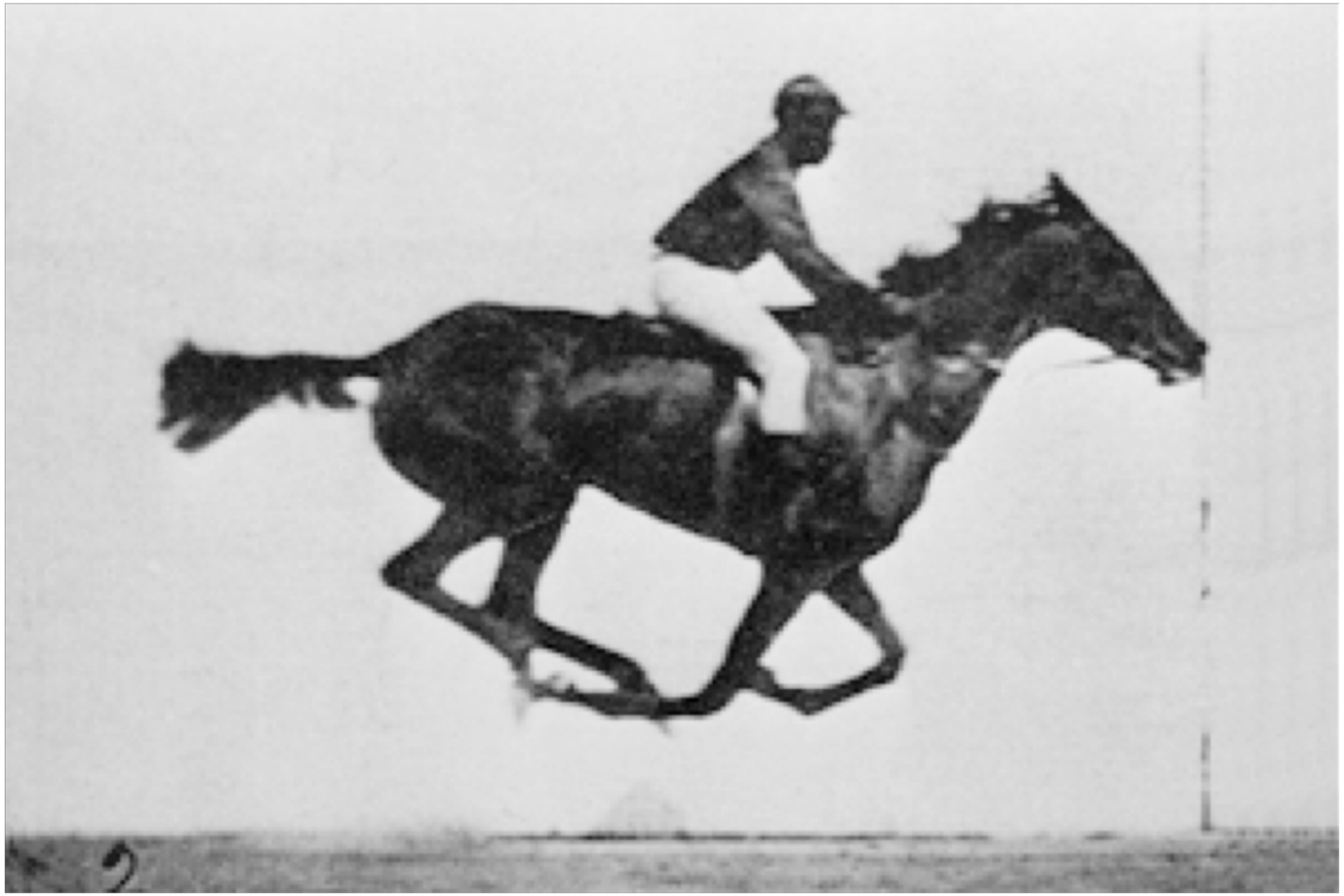
Dubai World Cup returns with record $35M purse 01:12

$7.2M for two minutes' work -- the world's richest race

Bollywood superstar Deepika Padukone offers glimpse of upcoming...

Serena Williams withdraws from Miami Open through injury

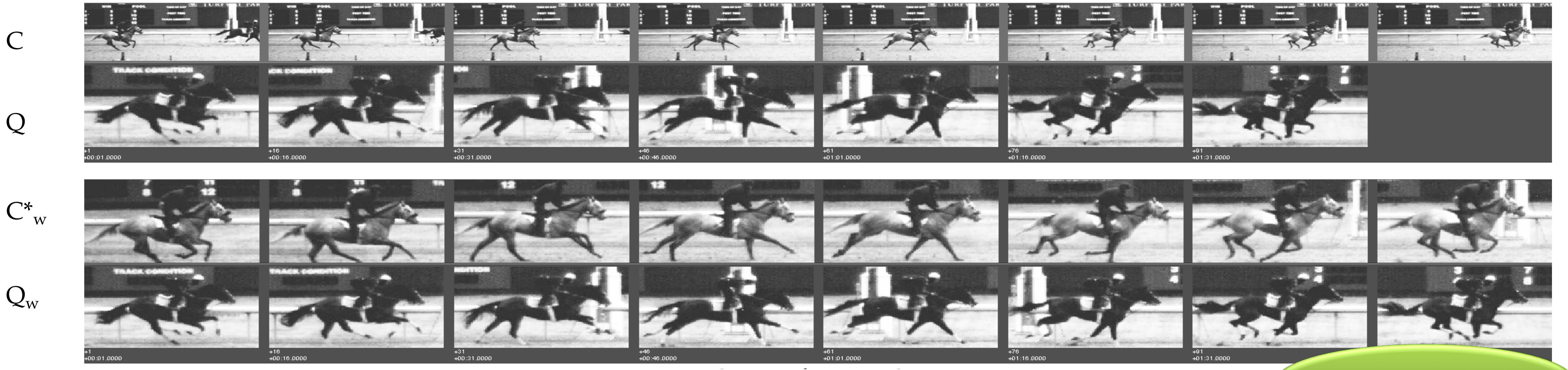
https://edition.cnn.com/2019/03/27/sport/dubai-world-cup-richest-horse-racing-winning-post-uae-spt-intl/index.html



- The first practical application of high-speed photography was Eadweard Muybridge's 1878 investigation into whether horses' feet were actually all off the ground at once during a gallop.
- The first photograph of a supersonic flying bullet was taken by the Austrian physicist Peter Salcher in Rijeka in 1886.

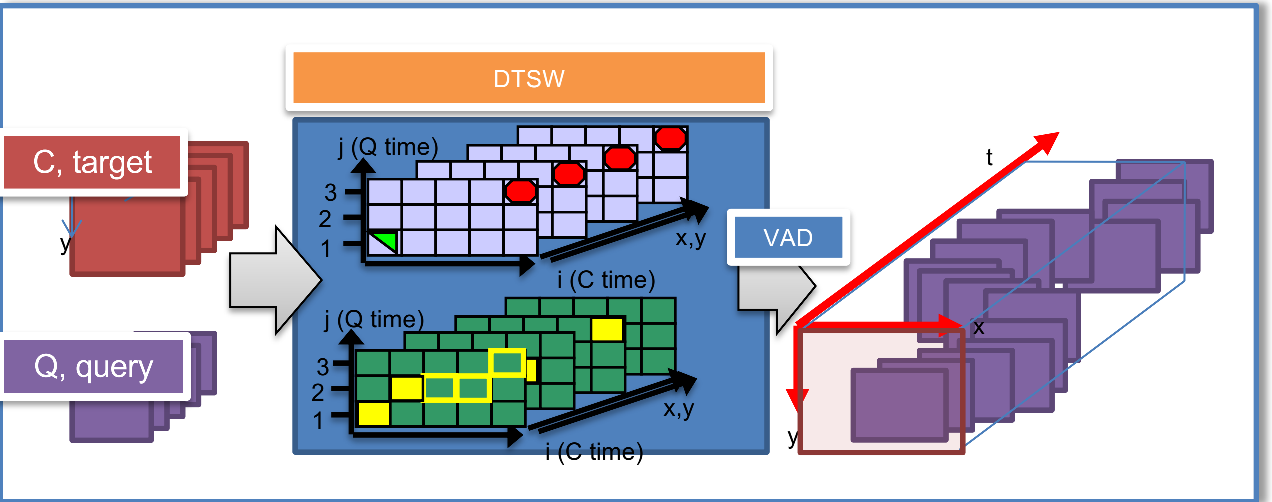
Example: Horse Racing

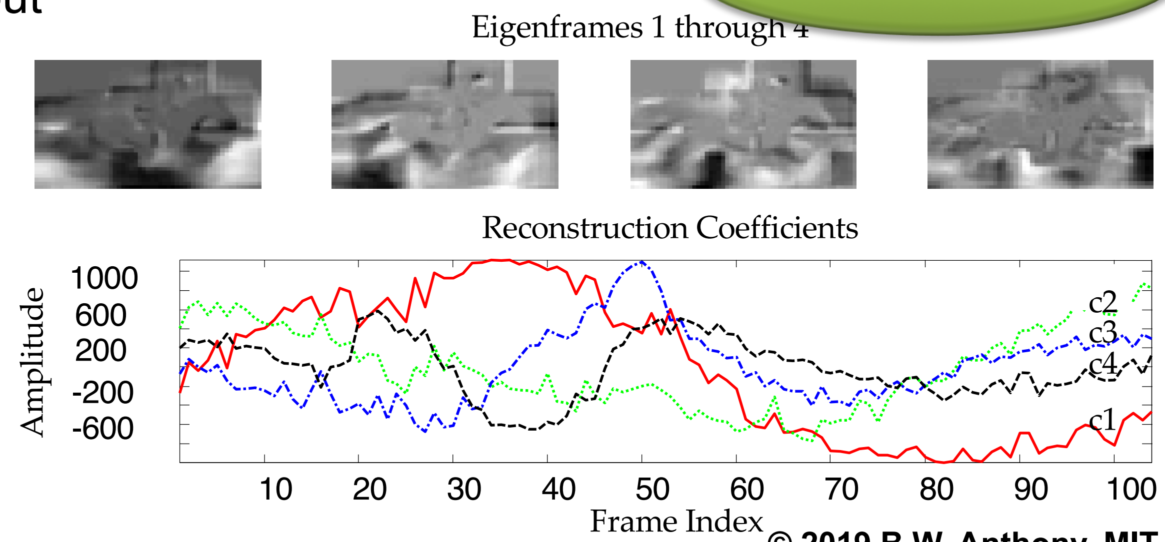
Input



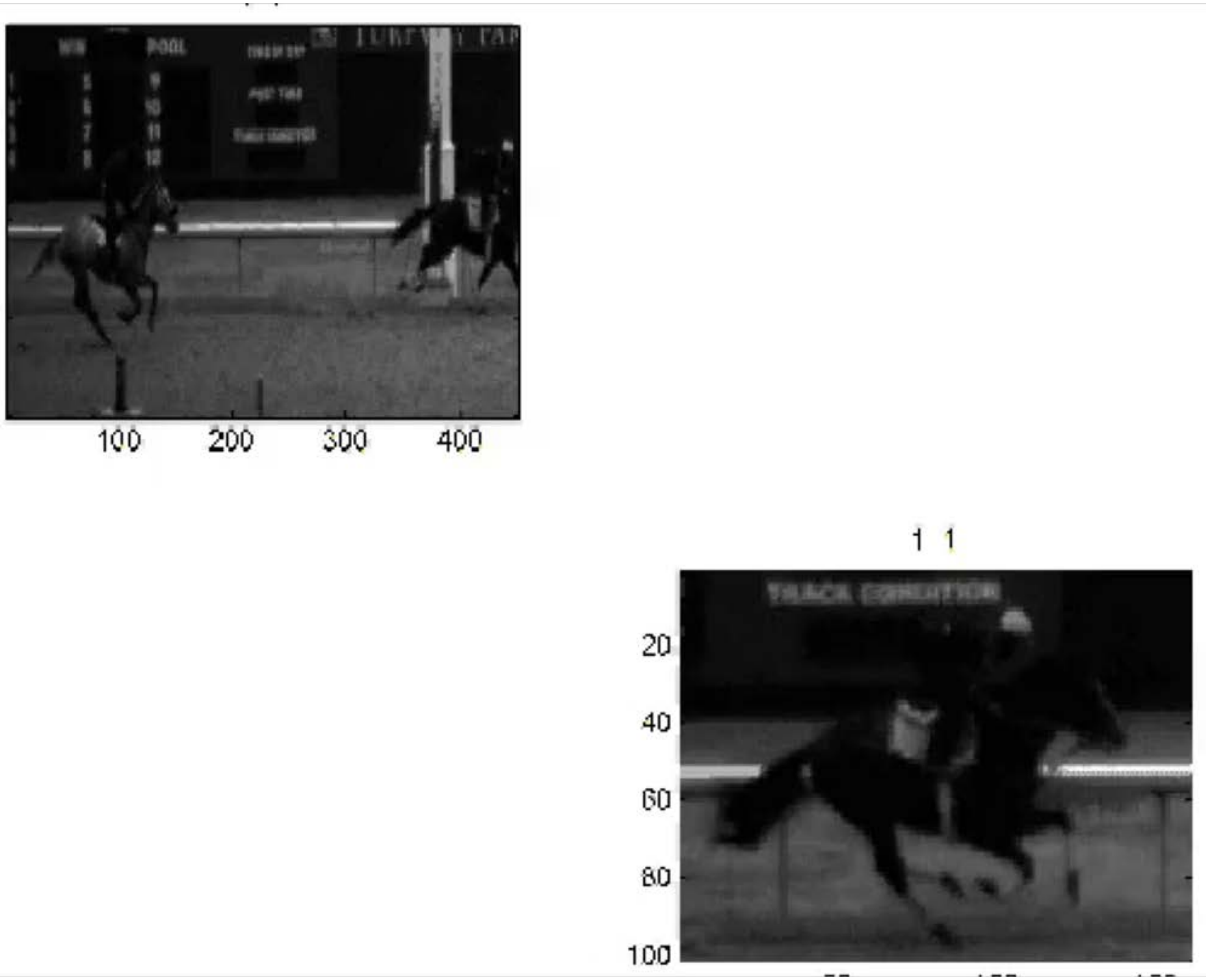
SHOW VIDEOS

Output





Alignment



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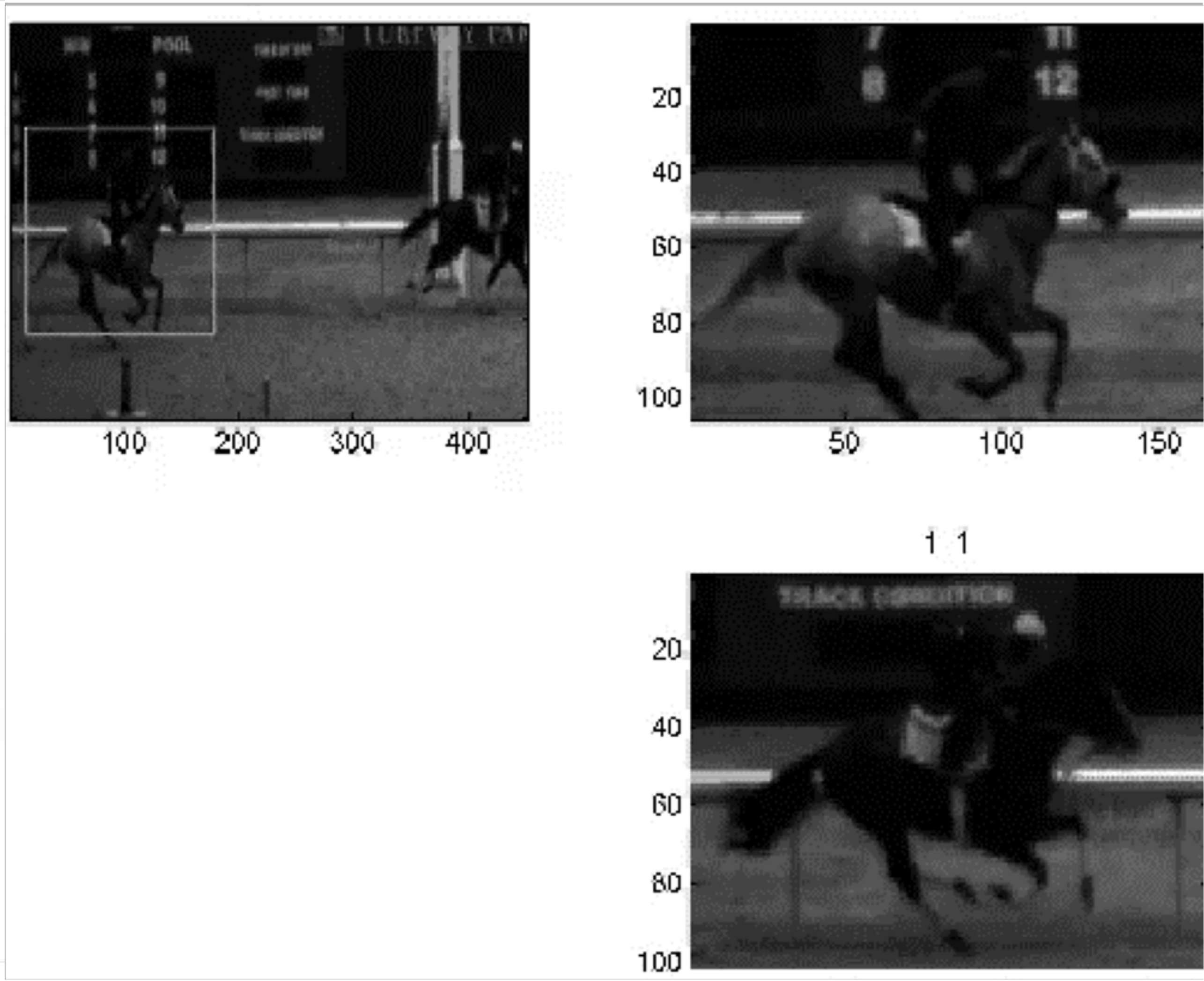

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Big and Streaming Video Data in the Smart Factory

Prost

and

Thank you

Brian W. Anthony, PhD
banthony@mit.edu

Associate Director,
MIT.nano