
Target Recognition in Cluttered Infrared Scenes via Pattern Theoretic Representations and Jump-Diffusion Processes

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Variability in Complex Scenes

- Geometric variability
 - **Position**
 - **Orientation**
 - **Articulation**
 - **Fingerprint (in the Bob Hummel sense)**
- Environmental variability
 - **Thermodynamic variability in infrared**
 - **Illumination variability in visual**
- Complexity variability
 - **Number of objects not known**



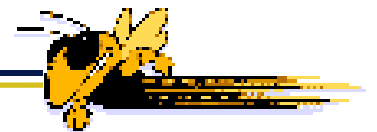
Pattern Theory: The Grenander Program

- **Representation:**
 - Incorporate variability in the parameter space
 - **Possibly many nuisance parameters**
 - Model mapping from parameters to data
- **Inference:**
 - Build inference algorithms using the representation
 - Ex.: Markov chain Monte Carlo (jump-diffusion)
- **General notion: avoid “preprocessing” or “feature extraction” as much as possible to avoid loss of information**
 - Recall Biao Chen’s mention of the Information Processing Inequality
- **Apply tools of Bayesian inference to weird things**



Legacy Work

- **Sponsored by**
 - U.S. Army Center for Imaging Science
(ARO - David Skatrud/Bill Sander)
 - ONR (Bill Miceli)
- **Collaborators**
 - Michael Miller (now at Johns Hopkins)
 - Donald Snyder (Washington Univ.)
 - Anuj Srivastava (now with Dept. of Stat., Florida State)
 - **Airborne targets – radar**
 - Matt Cooper (now with Xerox)
 - **Thermodynamic variability of targets**



Parameter Space for ATR

- **Parameter space for a single target:**

$$\mathcal{X}(1) = \mathfrak{R}^2 \times [0, 2\pi) \times A$$

$$A = \{M 2, M 60, T 62 \dots\}$$

- **Parameter space for an n -target scene:**

$$\mathcal{X}(n) = [\mathfrak{R}^2 \times [0, 2\pi) \times A]^n$$

- **Number of targets not known in advance:**

$$\mathcal{X} = \bigcup_{n=0}^{\infty} [\mathfrak{R}^2 \times [0, 2\pi) \times A]^n$$

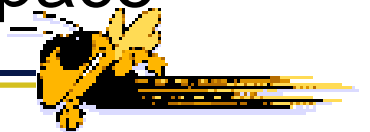


Ingrid's Third Approach

- **Data** y , parameters x
- **Likelihood** $p(y | x)$
 - Render infrared scene onto detector plane
 - Model sensor noise effects
- **Prior** $p(x)$
- **Bayesian posterior**

$$\pi(x) \equiv p(x | y) \propto p(y | x) p(x)$$

- Analytically forboding!
- **Sample via jump-diffusion processes**
 - Jump from subspace to subspace
 - Diffuse to refine estimates within a subspace

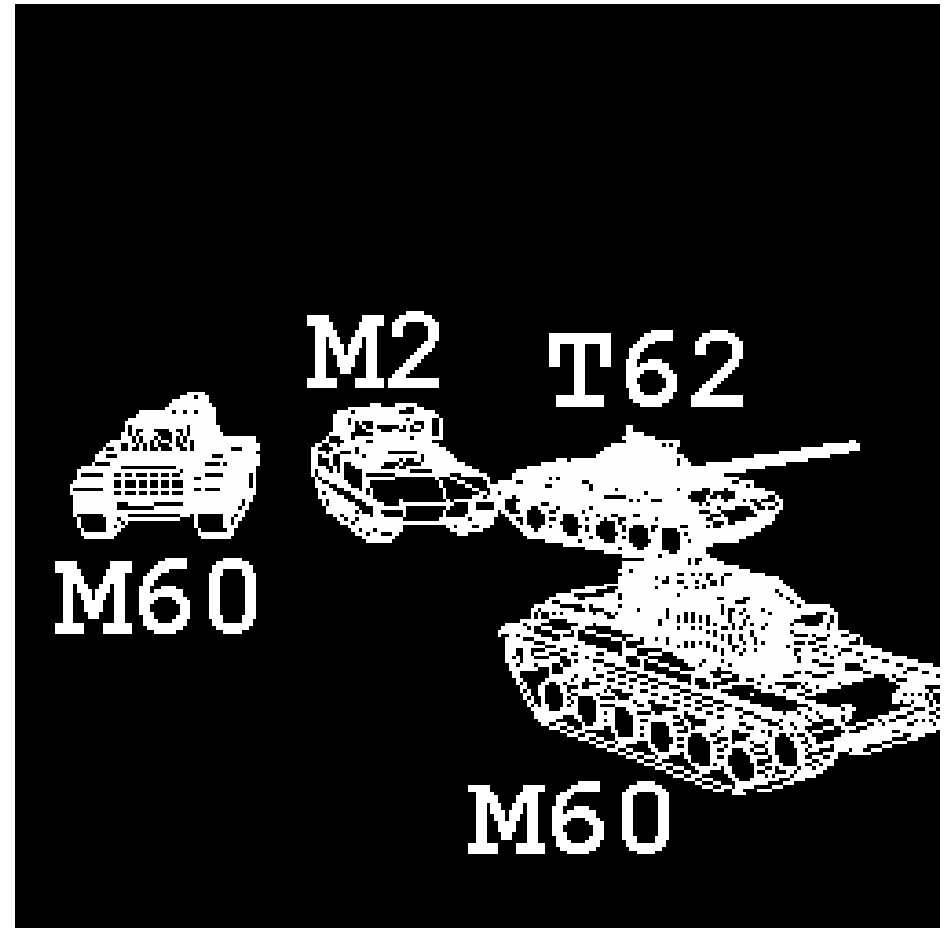
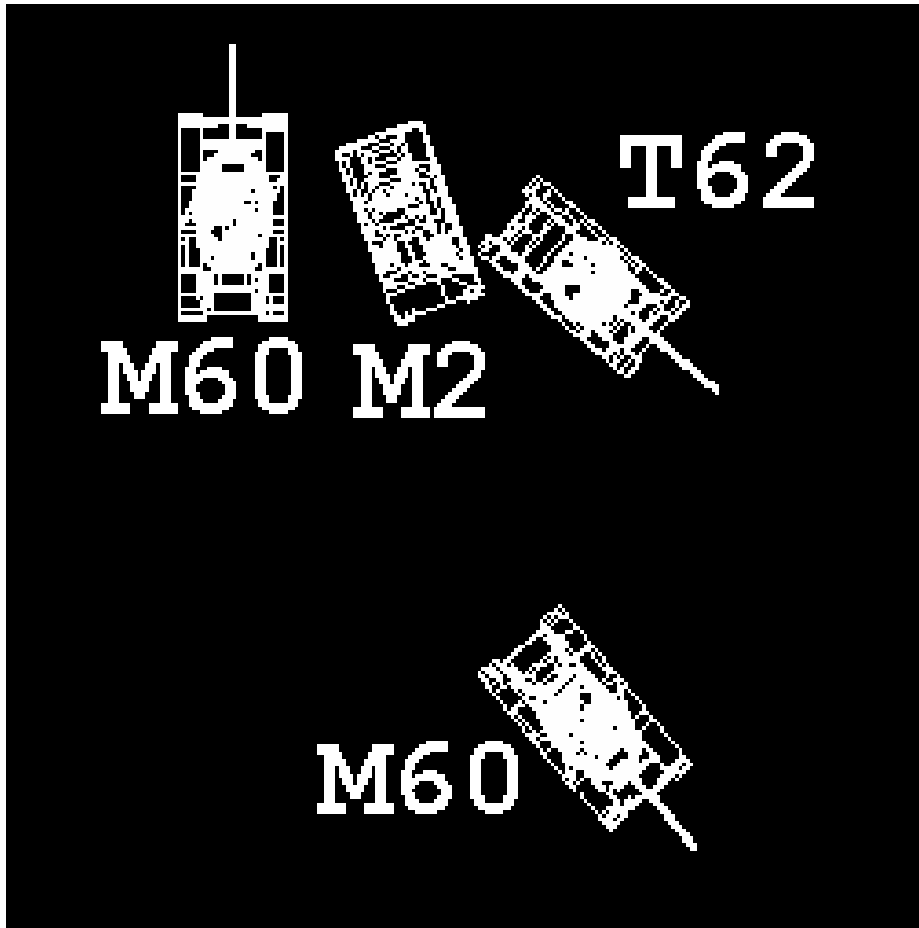


Take Home Message

**Go read
Ulf Grenander's
papers and books.
They are very cool.**



Perspective Projection

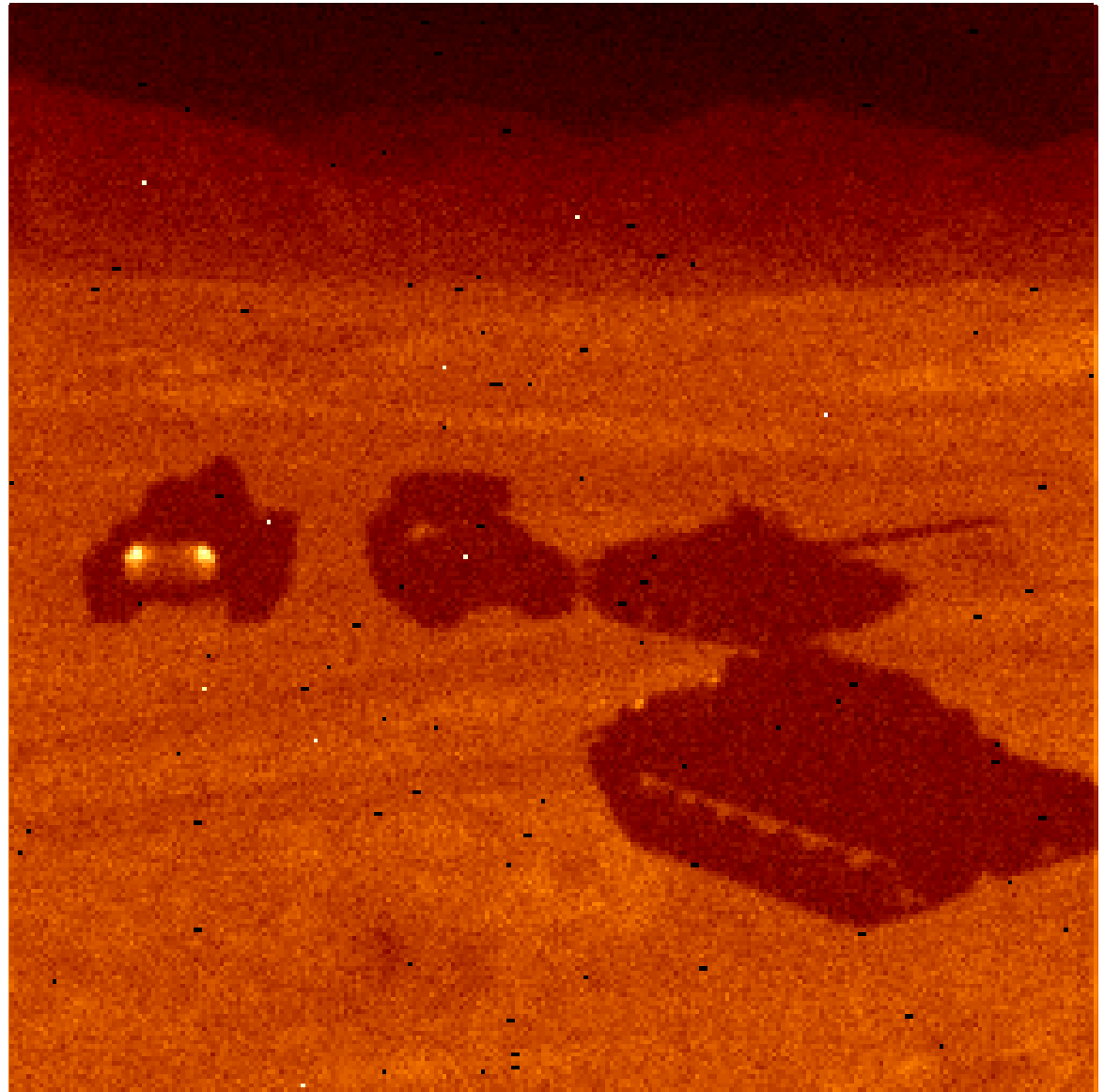


Sensor Effects

Optical PSF

Poisson
Photocounting
Noise

Dead and
Saturated
Pixels



FLIR Loglikelihood

- **CCD loglikelihood of Snyder, Hammoud, and White**

$$L_{CCD}(y | \lambda) = -\sum_i \mu(i) + \sum_i y(i) \ln \mu(i)$$

where $\mu(j) = \sum_j \text{psf}(i | j) \lambda(j)$

- **Cascade with render: $x \rightarrow \lambda$**

$$L(y | x) = L_{CCD}(y | \text{render}(x))$$

- **Sensor fusion natural; just add loglikelihoods**



Langevin Processes Process

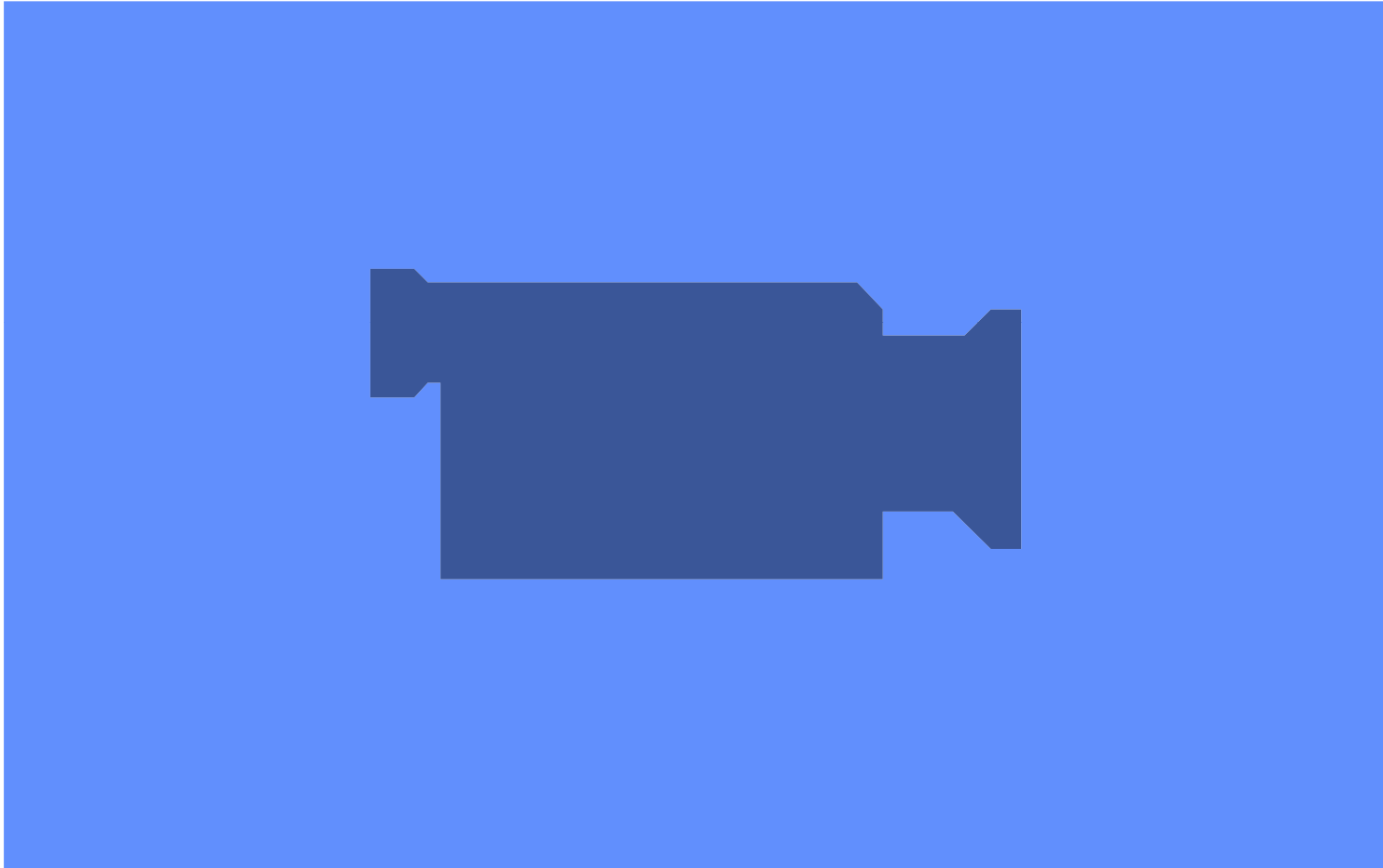
- Write posterior in Gibbs form: $\pi(x) = \exp\{H(x)\} / Z$
- Consider a fixed number of N targets and target classes
- Simulate Langevin diffusion:

$$dX_N(\tau) = \nabla_{X_N} \{H(X_n(\tau))\} + dW_N(\tau)$$

- Distribution of $X_N(\tau) \xrightarrow{\tau \rightarrow \infty} \pi_N(x_n)$
- Computed desired statistics from the samples
- Generalizes to non-Euclidean groups like rotations
- Gradient computation
 - Numeric approximations
 - Easy and fast on modern 3-D graphics hardware

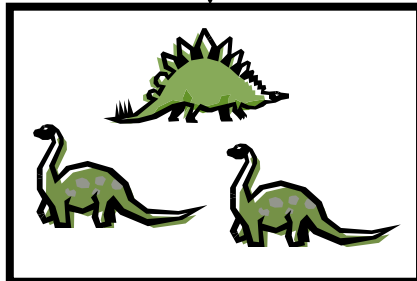
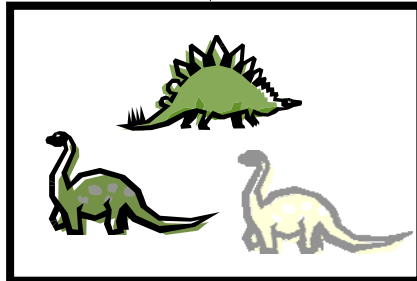
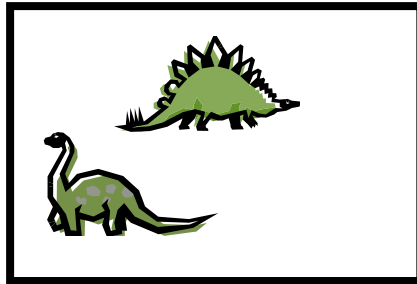


Diffusion Example on AMCOM Data

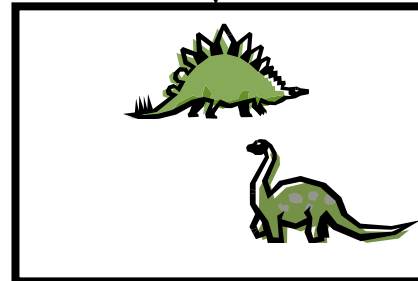
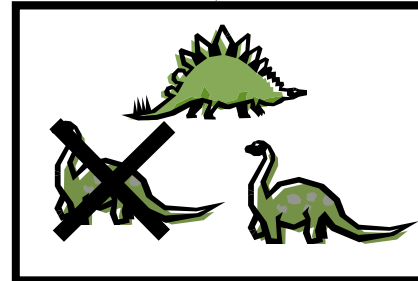
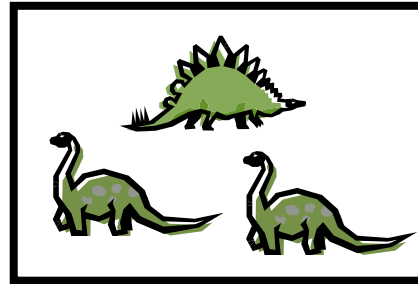


Jump Moves

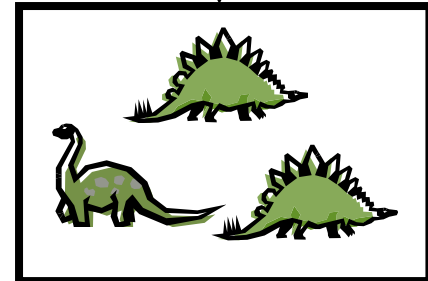
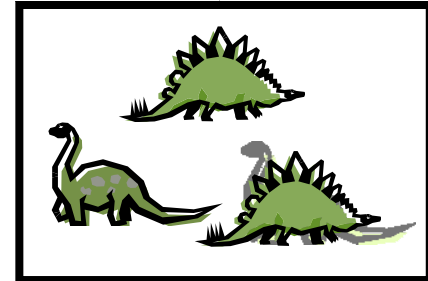
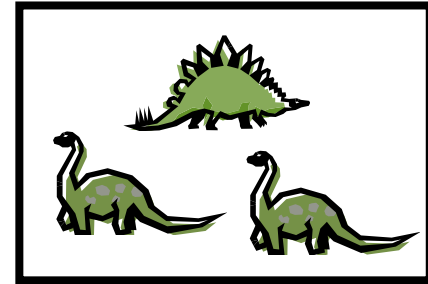
Birth



Death



Type-change



Helpful Properties of Jump Processes

- **Jump at exponentially distributed times**

$$\mathcal{T}^1(x) = \{\text{states reachable from } x\}$$

$$\mathcal{T}^{-1}(x) = \{\text{states from which } x \text{ can be reached}\}$$

- **Move reversability:** $\mathcal{T}^1(x) = \mathcal{T}^{-1}(x)$
- **Connectedness:** can go from any point to any other in a finite number of jumps
- **Detailed balance (in discrete form)**

$$\pi(x) \Pr(x \rightarrow z) = \pi(z) \Pr(z \rightarrow x)$$

(continuous form slightly more complicated)

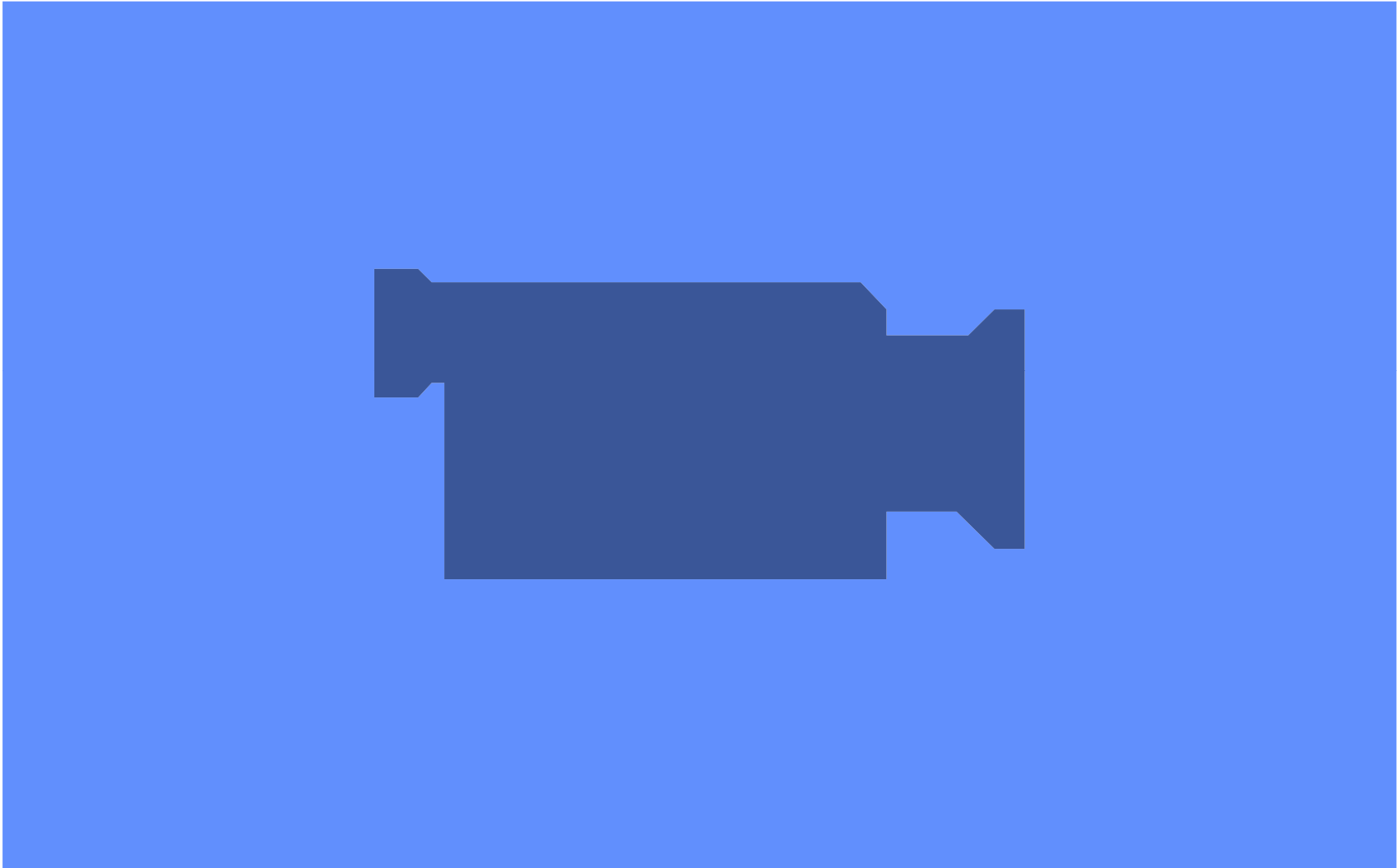


Jumping Strategies

- **Gibbs**
 - Sample from a restricted part of the posterior
- **Metropolis-Hastings style**
 - Draw a “proposal” from a “proposal density”
 - Accept (or reject) the proposal with a certain probability



Example Jump-Diffusion Process



How to Model Clutter?

- **Problem: Algorithm only knows about tanks (which Bob doesn't like anyway), and will try to explain everything with tanks!**
 - Cows, swimming pools, school buses
- **Solution (?): Let the algorithm use *flexible representation* in addition to rigid objects**
 - Blobs: Simple connected shapes on the lattice to represent *structured* clutter
 - Could use active curves, level set methods (Clem Karl), active polygons (Hamid Krim)
 - Clutter might be interesting in its own right!



Random Sampling for Blobs

- **Set of jump moves**
 - Add a pixel along the boundary
 - Remove a pixel along the boundary
 - Keep the blob a blob
- **Pick move based on posterior probability**



Blob Estimation Examples

M60 spreading



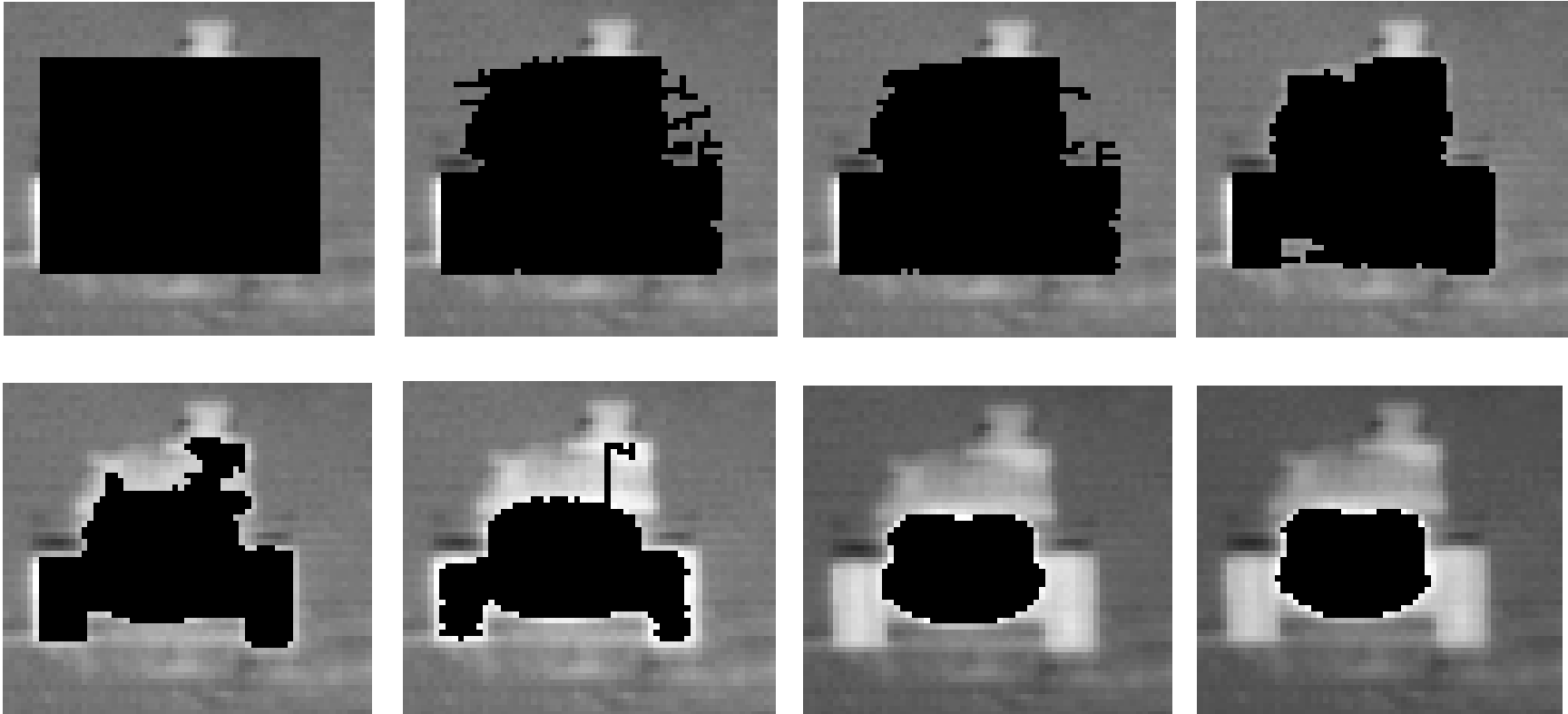
M60 decaying



Ship decaying



NVESD M60 Example



Saccadic Detection

- **Current implementation “births” specific target types**
- **May be better to birth simple shapes, and later change them to more specific target types (clutter or target)**
- **Example:**
 - Birth squares
 - Deform into rectangles
 - Then jump to more detailed targets



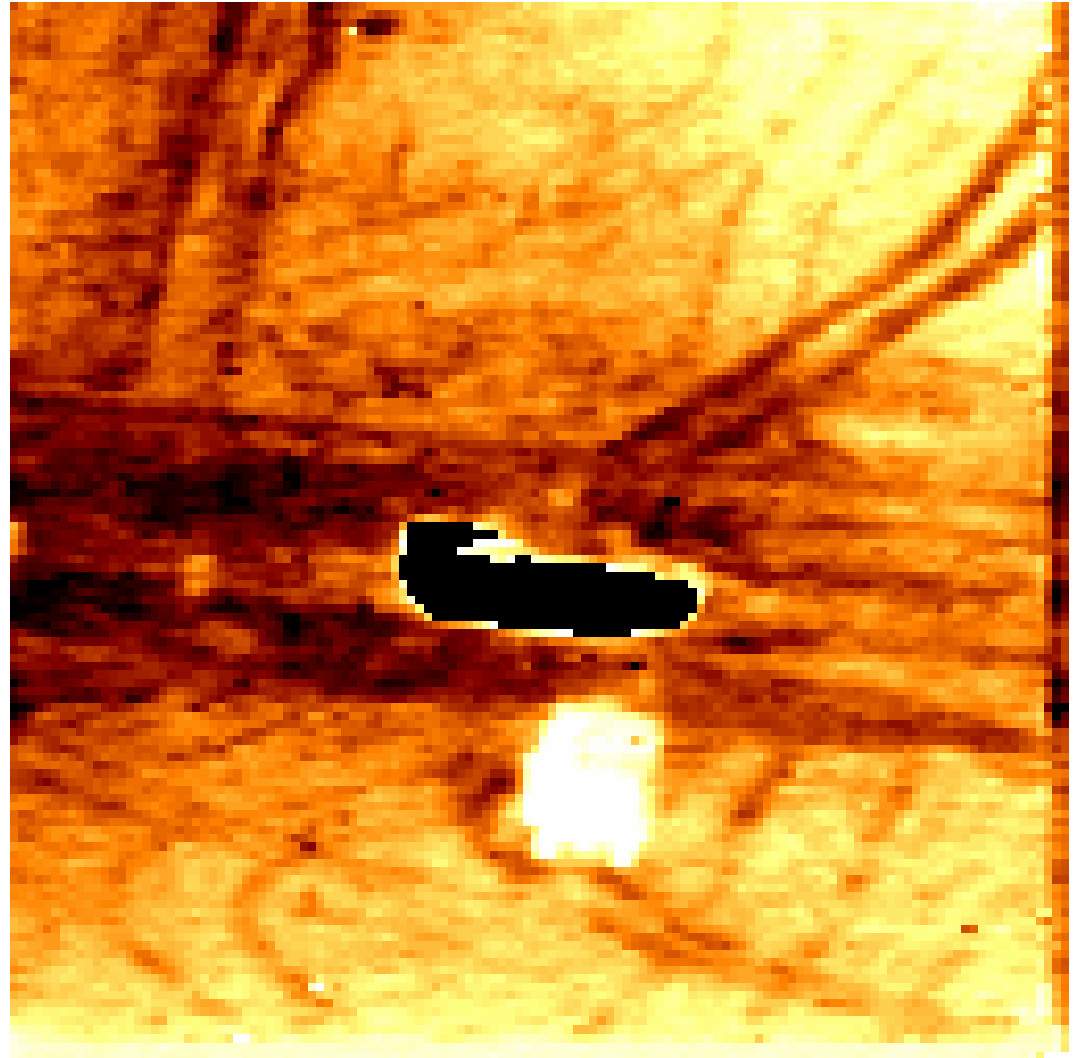
AMCOM Data Ex.: Finding Tank 1

Initial Detection

**Low-dimensional
refinement**

**High-dimensional
refinement**

Equilibrium

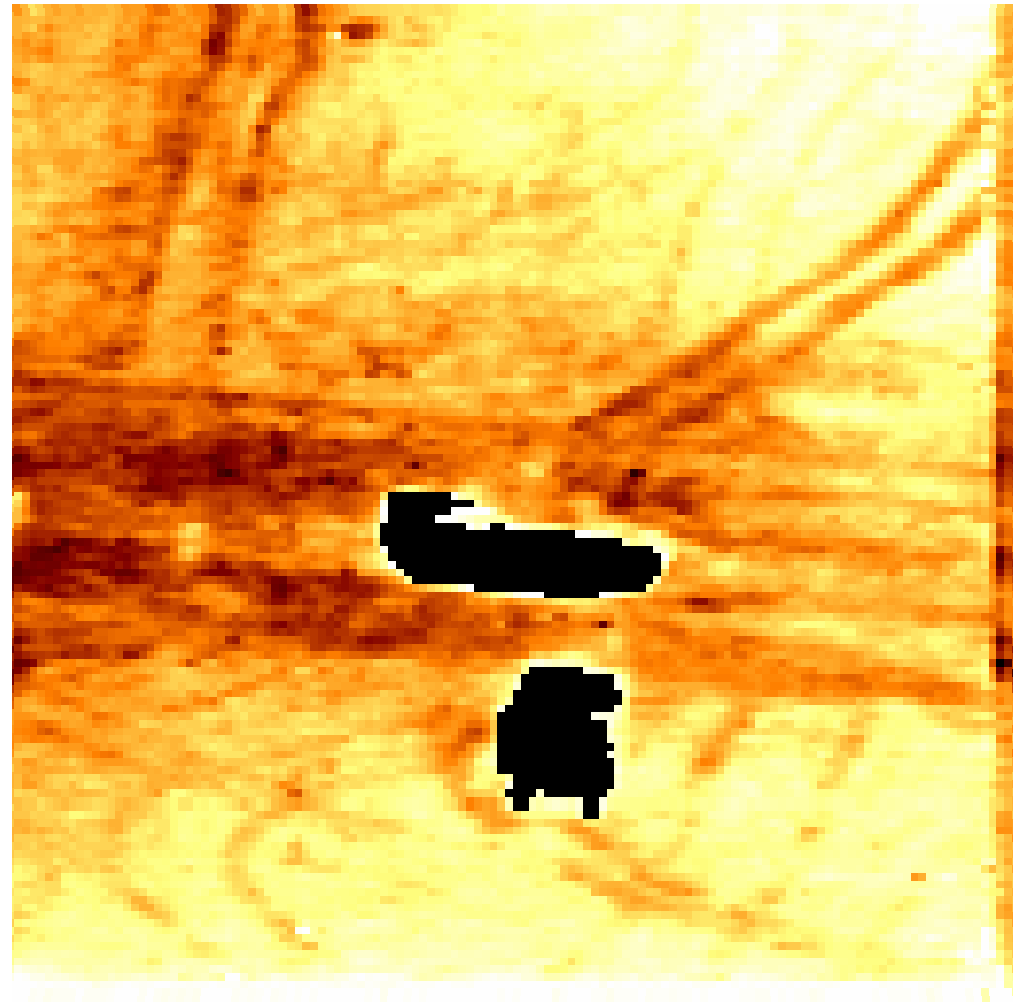


AMCOM Data Ex.: Finding Tank 2

Initial Detection

**Low-dimensional
refinement**

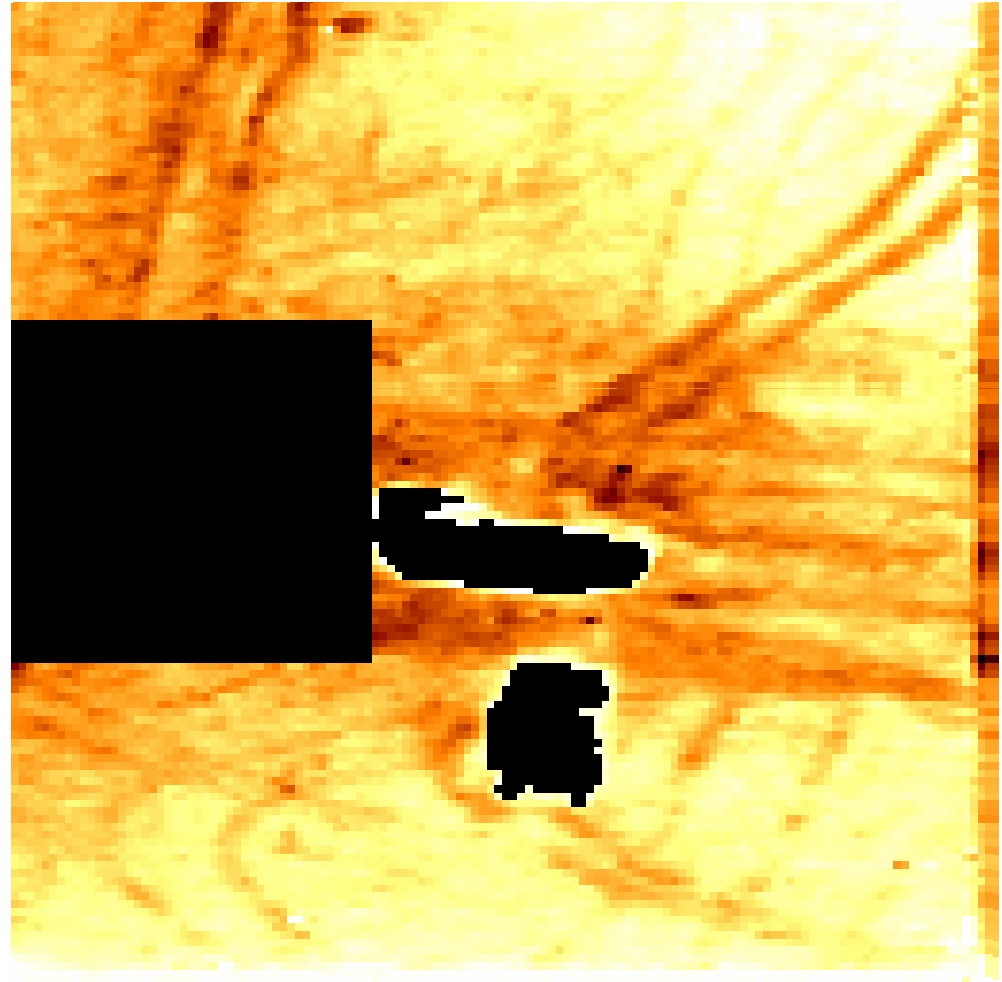
Equilibrium



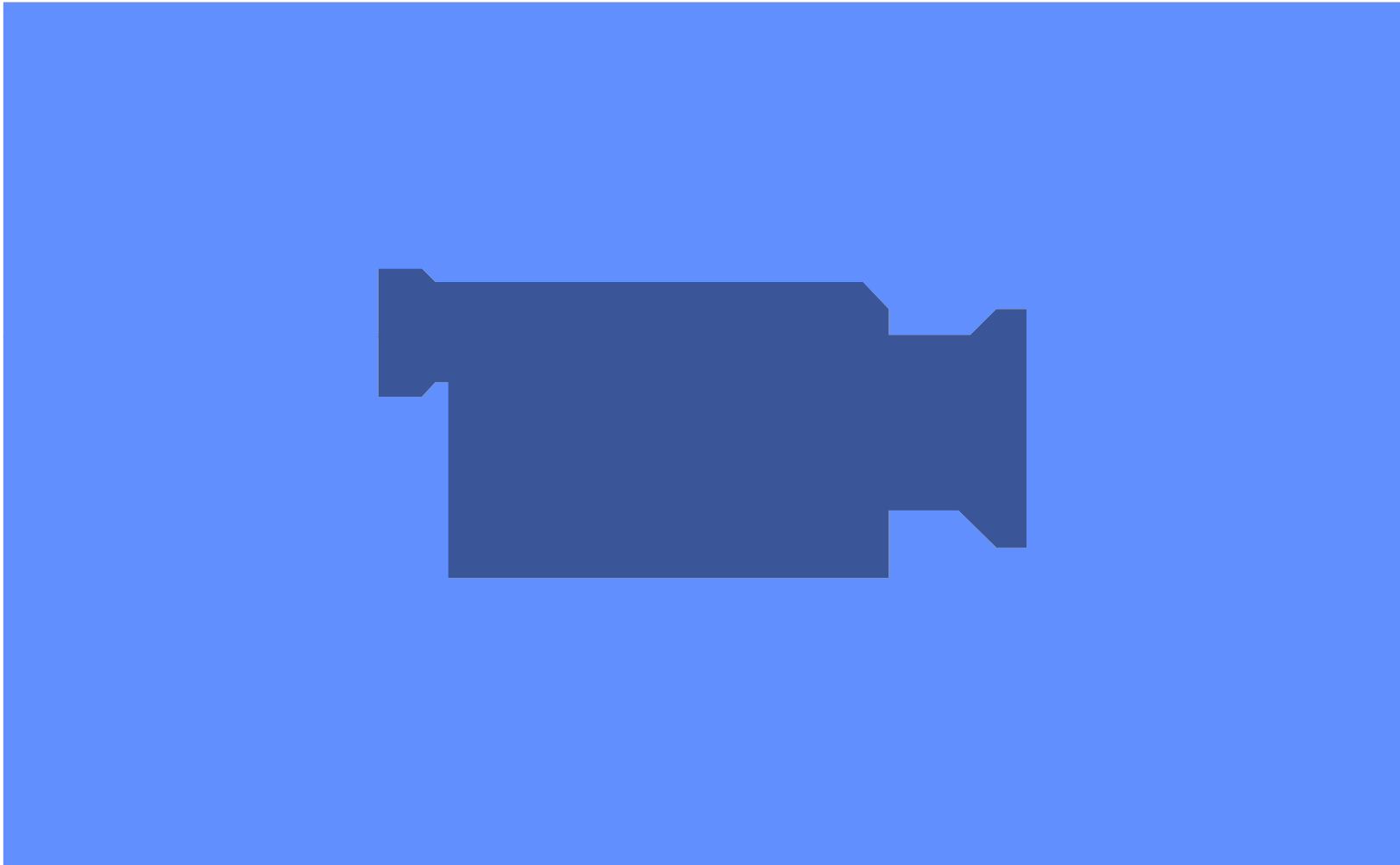
AMCOM Data Ex.: Finding ??????

Initial Detection

**Low-dimensional
refinement**



Factory Example



Unified Algorithm

- **Extended jump moves**
 - Saccadic \leftrightarrow blob
 - Saccadic \leftrightarrow rigid
 - Blob \leftrightarrow rigid
 - Break/combine blobs
 - Change rigid target types
- **Difficulty: Make parameters make sense between representation types**

