Representing Moving Images with Layers

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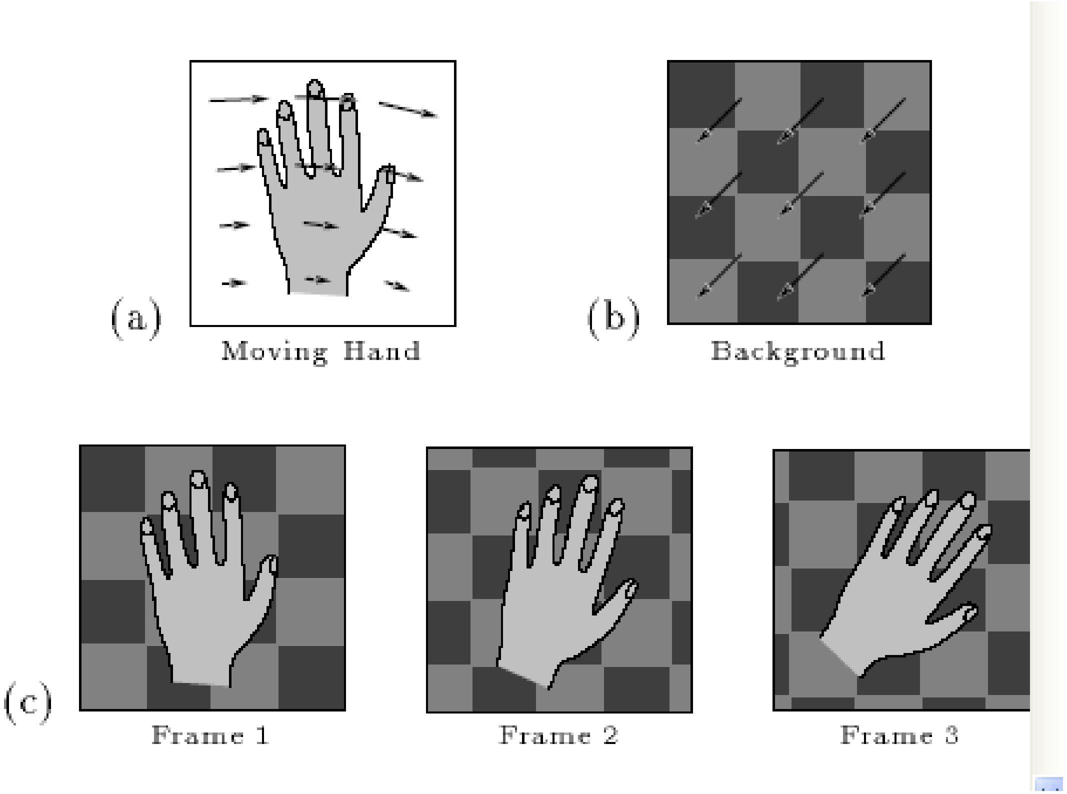
Goal

- Represent moving images with sets of overlapping layers
- Layers are ordered in depth and occlude each other
- Velocity maps indicate how the layers are to be warped over time

Simple Domain: Gesture Recognition

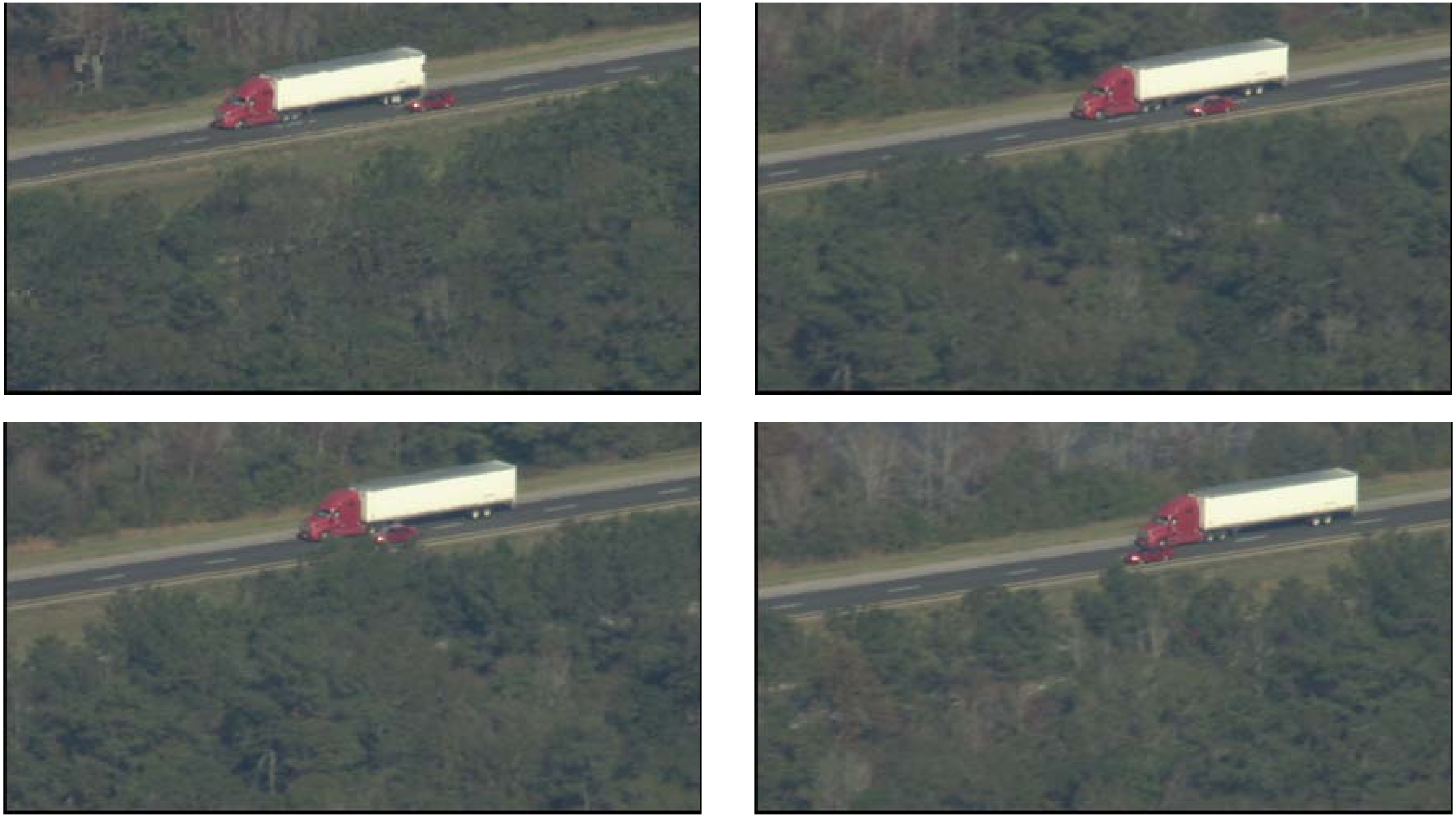


(a) Moving Hand

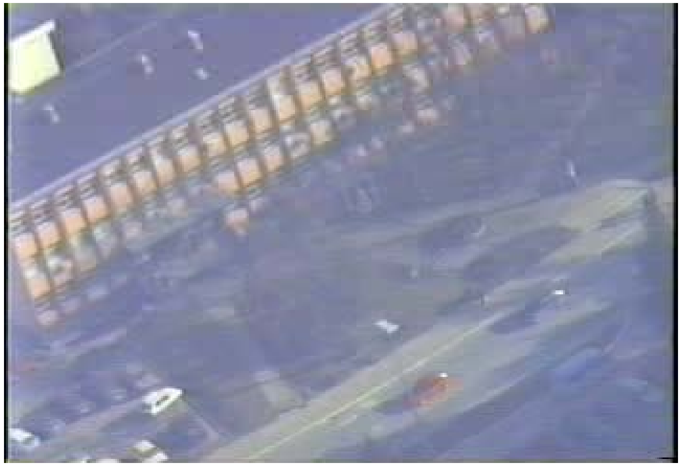
(b) Background

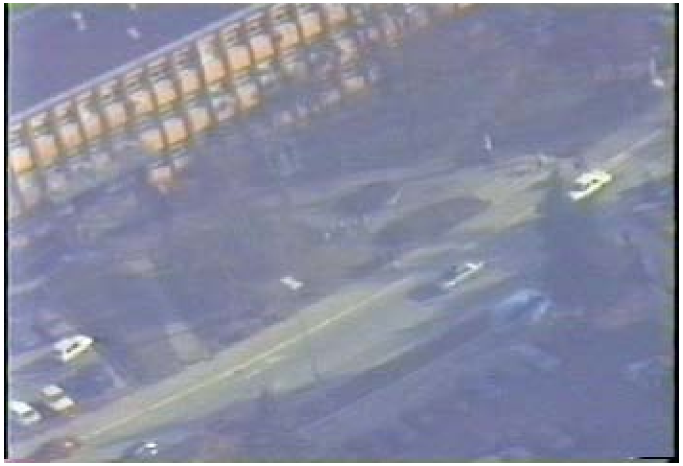
(c) Frame 1 Frame 2 Frame 3

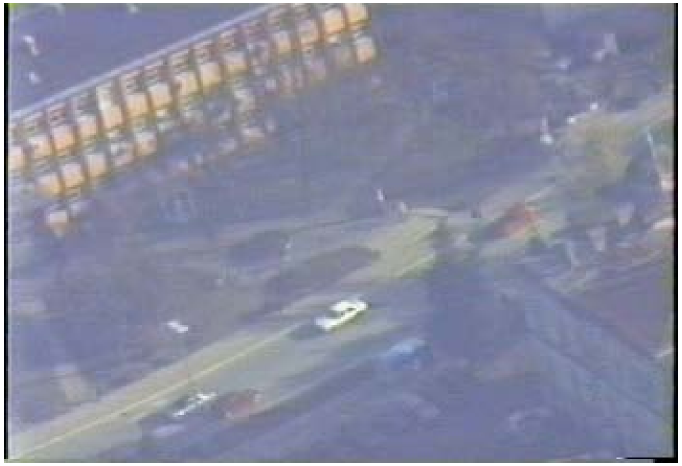
More Complex:
What are the layers?

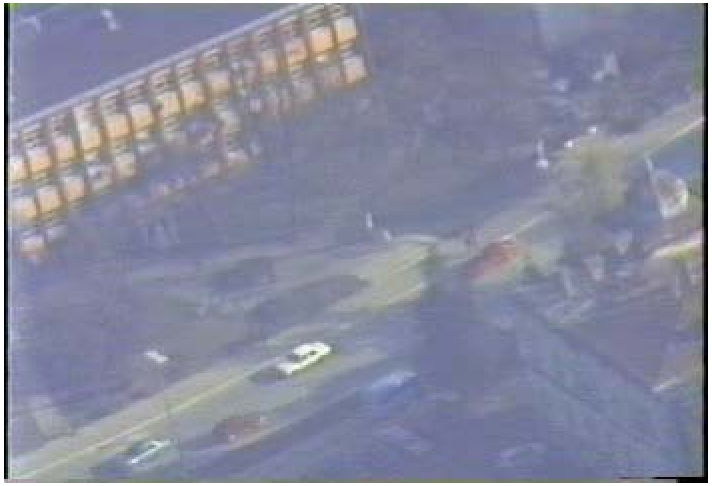


Even More Complex:
How many layers are there?









Definition of Layer Maps

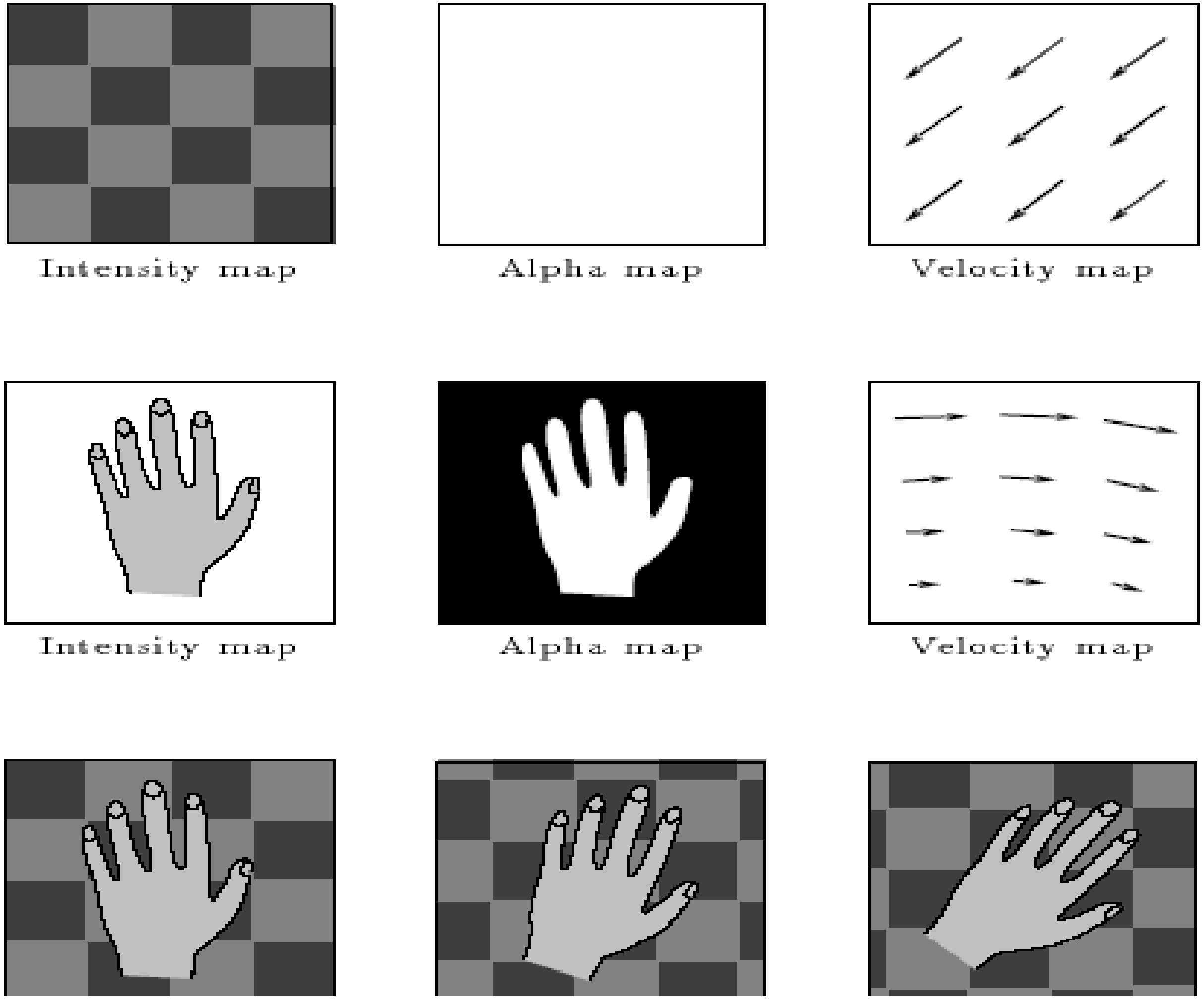
- Each layer contains three maps

  1. intensity map (or texture map)
  2. alpha map (opacity at each point)
  3. velocity map (warping over time)

- Layers are ordered by depth

- This can be for vision or graphics or both

Layers for the Hand Gestures



Background Layer

Intensity map

Alpha map

Velocity map

Hand Layer

Intensity map

Alpha map

Velocity map

Re-synthesized Sequence

Optical Flow Doesn’t Work

- Optical flow techniques typically model the world as a 2-D rubber sheet that is distorted over time.
- When one object moves in front of another, the rubber sheet model fails.
- Image information appears and disappears; optical flow can’t represent this.
- Motion estimates near boundaries are bad.

Block Matching Can’t Do It

- Block motion only handles translation well.
- Like optical flow, block matching doesn’t deal with occlusion or objects that suddenly appear or disappear off the edge of the frame.

Layered Representation: Compositing

$$I_1(x,y) = E_0(x,y)(1-\alpha_1(x,y)) + E_1(x,y)\alpha_1(x,y). \quad (1)$$

- E_0 is the background layer.
- E_1 is the next layer (and there can be more).
- α_1 is the alpha channel of E_1, with values between 0 and 1 (for graphics).
- The velocity map tells us how to warp the frames over time.
- The intensity map and alpha map are warped together, so they stay registered.

Analysis: Flower Garden Sequence

Frame 1 Frame 15 Frame 30

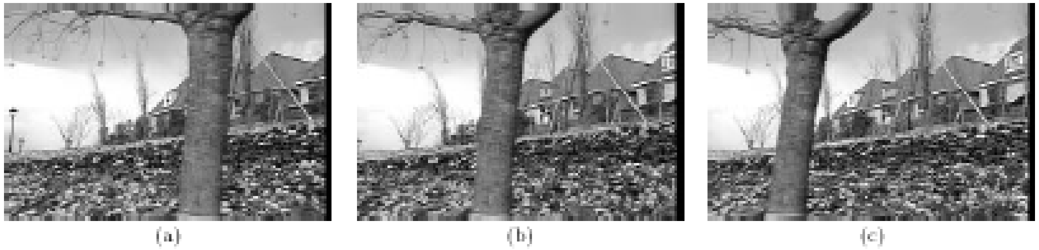
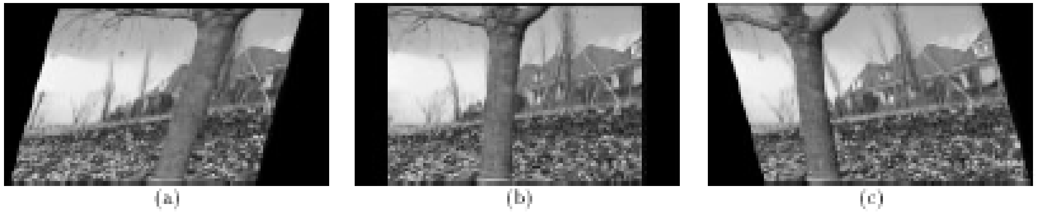


Figure 6: Frames 0, 15 and 30, of MPEG flower garden sequence are shown in figures (a-c), respectively.

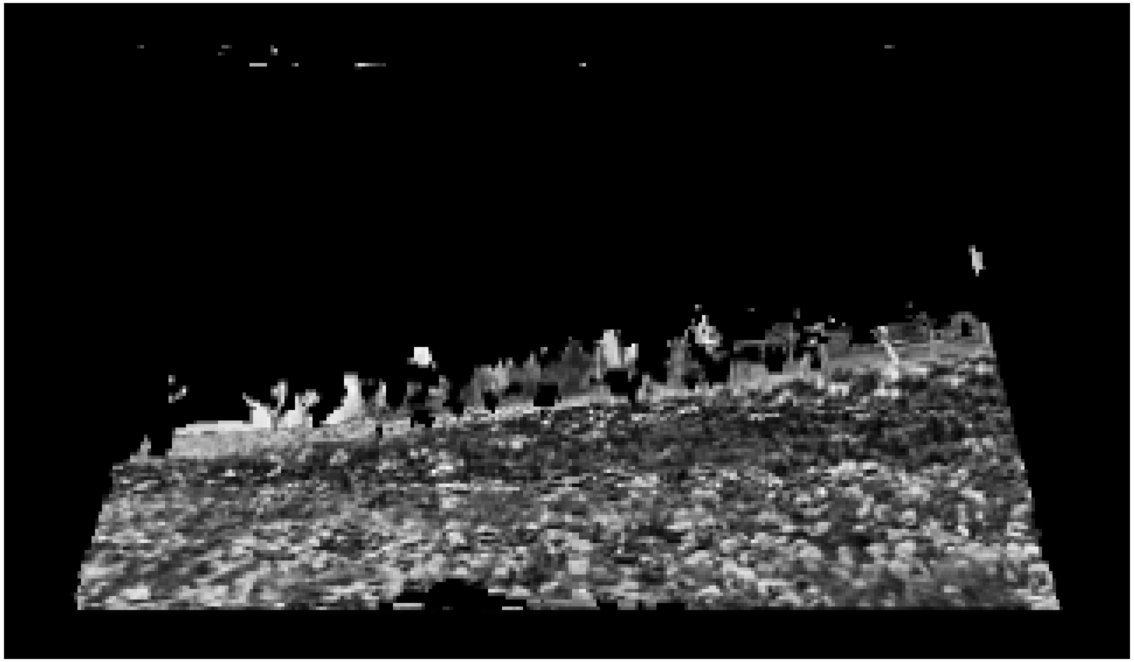
Camera is panning to the right.



Frame 1 warped Frame 15 Frame 30 warped

What's going on here?

Accumulation of the Flowerbed Layer



Motion Analysis

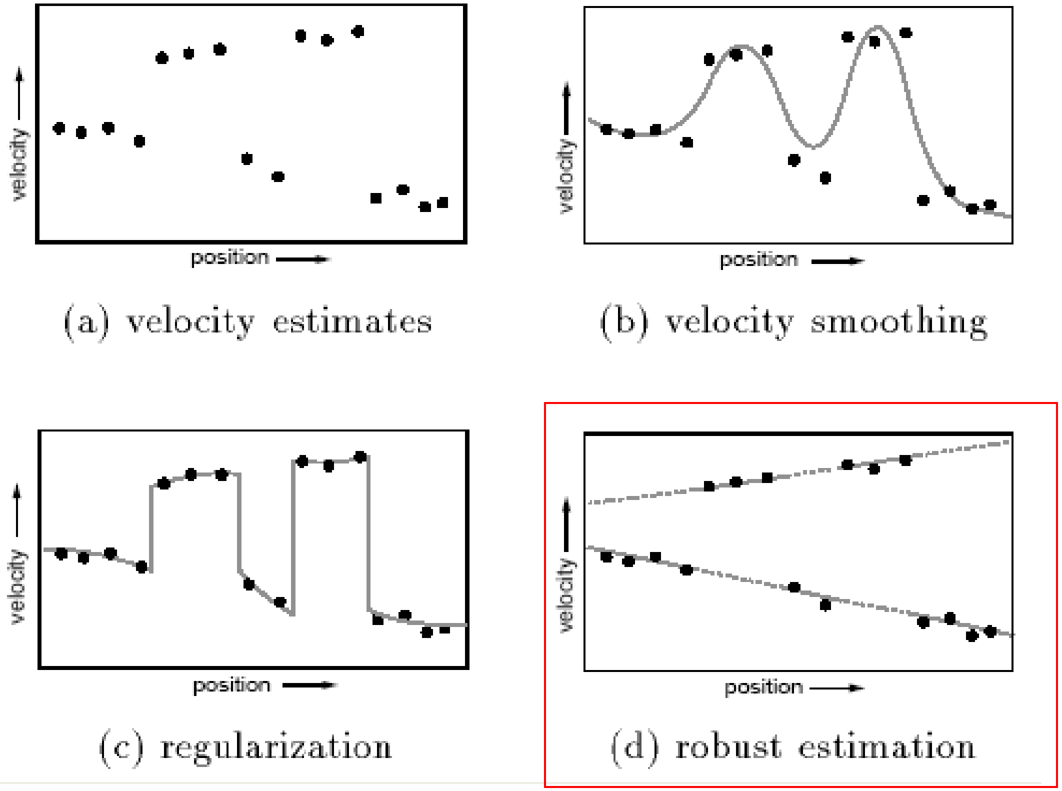
1. Robust motion segmentation using a parametric (affine) model.

$$V_x(x,y) = a_{x0} + a_{xx}x + a_{xy}y$$

$$V_y(x,y) = a_{y0} + a_{yx}x + a_{yy}y$$

2. Synthesis of the layered representation.

Motion Analysis Example



(a) velocity estimates

(b) velocity smoothing

(c) regularization

(d) robust estimation

2 separate layers shown as 2 affine models (lines);

The gaps show the occlusion.

Motion Estimation Steps

1. Conventional optical flow algorithm and representation (uses multi-scale, coarse-to-fine Lucas-Kanade approach).

2. From the optical flow representation, determine a set of affine motions. Segment into regions with an affine motion within each region.

Motion Segmentation

1. Use an array of non-overlapping square regions to derive an initial set of motion models.

2. Estimate the affine parameters within these regions by linear regression, applied separately on each velocity component (dx, dy).

3. Compute the reliability of each hypothesis according to its residual error.

4. Use an adaptive k-means clustering that merges two clusters when the distance between their centers is smaller than a threshold to produce a set of likely affine models.

Region Assignment by Hypothesis Testing

- Use the motion models derived from the motion segmentation step to identify the coherent regions.
- Do this by minimizing an error (distortion) function:

$$G(i(x,y)) = \sum_{x,y} (V(x,y) - V_{ai}(x,y))^2$$

where $i(x,y)$ is the model assigned to pixel (x,y)

and $V_{ai}(x,y)$ is the affine motion for that model.

- The error is minimized at each pixel to give the best model for that pixel position.
- Pixels with too high error are not assigned to models.

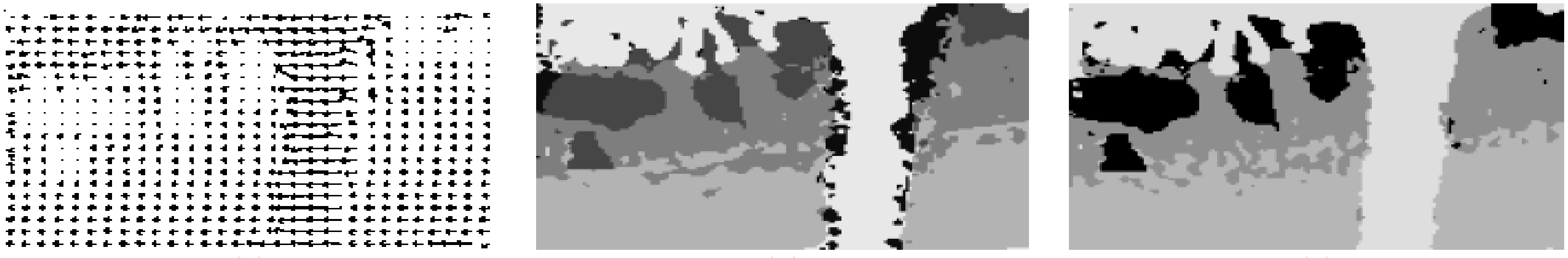
Iterative Algorithm

- The initial segmentation step uses an array of square regions.
- At each iteration, the segmentation becomes more accurate, because the parameter estimation is within a single coherent motion region.
- A region splitter separates disjoint regions.
- A filter eliminates small regions.
- At the end, intensity is used to match unassigned pixels to the best adjacent region.

Layer Synthesis

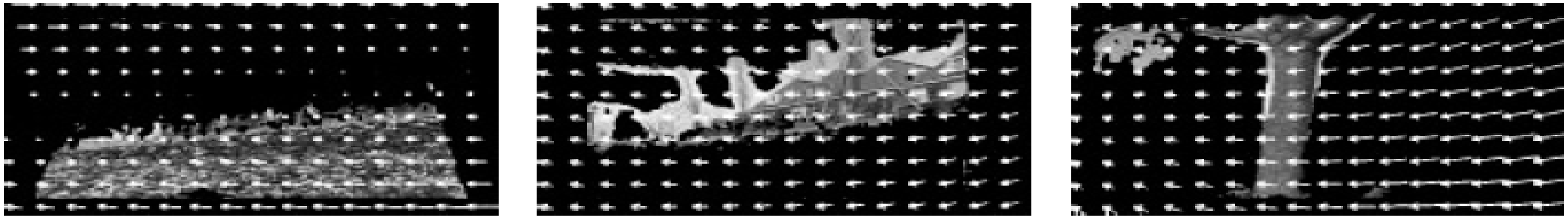
- The information from a longer sequence must be combined over time, to accumulate each layer.
- The transforms for each layer are used to warp its pixels to align a set of frames.
- The median value of a pixel over the set is used for the layer.
- Occlusion relationships are determined.

Results



(a) (b) (c)

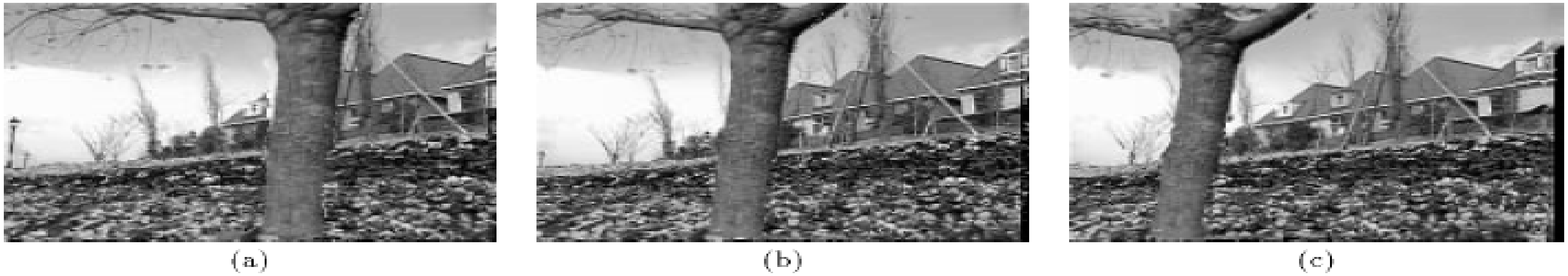
Figure 11: (a) The optic flow from multi-scale gradient method. (b) Segmentation obtained by clustering optic flow into affine motion regions. (c) Segmentation from consistency checking by image warping. Representing moving images with layers.



(a) (b) (c)

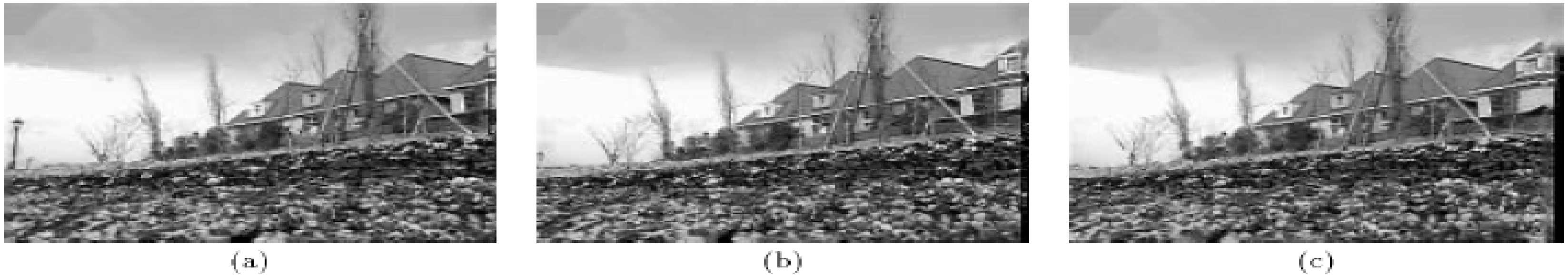
Figure 12: The layers corresponding to the tree, the flower bed, and the house shown in figures (a-c), respectively. The affine flow field for each layer is superimposed.

Results



(a) (b) (c)

Figure 13: Frames 0, 15, and 30 as reconstructed from the layered representation shown in figures (a-c), respectively.



(a) (b) (c)

Figure 14: The sequence reconstructed without the tree layer shown in figures (a-c), respectively.

Results

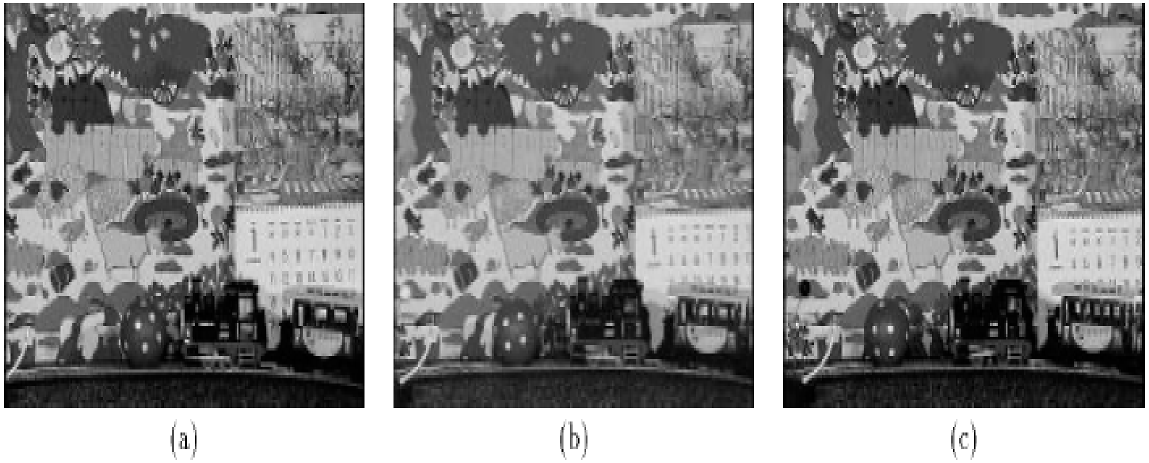

(a) (b) (c)

Figure 15: Frames 0, 15 and 30, of MPEG Calendar sequence shown in figures (a-c), respectively.

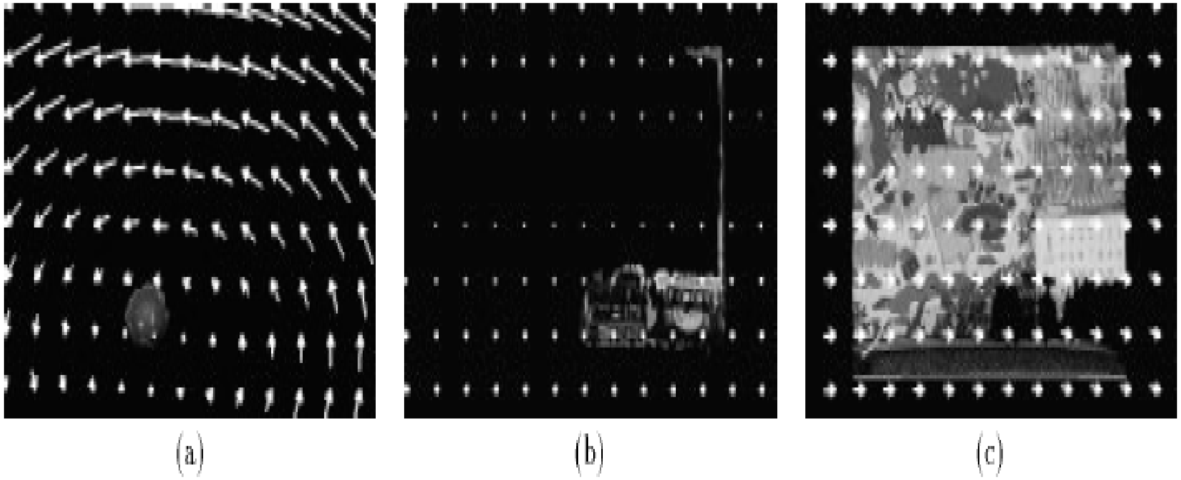

(a) (b) (c)

Figure 16: The layers corresponding to the ball, the train, and the background shown in figures (a-c), respectively.