Lifting Detail from Darkness

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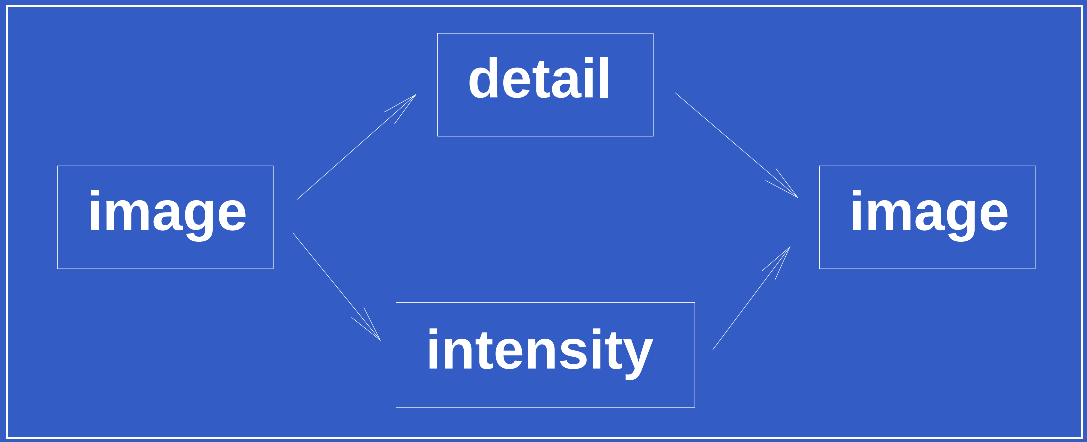
Disney The Secret Lab

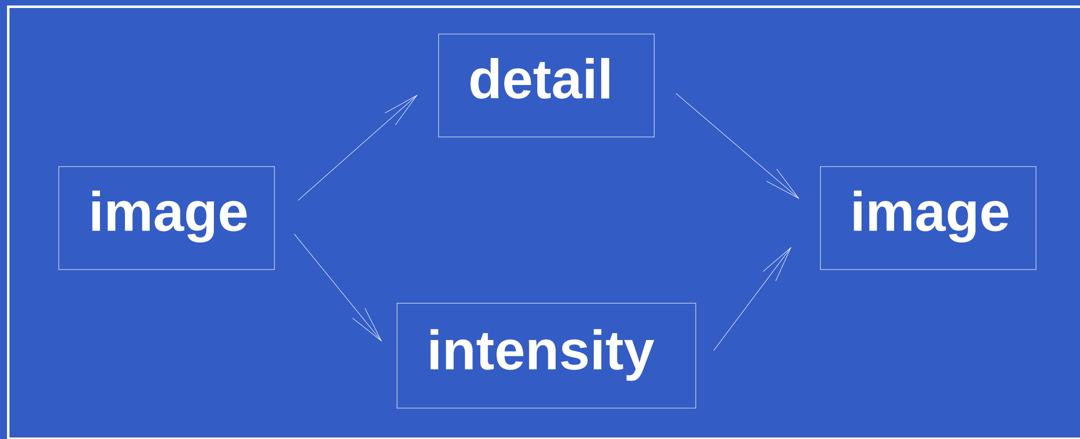
Brightness-Detail Decomposition



- Separate detail by Wiener filter
- Represent brightness by membrane PDE
- “Unsharp masking 2.0”

Topics: Wiener filter, Laplace PDE, multigrid

Brightness-Detail Decomposition



- Modify detail, keep brightness. Example: texture replacement (subject to limitations of 2D technique)
- Modify brightness, keep detail. Example: 102 Dalmatians spot removal

Motivation: 102-Dalmatians

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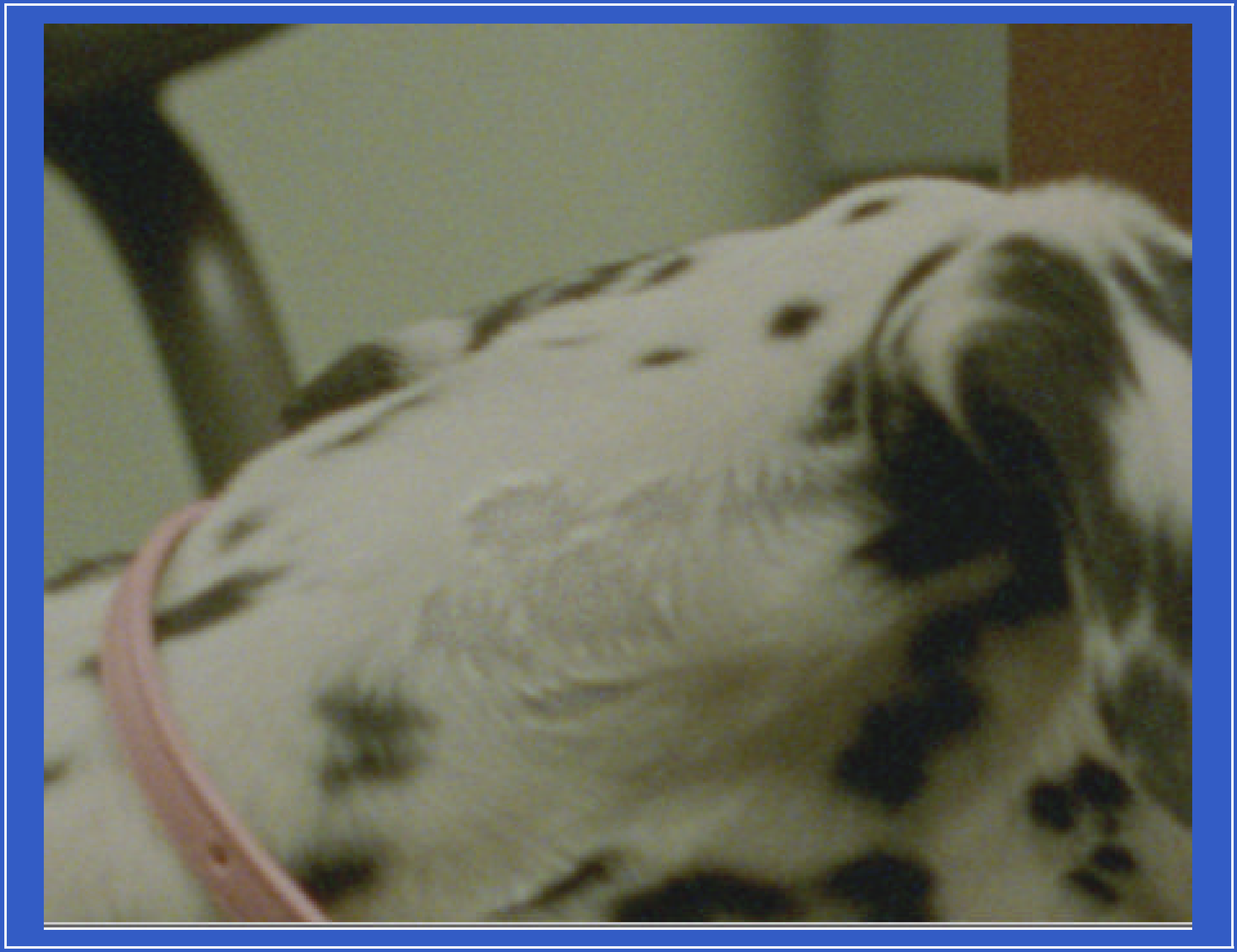
..."It turned out to be a huge job, much bigger than any of us had imagined."

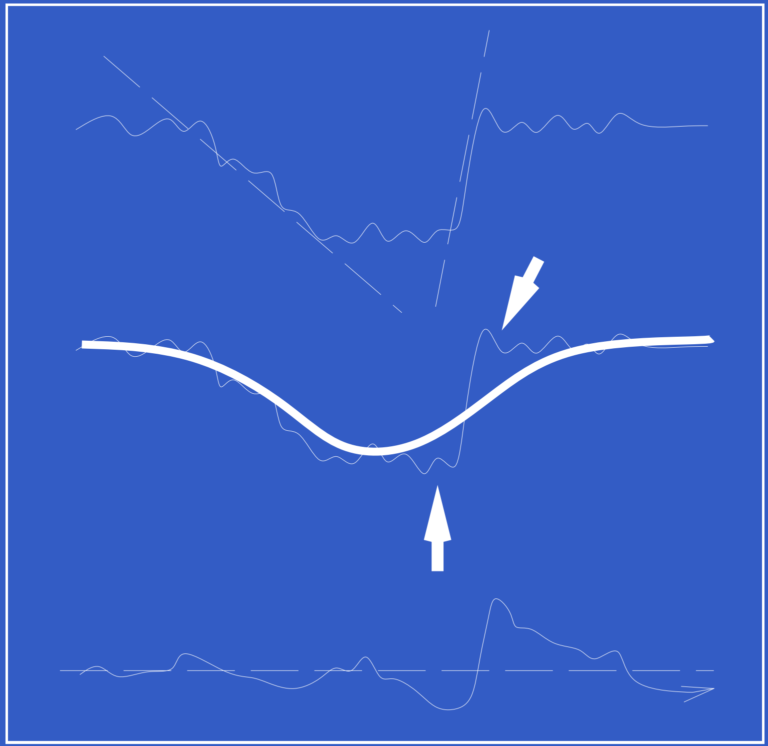
..."*any* spot that procedural could get rid of would help"...

— Jody Duncan, “Out, Out, Damned Spot,” *Cinefex* 84 (January 2001), p. 56.

No easy trick



No easy trick



Hypothetical spot luminance profile, blurred luminance (heavy), and unsharp mask (bottom).

No easy trick

Spot transition width is quite different on opposite sides of the same spot.

Wiener

- optimal linear estimator; for Gaussian data is optimal period.
- same principles can be applied as
  - filter
  - interpolator
  - predictor
- apply in frequency domain *or* spatially, recursive setting $\rightarrow$ Kalman

Wiener 1D

$y = x + n$	x: the unknown, y: observation
$\hat{x} = ay$	$\hat{x}$ is estimate. Find best a
E	expectation operator
$E[ax + by]$	E is linear
$= aE[x] + bE[y]$	
$E[xn] = 0$	noise not correlated with signal

Wiener 1D

min$_a$ $E[(\hat{x}-x)^2]$ Find a that minimizes expected err^2

min$_a$ $E[a^2y^2 - 2ayx + x^2]$ expand square, $\hat{x}$

min$_a$ $E[a^2(x+n)^2 - 2a(x+n)x + x^2]$ expand y

Expand products; $E[xn] = 0$:

min$_a$ $E[a^2(x^2 + 2xn + n^2) - 2a(x^2 + xn) + x^2]$

$\frac{\partial}{\partial a} = 0 = 2aE[x^2 + n^2] - 2E[x^2]$ minimize

$a = \frac{E[x^2]}{E[x^2+n^2]}$

Wiener principle

$$a = \frac{E[x^2]}{E[x^2 + n^2]}$$

Signal variance divided by signal variance + noise variance.

How to use Wiener

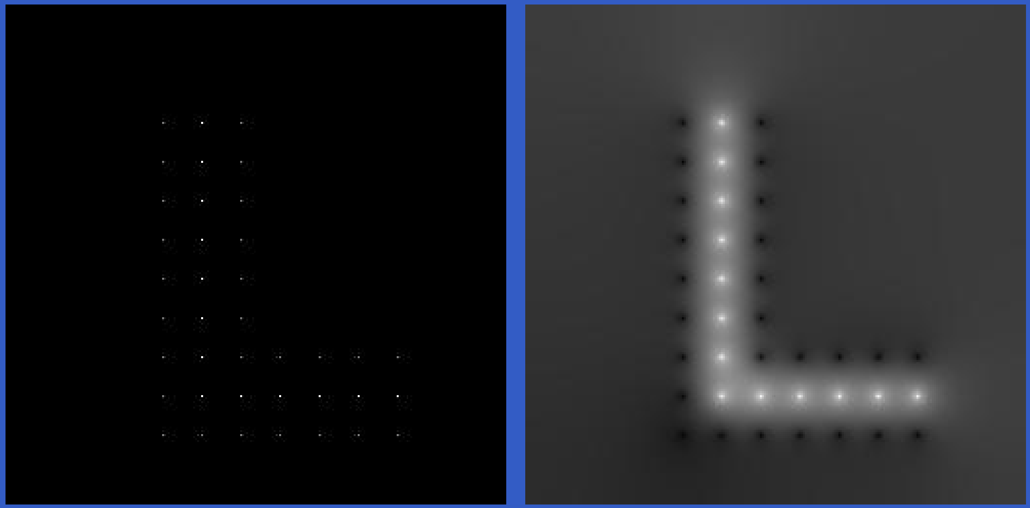
Interpret “noise” as detail, “signal” as brightness.

Membrane

$$\nabla^2 u = 0 \quad (\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2})$$

- scattered interp for when there are lots of data (c.f. radial basis, other: invert N^2 matrix for N data points)
- minimizes integrated gradient-squared (roughness)
- minimizes small-deflection approx. to surface area

Membrane



Left - impulses in ‘L’ pattern. Black means no data, intepolate.

Right - membrane interpolation.

Membrane: minimize roughness

roughness $$R = \int |\nabla u|^2 du \approx \sum (u_{k+1} - u_k)^2$$

for a particular k: $$\frac{dR}{du_k} = \frac{d}{du_k}[(u_k - u_{k-1})^2 + (u_{k+1} - u_k)^2]$$

$$= 2(u_k - u_{k-1}) - 2(u_{k+1} - u_k) = 0$$

$$u_{k+1} - 2u_k + u_{k-1} = 0$$

or $$\rightarrow \nabla^2 u = 0$$

Laplacian mask

```
1D:          1 -2  1

2D:             1
             1 -4  1
                1
```

Membrane as matrix eqn

$$\nabla^2 u = 0$$

rewrite ∇^2 as matrix $\quad Mu = 0$

rows looks like:

$$\ldots 1, \ldots \quad \ldots, 1, -4, 1, \ldots \quad \ldots, 1, \ldots$$
$$\ldots 1, \ldots \quad \ldots, 1, -4, 1, \ldots \quad \ldots, 1, \ldots$$
$$\ldots 1, \ldots \quad \ldots, 1, -4, 1, \ldots \quad \ldots, 1, \ldots$$

M is huge - number of pixels in the region, squared! But M is sparse, five diagonal bands.

Membrane: relaxation

$Mu = 0$ is too large to solve by conventional matrix inverse, solve by *relaxation*.

$$u_{k+1} - 2u_k + u_{k-1} = 0$$

$$u_k \leftarrow 0.5(u_{k+1} + u_{k-1})$$

Membrane: boundary conditions

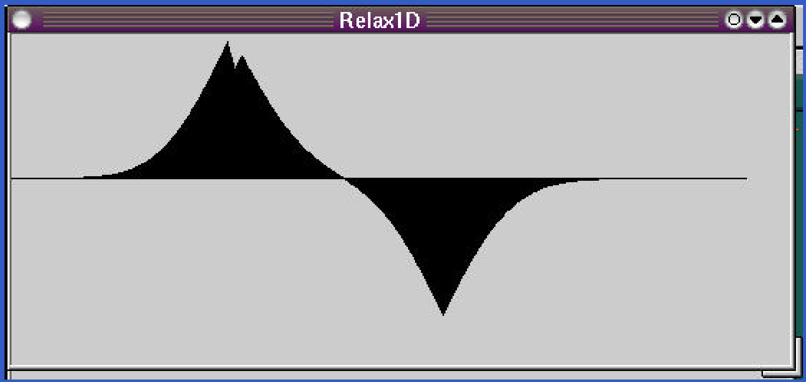
For *interpolation* some $u_{r,c}$ are known/specified rather than free. In setting up the linear system, subtract these from both sides of the eq, so the known quantities move to the rhs.

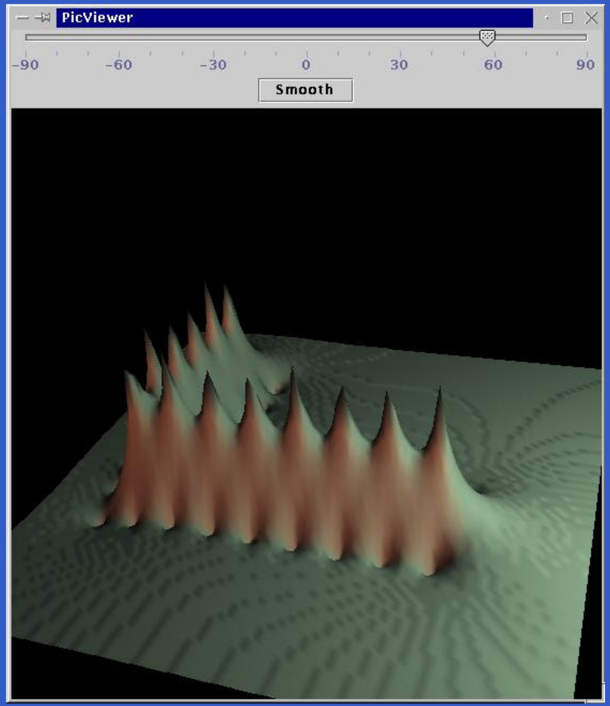
$$\frac{1}{h^2}\left(u_{+0} + u_{-0} + u_{0+} + u_{0-} - 4u_{00}\right) = 0$$

Say u_{+0} is known/fixed, then

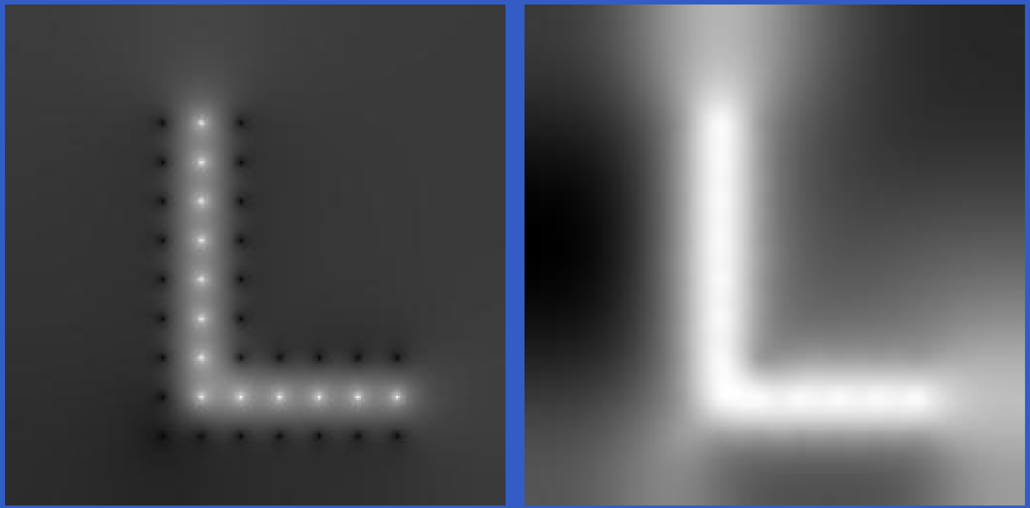
$$\frac{1}{h^2}\left(u_{-0} + u_{0+} + u_{0-} - 4u_{00}\right) = -\frac{1}{h^2}u_{+0}$$

Membrane artifact





Membrane vs. Thin Plate



Left - membrane interpolation, right - thin plate.

Multigrid

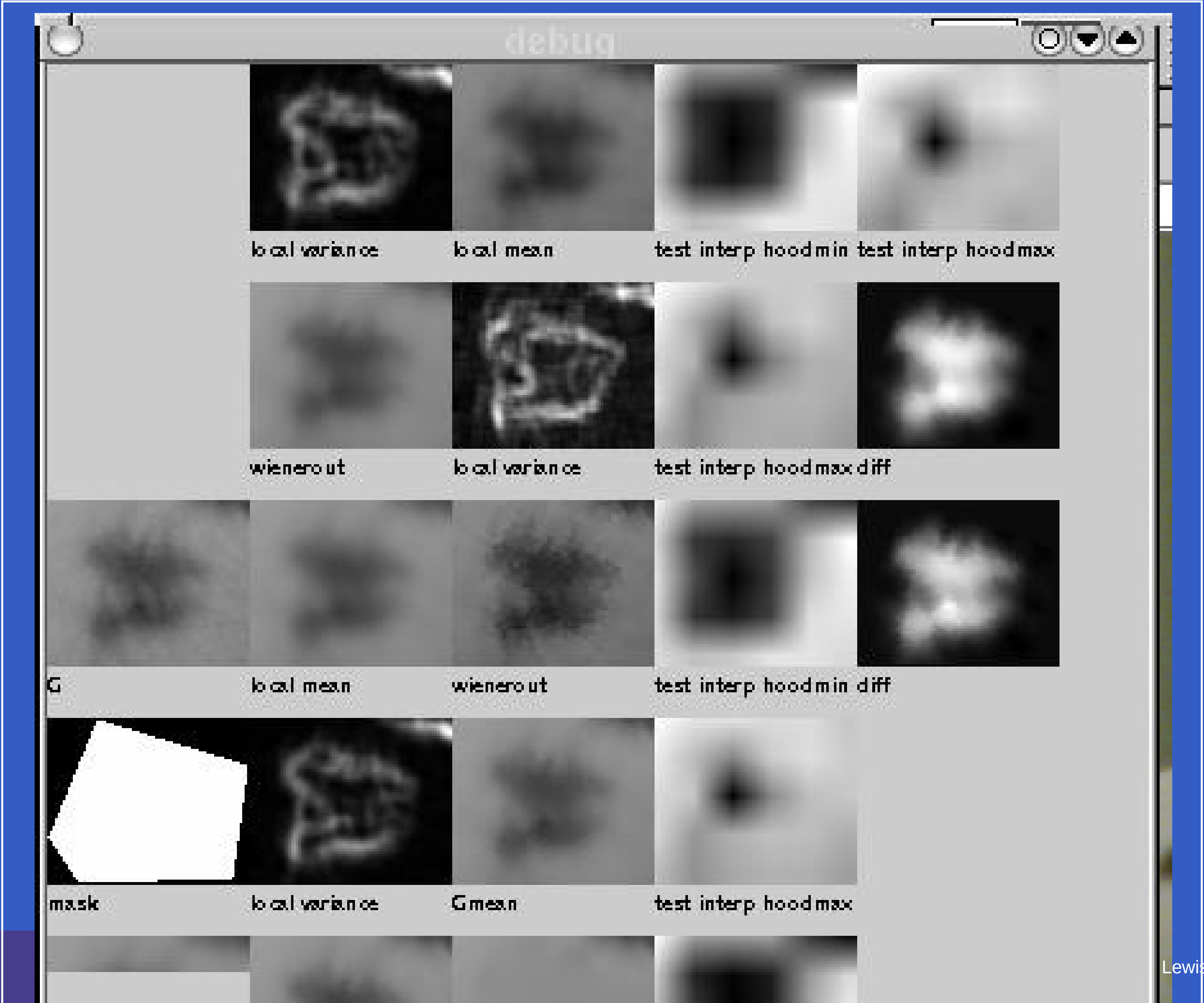
	$Ax = b$
approximate solution	$\hat{x} = x + e$
r: residual, e: error	$r = A\hat{x} - b$
	$r = Ax + Ae - b$
but $Ax = b$ so	$r = Ae$

Residual has lower frequencies, so e can be solved at low res and subtracted from $\hat{x}$ to give x.

Multigrid results

- before: several minutes, > 1/2 gig of memory
- after: several seconds, memory not noticed

Algorithm steps



Recovered fur

Recovered fur: detail

Versus hand cloning (manual)

Versus hand cloning (auto)

Versus hand cloning (manual), edge

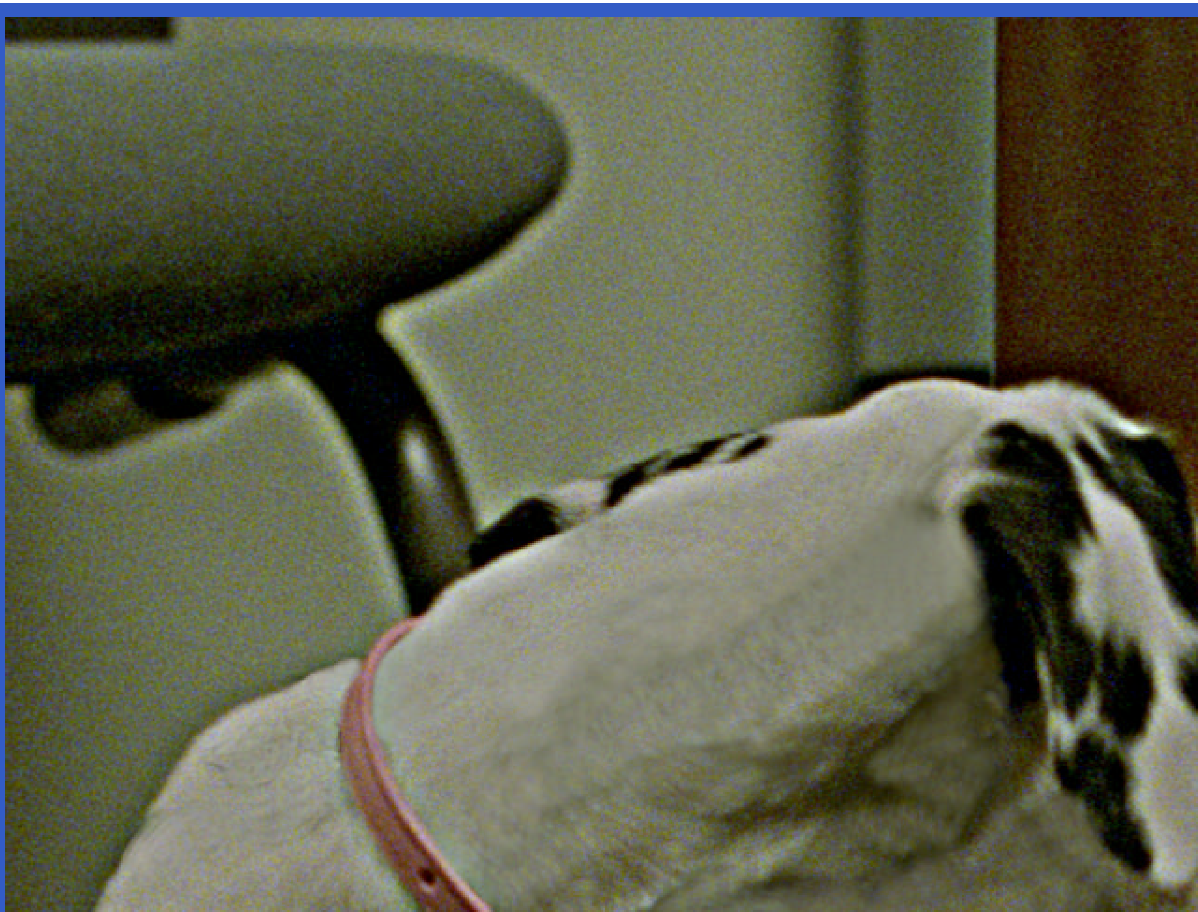


Image has been sharpened

Versus hand cloning (auto), edge

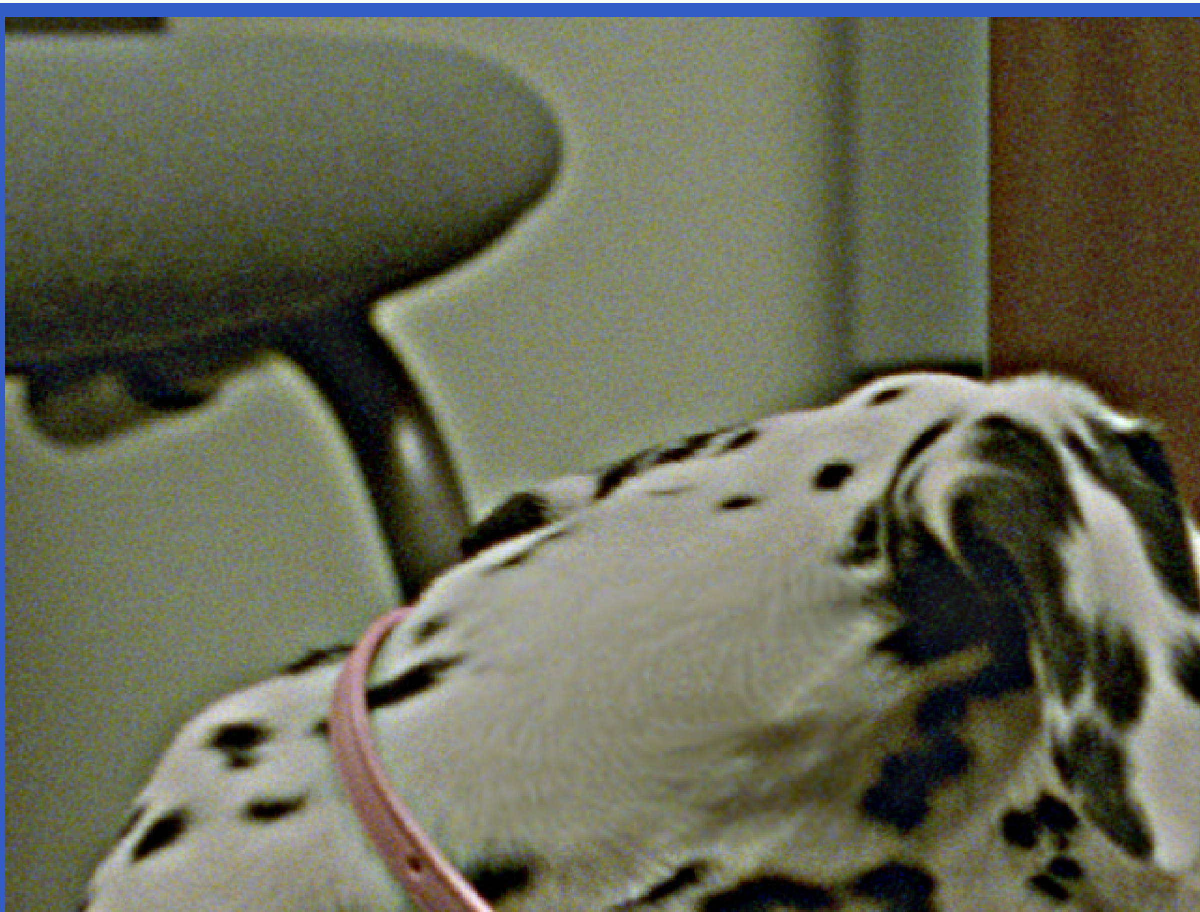


Image has been sharpened

Other applications

Conclusions+Demo

- image alterations produced quickly with no artistic skill (cloning requires some paint skill)
- produces consistent effects across frames (cloning may ‘chatter’ unless done skillfully)

Demo

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