# Seeing through Water

## Image Restoration using Model-based Tracking

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**Presented by:**
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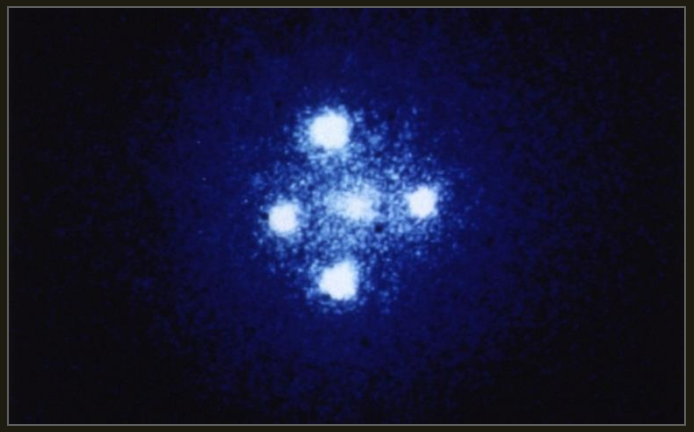
Daniel Lu

# Optical distortions

Water fluctuation

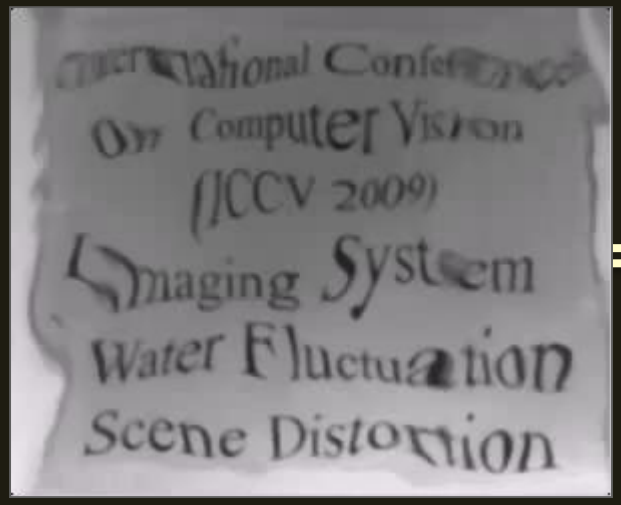

Turbulence



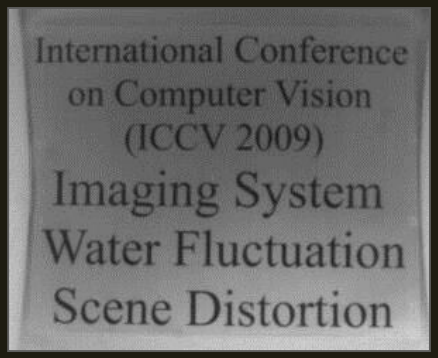
Telescopic imaging

Liquid lenses

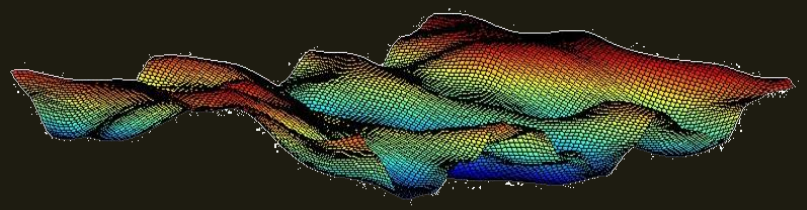
# Problem Statement



video sequence



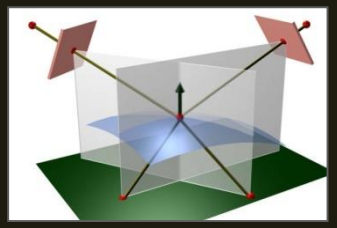

underlying static scene



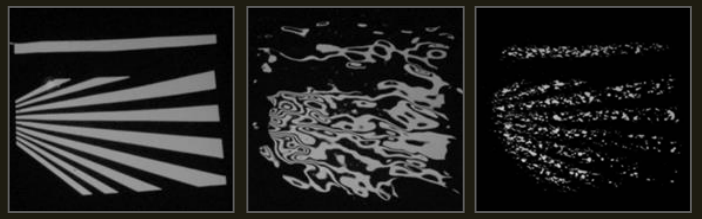
water surface

# Related work

- Calibration + Active lighting = Water surface



Refractive stereo [Morris et al, 2005]



Colored illumination [Ju et al, *2007*]

- Video sequence + Image statistics = Underlying scene


Convex Flow [Efros et al, 2004]

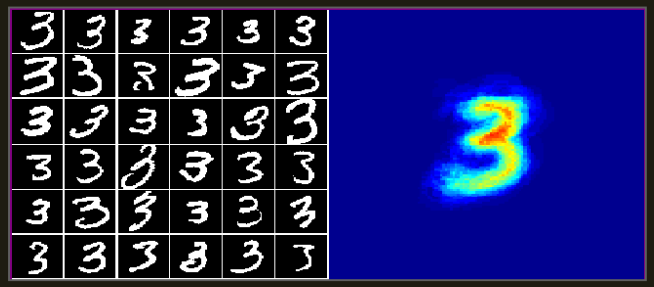

Bispectrum [Wen et al, 2007]

# Related work

- Image alignment

Estimate non-rigid distortion
*using* template

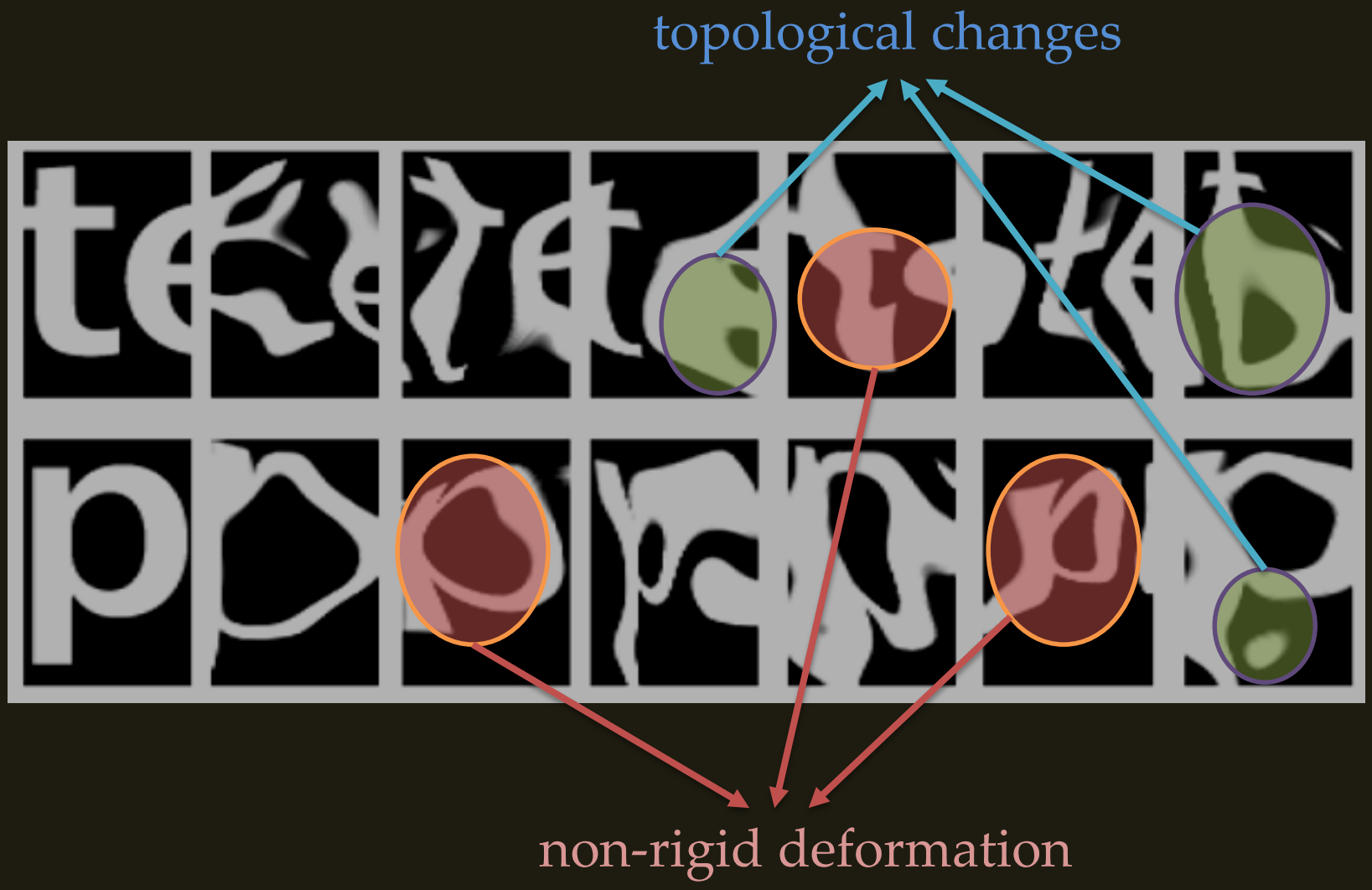
Active appearance models [Cootes et al, 2001]



Does not need template
But *no* temporal structure used

Congealing [Miller et al, 2005]

# Types of distortions

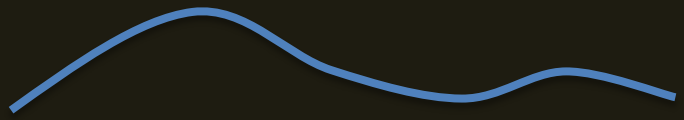


# Model-based approach

$$\frac{\partial^2 h(x,t)}{\partial t^2} = c^2 \nabla^2 h(x,t)$$

Physics of
water dynamics

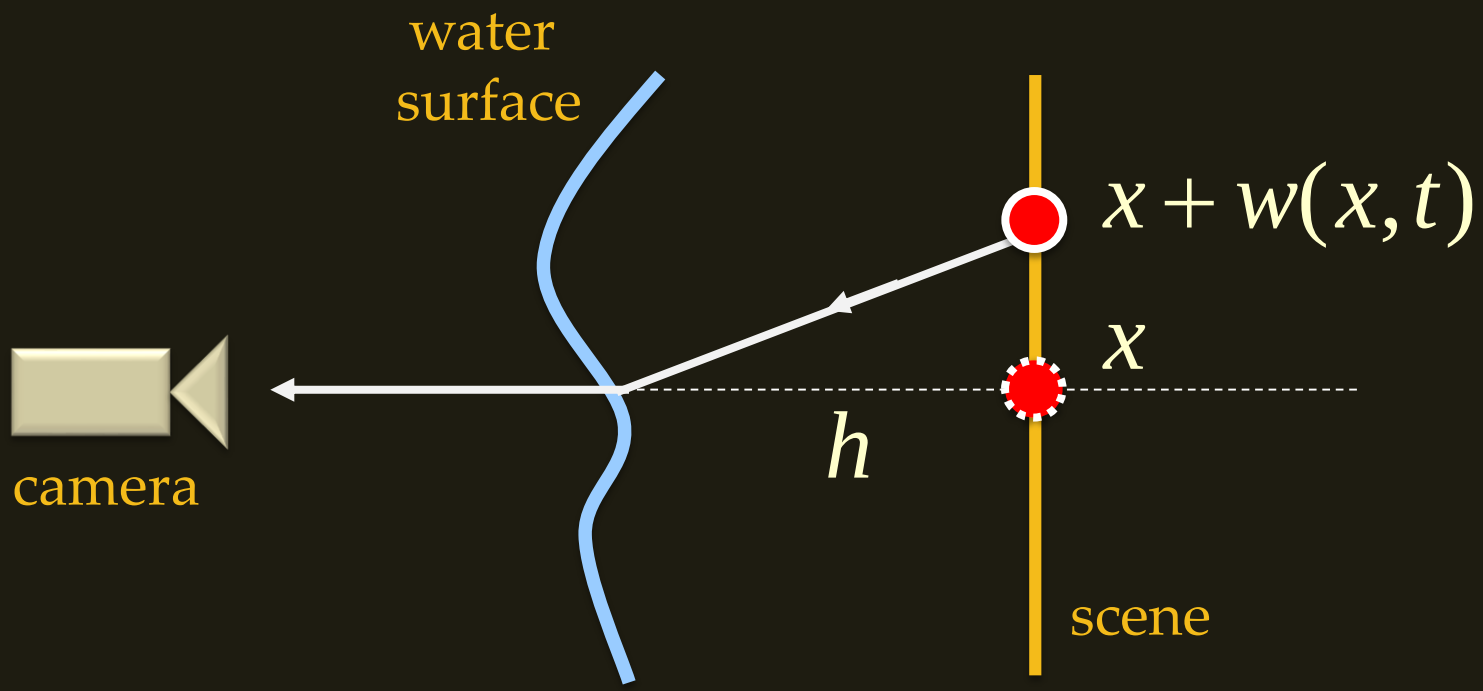
+



Smooth and
locally similar surface

Model governed by only a few parameters

# Image formation




Distorted Image

Video Frame ↓ | Scene ↓ | Distortion ↓

$$I(\mathbf{x},t) = I_g(\mathbf{x} + \mathbf{w}(\mathbf{x},t))$$

Image Distortion:

$$w(x,t) = \alpha \nabla h(x,t)$$

# Water dynamics

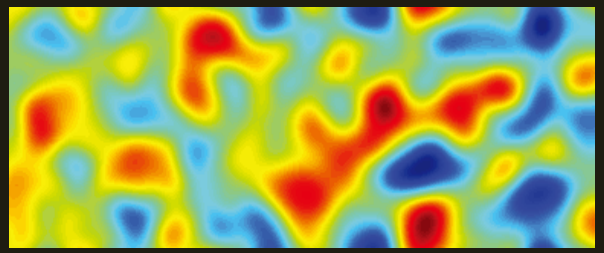
Wave equation:

$$\frac{\partial^2 h(x,t)}{\partial t^2} = c^2 \nabla^2 h(x,t)$$

water height

wave speed

Initial condition:

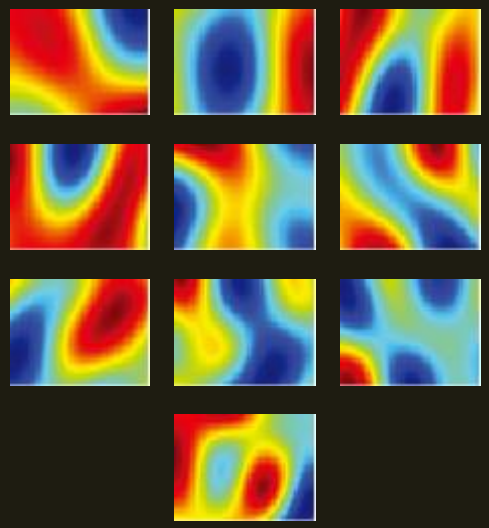


Random water height

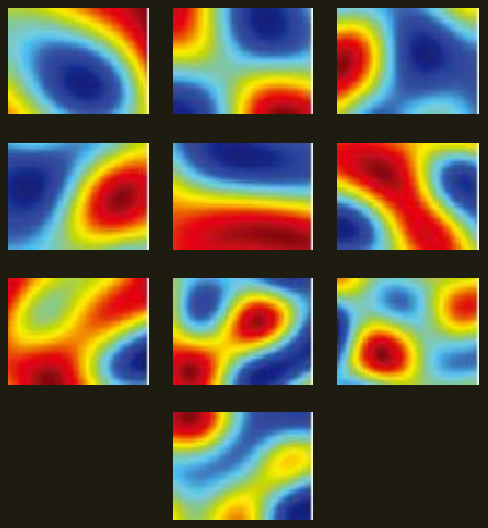
# Simulating water distortions

# Compact bases using PCA

- Distortion Parameter Reduction



x-components



y-components

We use 10 principle components

- Image Distortion

PCA Bases  Warping Coeffs.

$$\mathbf{w}(\mathbf{x}, t) \approx B(\mathbf{x})\,\mathbf{p}_t$$

# Validating reduction of dimensions

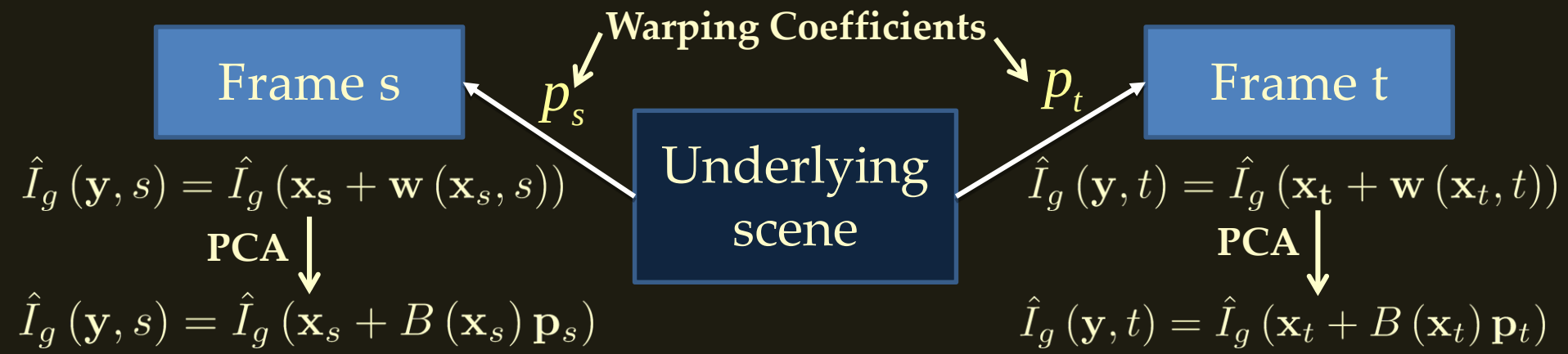
- Original

- Distorted

- Reconstructed

# Water tracking with no template

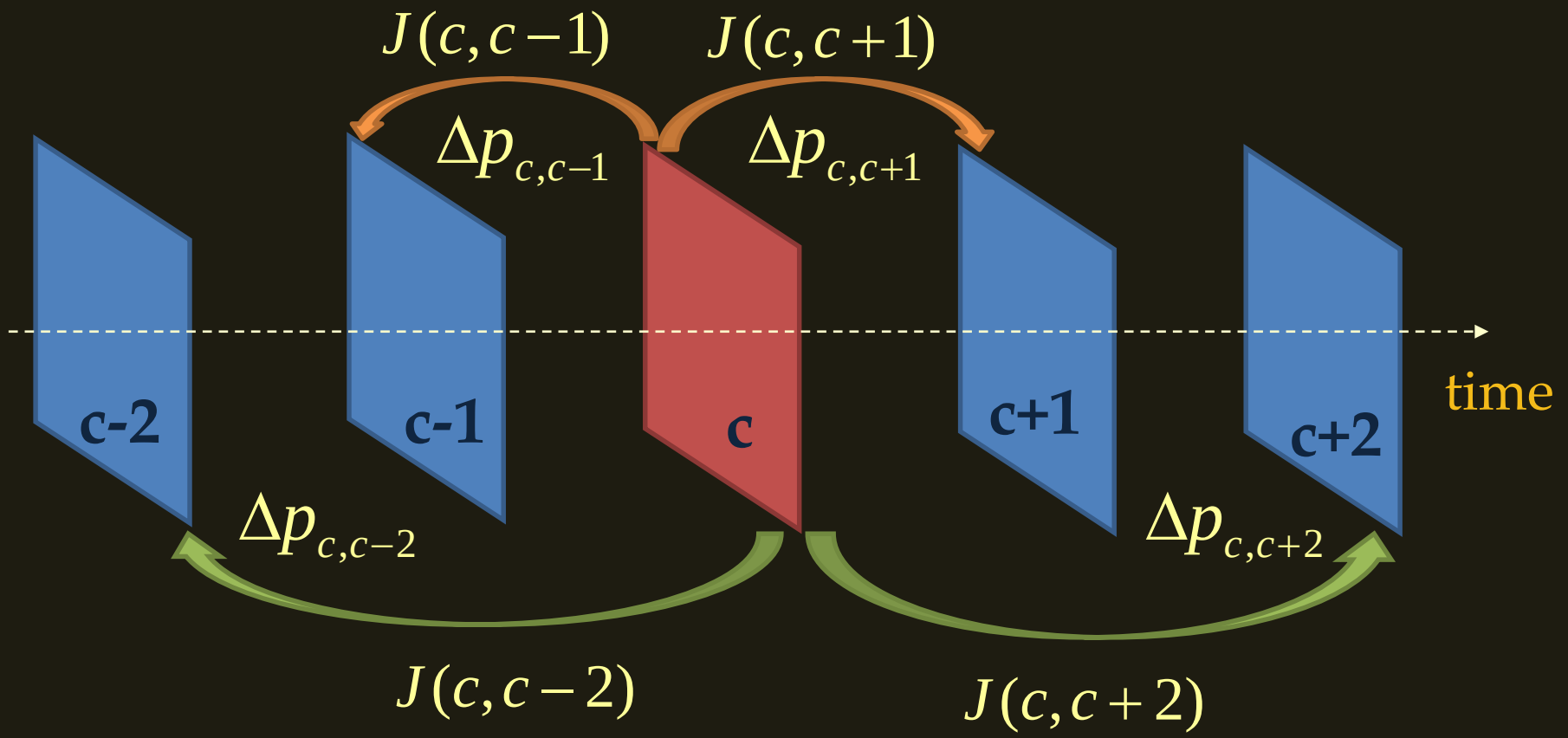
- Frame-to-scene mapping:




- Objective function:

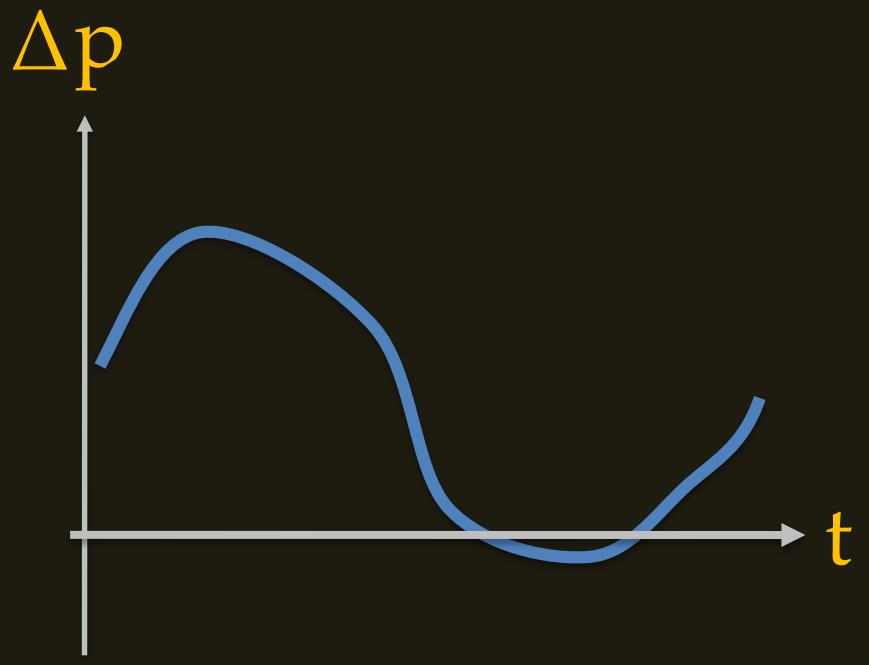
$$J(\mathbf{p_s}, \mathbf{p_t}) = \Big(\underbrace{\hat{I}_g(\mathbf{y}, s)}_{\text{Undistorted Frame s}} - \underbrace{\hat{I}_g(\mathbf{y}, t)}_{\text{Undistorted Frame t}}\Big)^2$$

# Exploiting temporal continuity



# Exploiting Temporal Stationarity

With $\{\Delta p_{c,t}\}$, the last piece of information: $p_c$



# Scene recovery

- Water surface

Distortion coefficients | Water bases | Surface integrator | Water surface

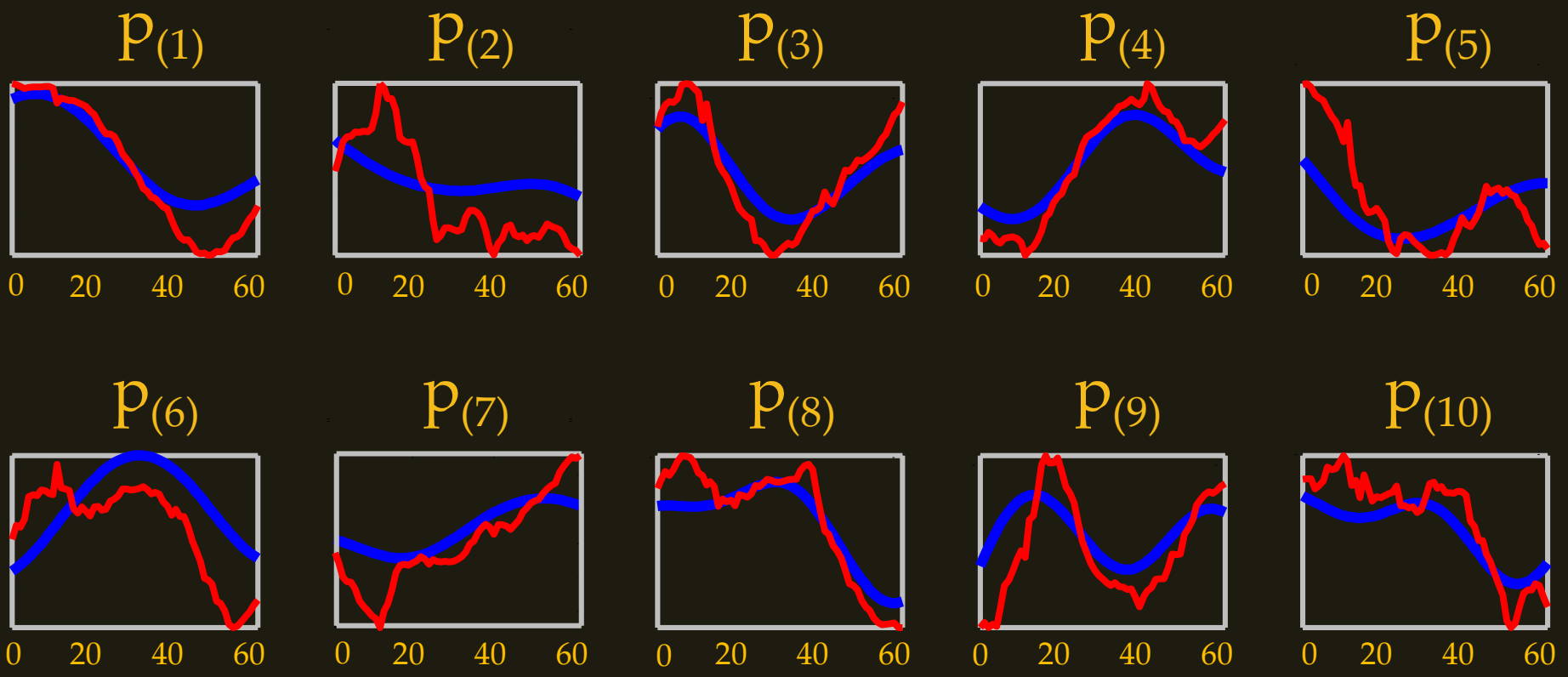
- Underlying scene

# Experiment with a synthetic scene

Input video frame

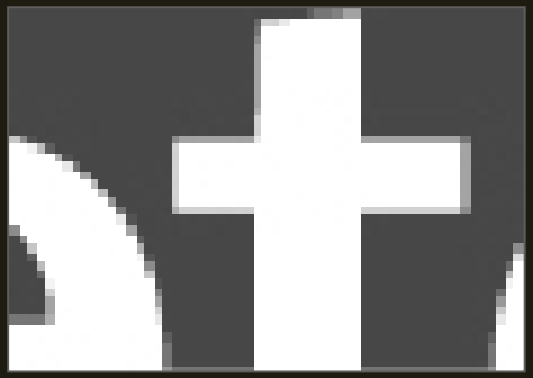
Underlying scene

# Experiment with a synthetic scene




Estimated coefficients versus Ground truth

# Experiment with a synthetic scene



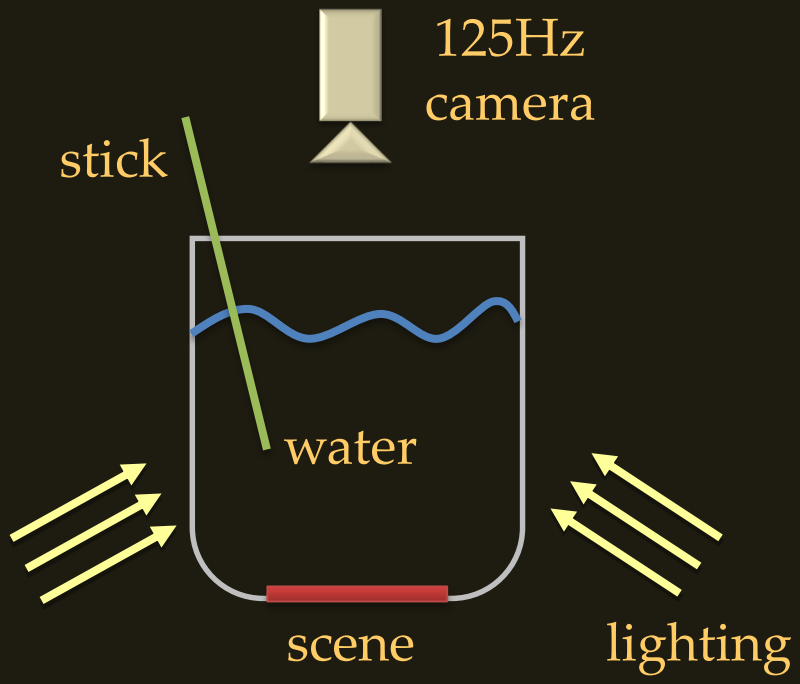
Underlying scene

Mean image

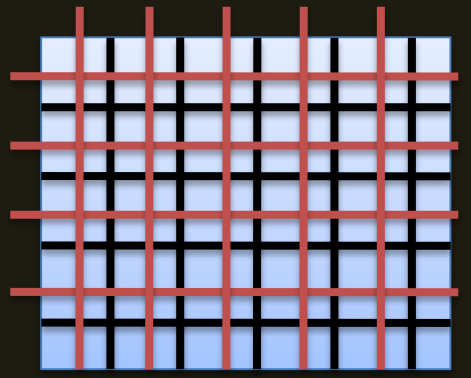
Median image

Our result

# Experiment with a real scene




Experimental setup

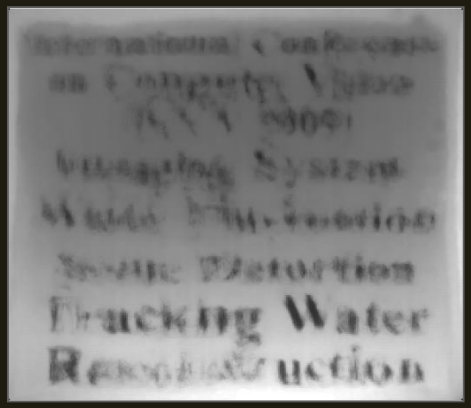


Partitioning the image

# Recover the underlying scene


Input video

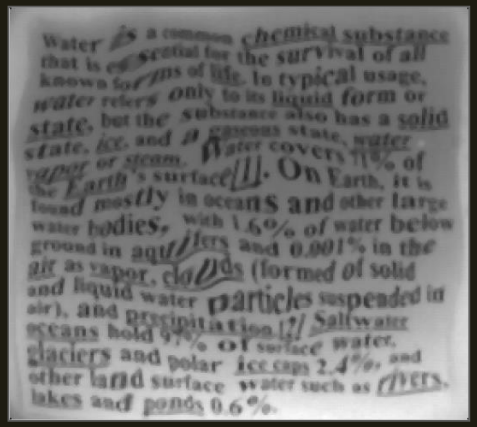
Mean image



Median image


Authors' method

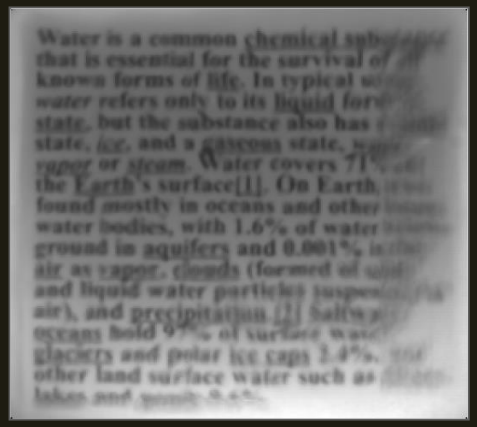
# Smaller fonts



Sample frame

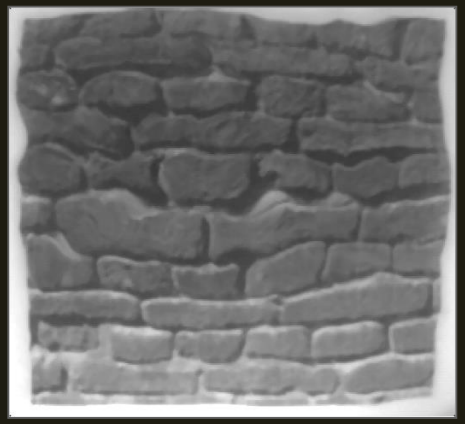
Mean image

Median image

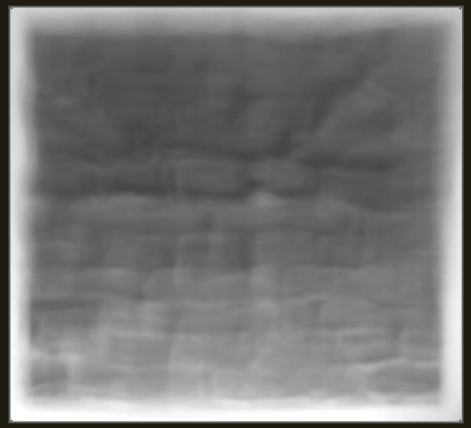


Authors' method

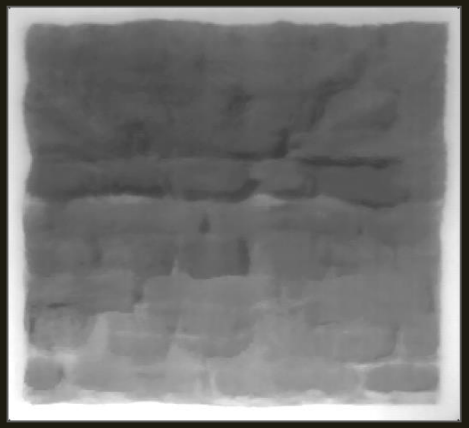
# Textures



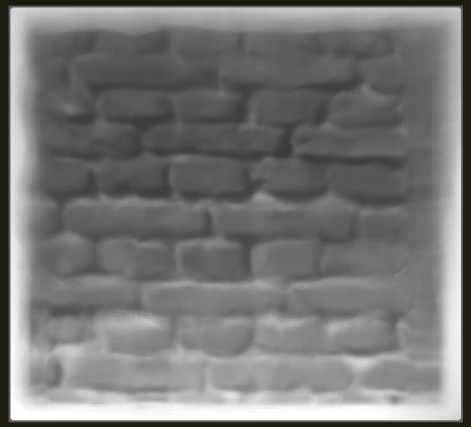
Sample frame



Mean image

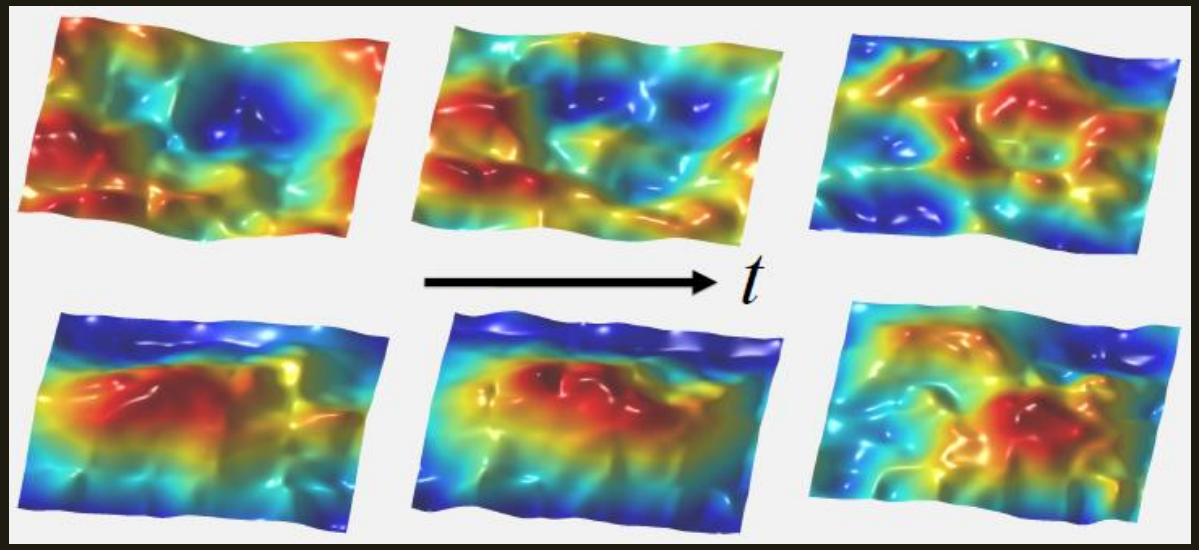


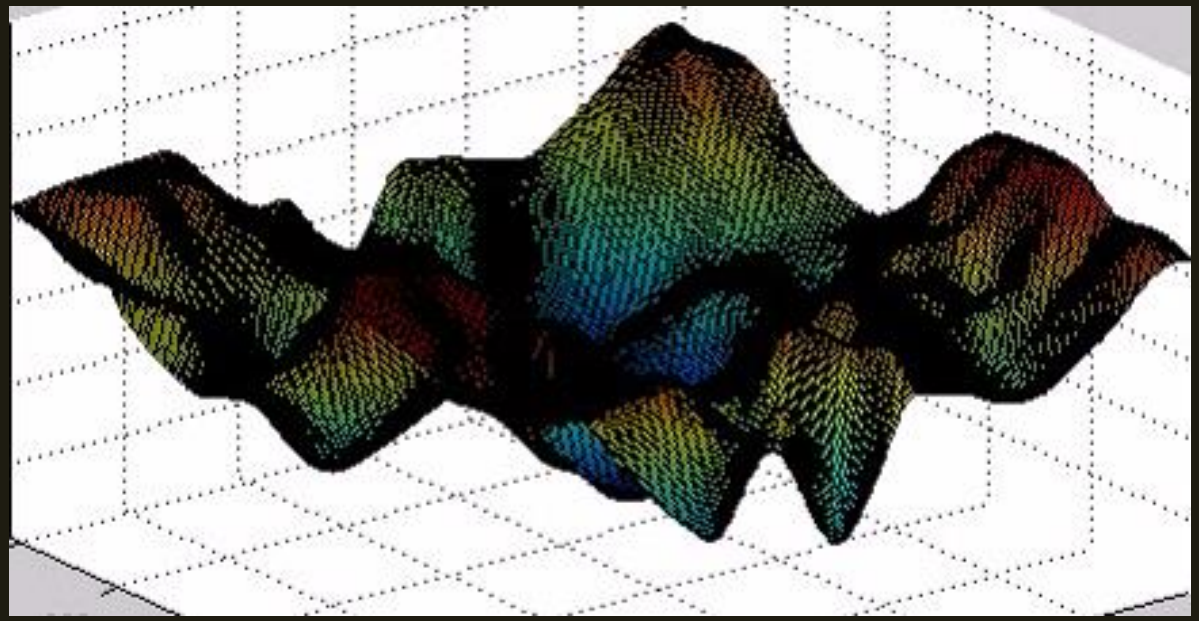
Median image



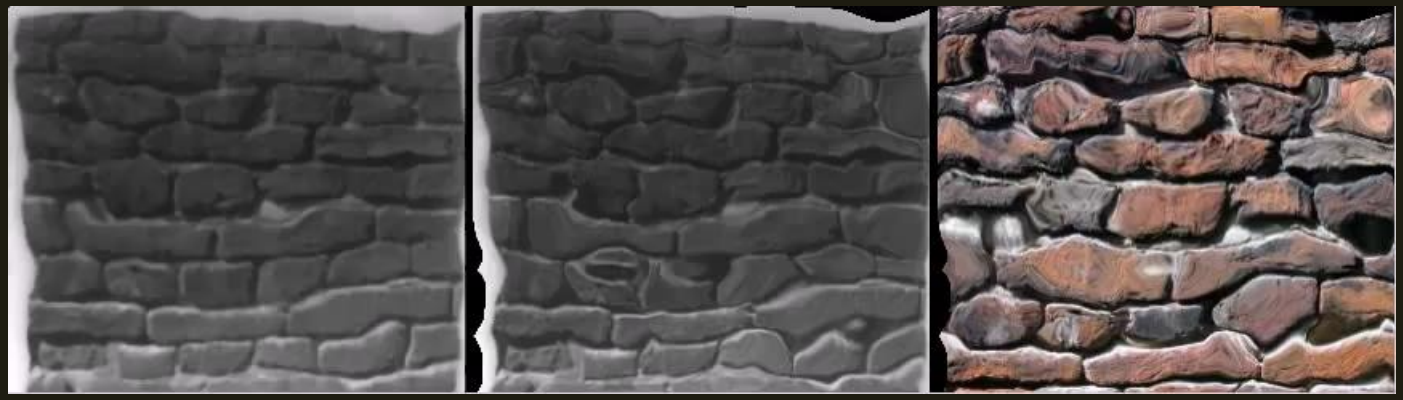
Authors' method

# Water surface



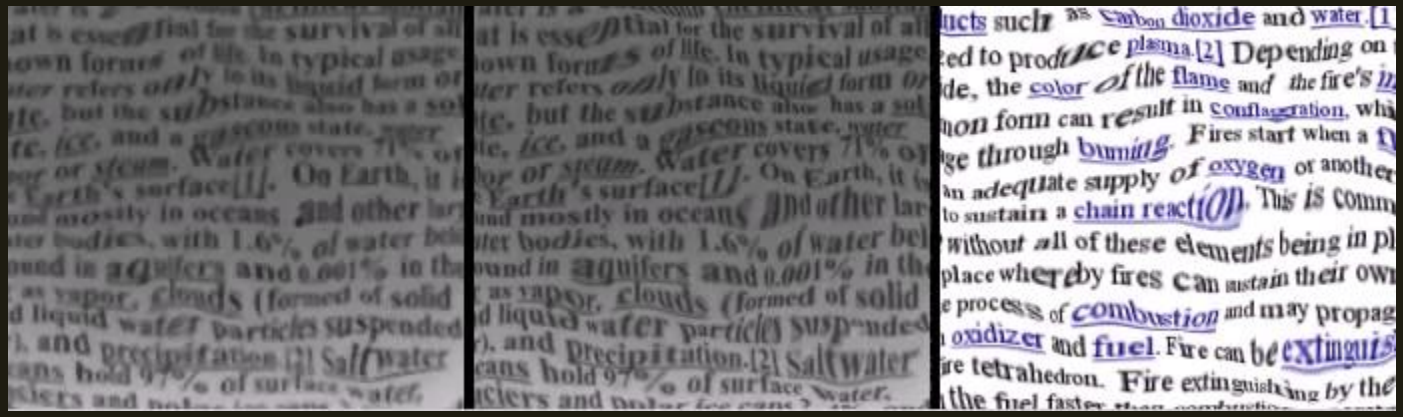
# Verification of surface reconstruction



Input video

Synthesis using estimated surface

Synthesis using a new texture



# Paper Summary

- Rating – 1.5
- Pros:
  - Provides compact model of water surface
  - Water tracking using temporal information
  - Image restoration and water surface reconstruction
  - Well written, nice figures
- Cons:
  - Requires higher than normal fps camera (125 Hz)
  - Does not work when caustics, reflections, or significant refractions are present
  - Requires knowing the wave speed and eyeballing smoothness of waves
  - Does not model boundary effects near edges, or viscosity, surface tension, and high frequency effects

# Questions?