# Reproducible Research in Image Processing:

# The Case of **IPOL**

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http://ipol.im



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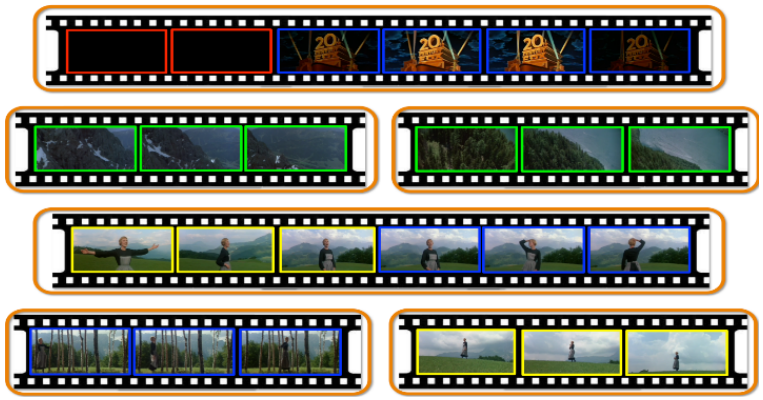
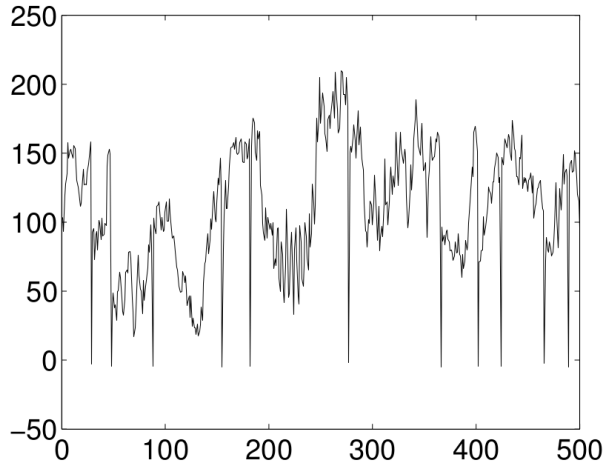
# Horror story №1

- CVPR article on detection of scene cuts in video
  *(beautiful, simple, without parameters!)*





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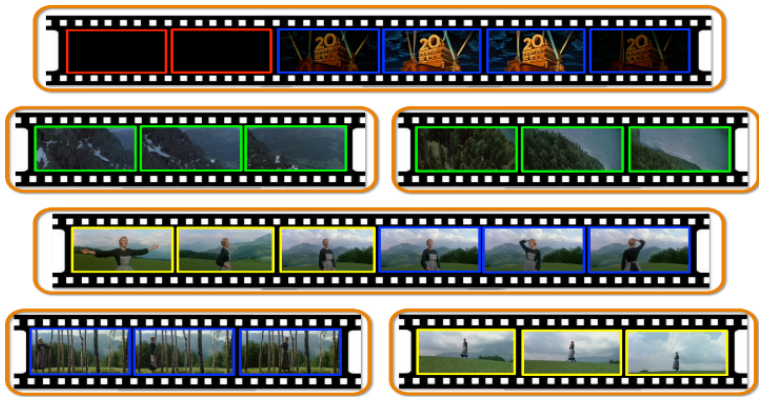

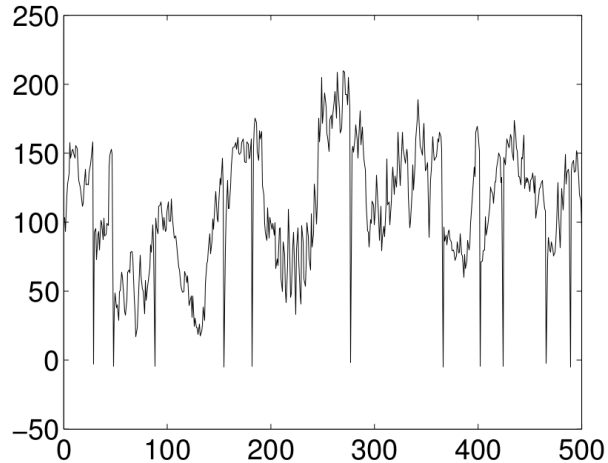


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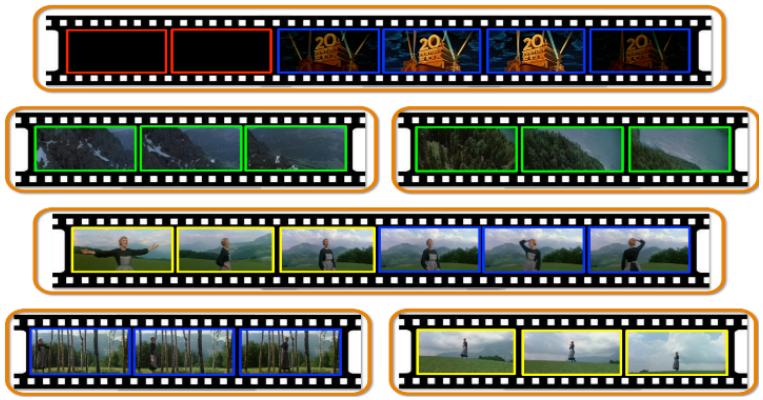

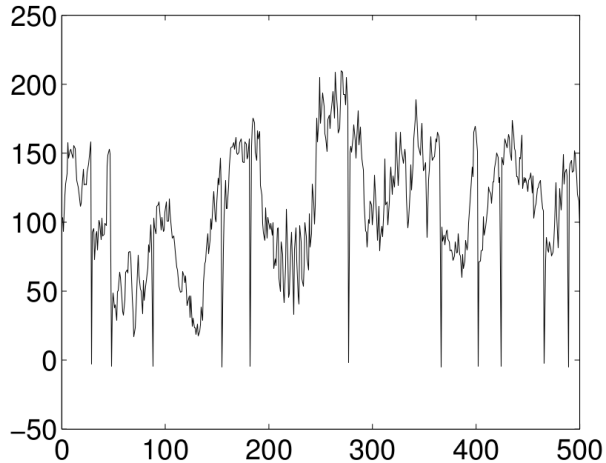


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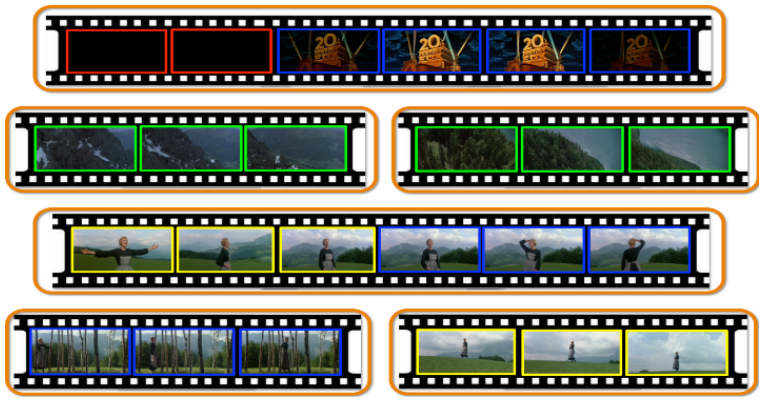

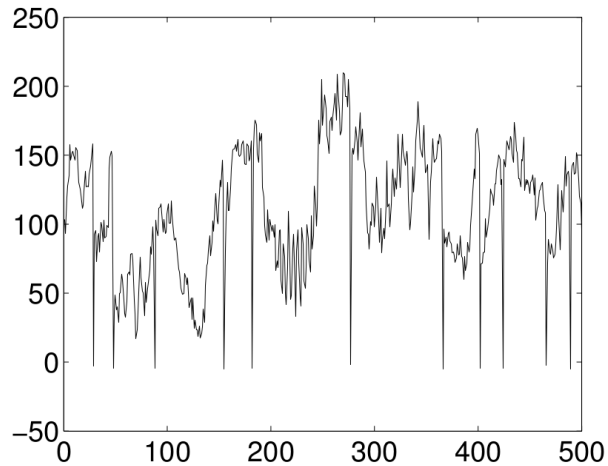


- The article contains this sentence: *In order to avoid division by zero, the points of the image where the spatial gradient is less than 2 are ignored.*
- We implement the algorithm. It does not work.
- Answer of the authors: first, you must blur the images with a gaussian kernel of $\sigma = 0.5$.

# Horror story №2

$$\begin{cases} \Delta\Delta u = 0 & \text{on } \Omega \\ u = f & \text{on } \partial\Omega \end{cases}$$

- Article solves biharmonic equation on arbitrary domains (...)
- The article contains this sentence: *The proposed multigrid algorithm converges to the solution of the problem in $O(N)$.*

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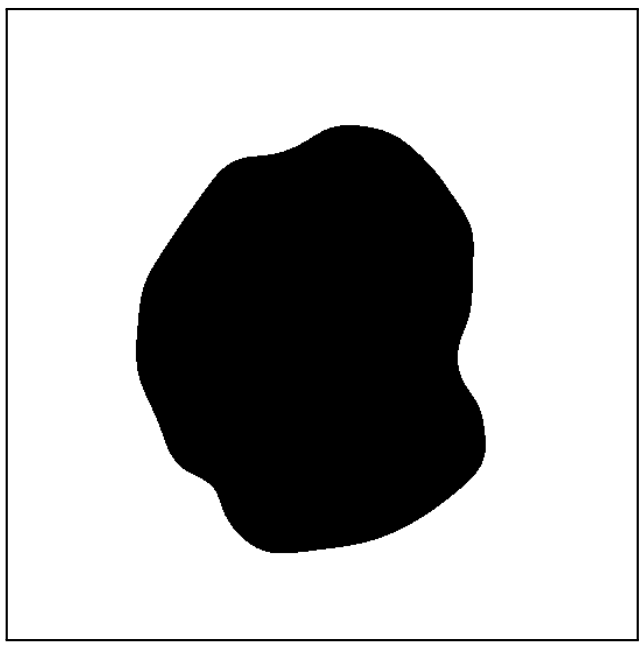
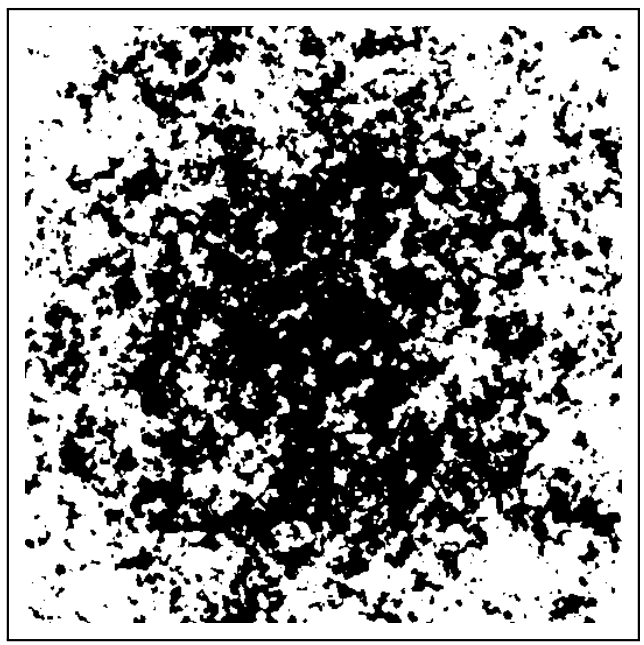
- We implement the algorithm. Convergence turns out to be slower than our naïve Gauss-Seidel implementation.
- Answer: our domains are "too complicated"



Domains used in the article



Our domains

# Horror story №3 "the virtual periscope"

- Theoretical article with an elegant method for the fusion of many deformed images (based on computing several deformation fields between pairs of images).


$I_1$

$\cdots$


$I_n$


solution

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$I_1$ $\cdots$ $I_n$ solution

- Problem: what optical flow to use?

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$I_1$ $\cdots$ $I_n$ solution

- Problem: what optical flow to use? "It depends"



Middlebury (indoor, no reflections)

SINTEL (synthetic video)

KITTI (only cars)

# Horror story №3 "the virtual periscope"

- Theoretical article with an elegant method for the fusion of many deformed images (based on computing several deformation fields between pairs of images).



$I_1$ $\cdots$ $I_n$ solution

- Problem: what optical flow to use? "It depends"
- According to "Middlebury": NNF-local (2013)
- According our tests: **Horn-Schunck (1981)**

Observation: online benchmarks are rather useless if we cannot try all the methods with our own images.

# Horror story №4

An “embarrassingly parallel” algorithm for optical flow

```
// inner loop

for (int j = 0; j < height; j++)
for (int i = 0; i < width;  i++)
        u(i,j) += tau * ( -4*u(i,j) + u(i+1,j) + u(i-1,j) + u(i,j+1) + u(i,j-1) ) + f(i,j);
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```

| OMP_NUM_THREADS | wall time |
|---|---|
| 1 | 6.2 |
| 2 | 3.1 |
| 3 | 2.1 |
| 4 | 1.7 |

Running times on my laptop

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| OMP_NUM_THREADS | wall time |
|---|---|
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| 2 | 3.2 |
| 4 | 1.8 |
| 8 | 1.6 |
| 16 | 1.6 |
| 31 | 1.5 |
| 32 | 25.2 (with wrong results) |

Running times on the server

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Running times on the server

**Idea**: running time* is part of the output and must be reproducible.

* As a function of input size and number of cores.

# Horror story №5

# Horror story №5

My life.

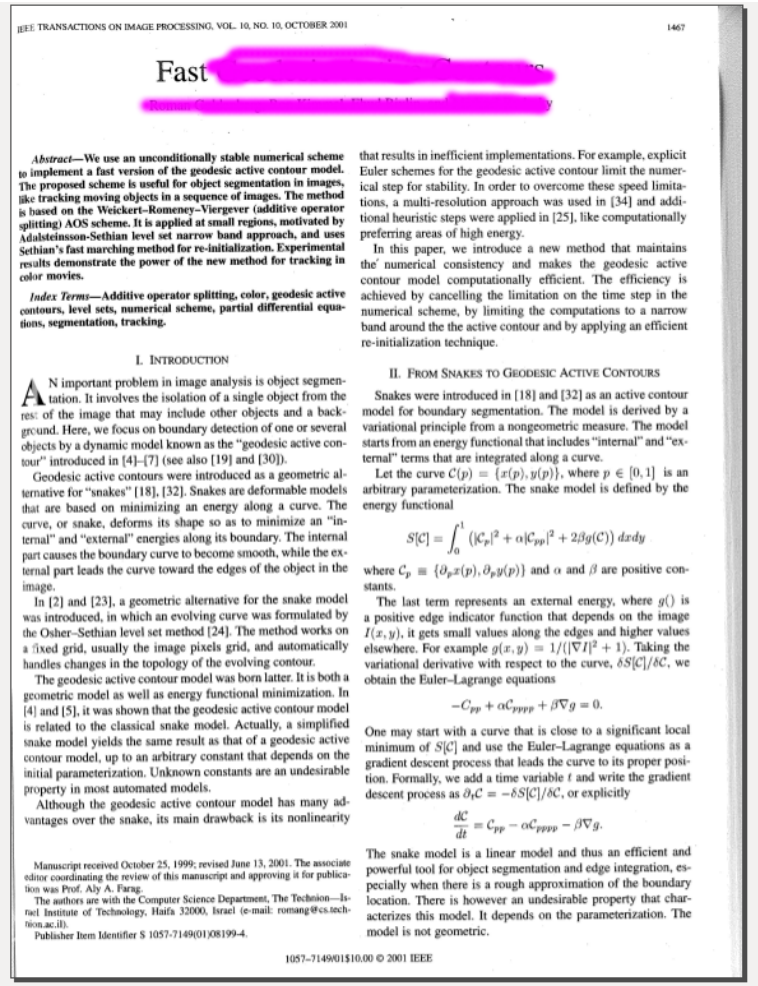
# Horror story №5

Have you ever published an article that:

- Did only work for images of side $2^N$?
- Had "secret" parameters?
- Did only work well for the images given as example?
- Did only work well for the images of a popular benchmark?
- Said "... *may be implemented in real time*" ?

# Typical article in image processing

What you get: PDF file



IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 10, NO. 10, OCTOBER 2001 1467

Fast [redacted]

*Abstract*—**We use an unconditionally stable numerical scheme to implement a fast version of the geodesic active contour model. The proposed scheme is useful for object segmentation in images, like tracking moving objects in a sequence of images. The method is based on the Weickert–Romeney–Viergever (additive operator splitting) AOS scheme. It is applied at small regions, motivated by Adalsteinsson-Sethian level set narrow band approach, and uses Sethian's fast marching method for re-initialization. Experimental results demonstrate the power of the new method for tracking in color movies.**

*Index Terms*—**Additive operator splitting, color, geodesic active contours, level sets, numerical scheme, partial differential equations, segmentation, tracking.**

I. Introduction

An important problem in image analysis is object segmentation. It involves the isolation of a single object from the rest of the image that may include other objects and a background. Here, we focus on boundary detection of one or several objects by a dynamic model known as the "geodesic active contour" introduced in [4]–[7] (see also [19] and [30]).

Geodesic active contours were introduced as a geometric alternative for "snakes" [18], [32]. Snakes are deformable models that are based on minimizing an energy along a curve. The curve, or snake, deforms its shape so as to minimize an "internal" and "external" energies along its boundary. The internal part causes the boundary curve to become smooth, while the external part leads the curve toward the edges of the object in the image.

In [2] and [23], a geometric alternative for the snake model was introduced, in which an evolving curve was formulated by the Osher–Sethian level set method [24]. The method works on a fixed grid, usually the image pixels grid, and automatically handles changes in the topology of the evolving contour.

The geodesic active contour model was born latter. It is both a geometric model as well as energy functional minimization. In [4] and [5], it was shown that the geodesic active contour model is related to the classical snake model. Actually, a simplified snake model yields the same result as that of a geodesic active contour model, up to an arbitrary constant that depends on the initial parameterization. Unknown constants are an undesirable property in most automated models.

Although the geodesic active contour model has many advantages over the snake, its main drawback is its nonlinearity that results in inefficient implementations. For example, explicit Euler schemes for the geodesic active contour limit the numerical step for stability. In order to overcome these speed limitations, a multi-resolution approach was used in [34] and additional heuristic steps were applied in [25], like computationally preferring areas of high energy.

In this paper, we introduce a new method that maintains the numerical consistency and makes the geodesic active contour model computationally efficient. The efficiency is achieved by cancelling the limitation on the time step in the numerical scheme, by limiting the computations to a narrow band around the the active contour and by applying an efficient re-initialization technique.

II. From Snakes to Geodesic Active Contours

Snakes were introduced in [18] and [32] as an active contour model for boundary segmentation. The model is derived by a variational principle from a nongeometric measure. The model starts from an energy functional that includes "internal" and "external" terms that are integrated along a curve.

Let the curve $\mathcal{C}(p) = \{x(p), y(p)\}$, where $p \in [0,1]$ is an arbitrary parameterization. The snake model is defined by the energy functional

$$S[\mathcal{C}] = \int_0^1 \left(|\mathcal{C}_p|^2 + \alpha|\mathcal{C}_{pp}|^2 + 2\beta g(\mathcal{C})\right) dxdy$$

where $\mathcal{C}_p \equiv \{\partial_p x(p), \partial_p y(p)\}$ and $\alpha$ and $\beta$ are positive constants.

The last term represents an external energy, where $g()$ is a positive edge indicator function that depends on the image $I(x,y)$, it gets small values along the edges and higher values elsewhere. For example $g(x,y) = 1/(|\nabla I|^2 + 1)$. Taking the variational derivative with respect to the curve, $\delta S[\mathcal{C}]/\delta\mathcal{C}$, we obtain the Euler–Lagrange equations

$$-\mathcal{C}_{pp} + \alpha\mathcal{C}_{pppp} + \beta\nabla g = 0.$$

One may start with a curve that is close to a significant local minimum of $S[\mathcal{C}]$ and use the Euler–Lagrange equations as a gradient descent process that leads the curve to its proper position. Formally, we add a time variable $t$ and write the gradient descent process as $\partial_t\mathcal{C} = -\delta S[\mathcal{C}]/\delta\mathcal{C}$, or explicitly

$$\frac{d\mathcal{C}}{dt} = \mathcal{C}_{pp} - \alpha\mathcal{C}_{pppp} - \beta\nabla g.$$

The snake model is a linear model and thus an efficient and powerful tool for object segmentation and edge integration, especially when there is a rough approximation of the boundary location. There is however an undesirable property that characterizes this model. It depends on the parameterization. The model is not geometric.

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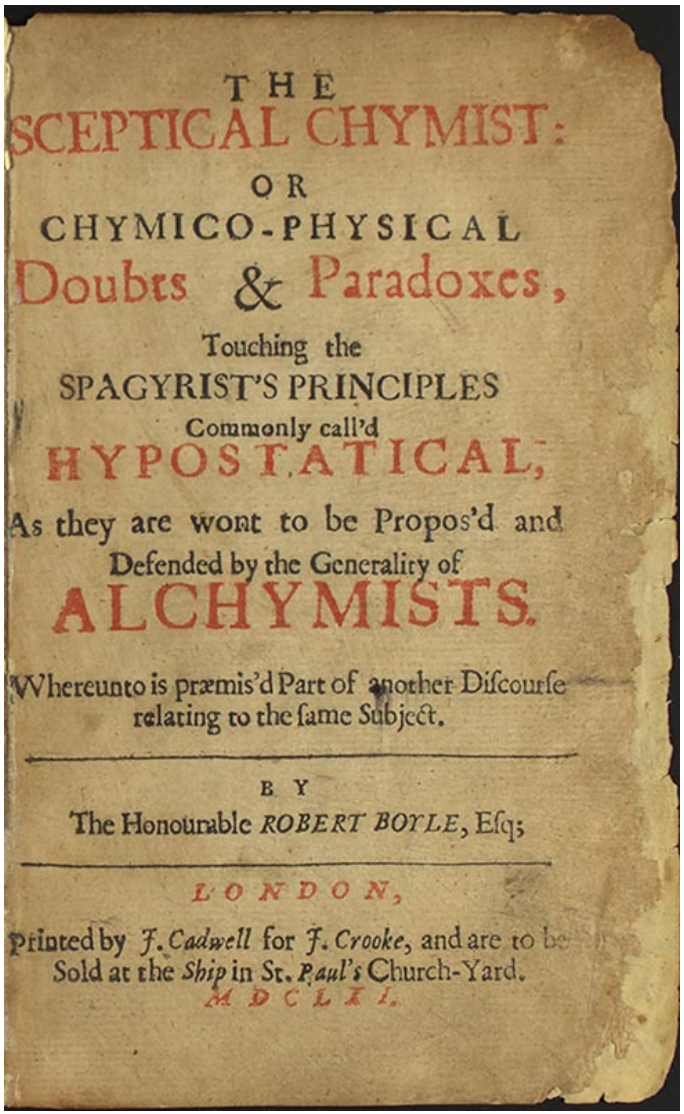
What can you do:

- ✔ read the formulas
- ✔ believe the results
- ✔ look at the low-res images
- ✘ verify the results
- ✘ **reproduce** the results
- ✘ look at the images in detail
- ✘ look at the graphs in detail
- ✘ try it on your own data

# Reproductibility split chemistry from alchemy


THE
SCEPTICAL CHYMIST:
OR
CHYMICO-PHYSICAL
Doubts & Paradoxes,
Touching the
SPAGYRIST'S PRINCIPLES
Commonly call'd
HYPOSTATICAL,
As they are wont to be Propos'd and
Defended by the Generality of
ALCHYMISTS.
Whereunto is præmis'd Part of another Diſcourſe
relating to the ſame Subject.
BY
The Honourable ROBERT BOYLE, Eſq;
LONDON,
Printed by J. Cadwell for J. Crooke, and are to be
Sold at the Ship in St. Paul's Church-Yard.
MDCLXI.

The Sceptical Chymist

Robert Boyle, 1661

*Me thinks the Chymists, in their searches after truth, are not unlike the Navigators of Solomons Tarshish Fleet, who brought home from their long and tedious Voyages, not only Gold, and Silver, and Ivory, but Apes and Peacocks too; For so the Writings of several (for I say not, all) of your Hermetick Philosophers present us, together with divers Substantial and noble Experiments, Theories, which either like Peacocks feathers make a great shew, but are neither solid nor useful; or else like Apes, if they have some appearance of being rational, are blemish'd with some absurdity or other, that when they are Attentively consider'd, makes them appear Ridiculous.*

# The article is only the *teaser* of research

David Donoho
Stanford

*An article about computational science in a scientific publication is* **not** *the scholarship itself, it is merely* **advertising** *of the scholarship. The actual scholarship is the complete software development environment and the complete set of instructions which generated the figures.*

# Reason for not giving the code: we trust our colleagues

Randall LeVeque
U. of Washington

*Suppose we lived in a universe where the standards for publication of mathematical theorems are quite different: papers present theorems without proofs, and readers are expected to simply believe the author when it is stated that the theorem has been proved.*