CS 3220: Introduction to Scientific Computing

Steve Marschner
Spring 2010

scientific computing: The use of computers to solve problems that arise in science (and engineering, medicine, …).

numerical methods: Algorithms (methods) for solving problems with real numbers by numerical (as opposed to symbolic) means.

If your variables represent real-valued quantities, you're doing numerical computing. Perhaps surprising are:

- audio (stream of sound pressure samples)
- video (grids of intensity or color samples)
- computational geometry (positions in space)
- computer graphics and vision (geometry, color, light…)
- information retrieval (more on this in a moment)

with abundant computing power, more applications are using numerical methods all the time.

Numerical computing in science and medicine

Computed tomography: seeing into the body

X-ray crystallography: learning the shape of proteins

Climatology: predicting global warming

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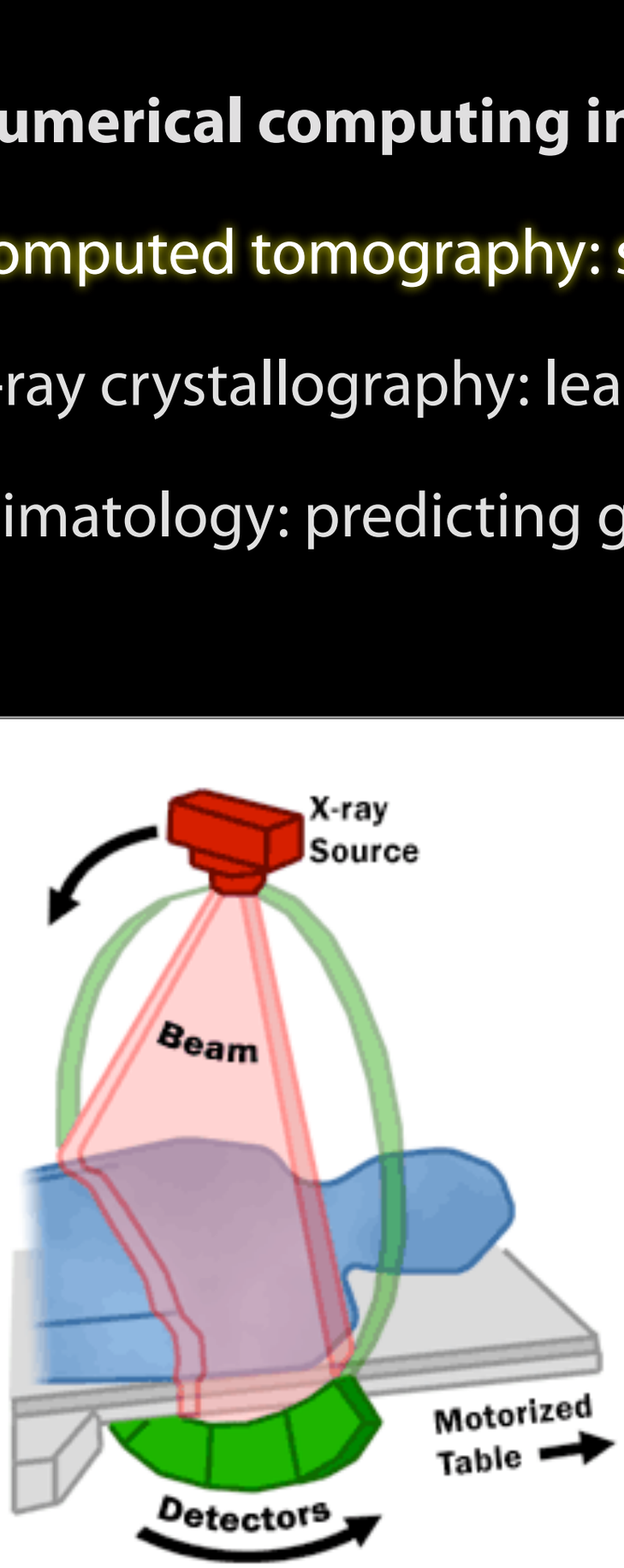

U.S. FDA

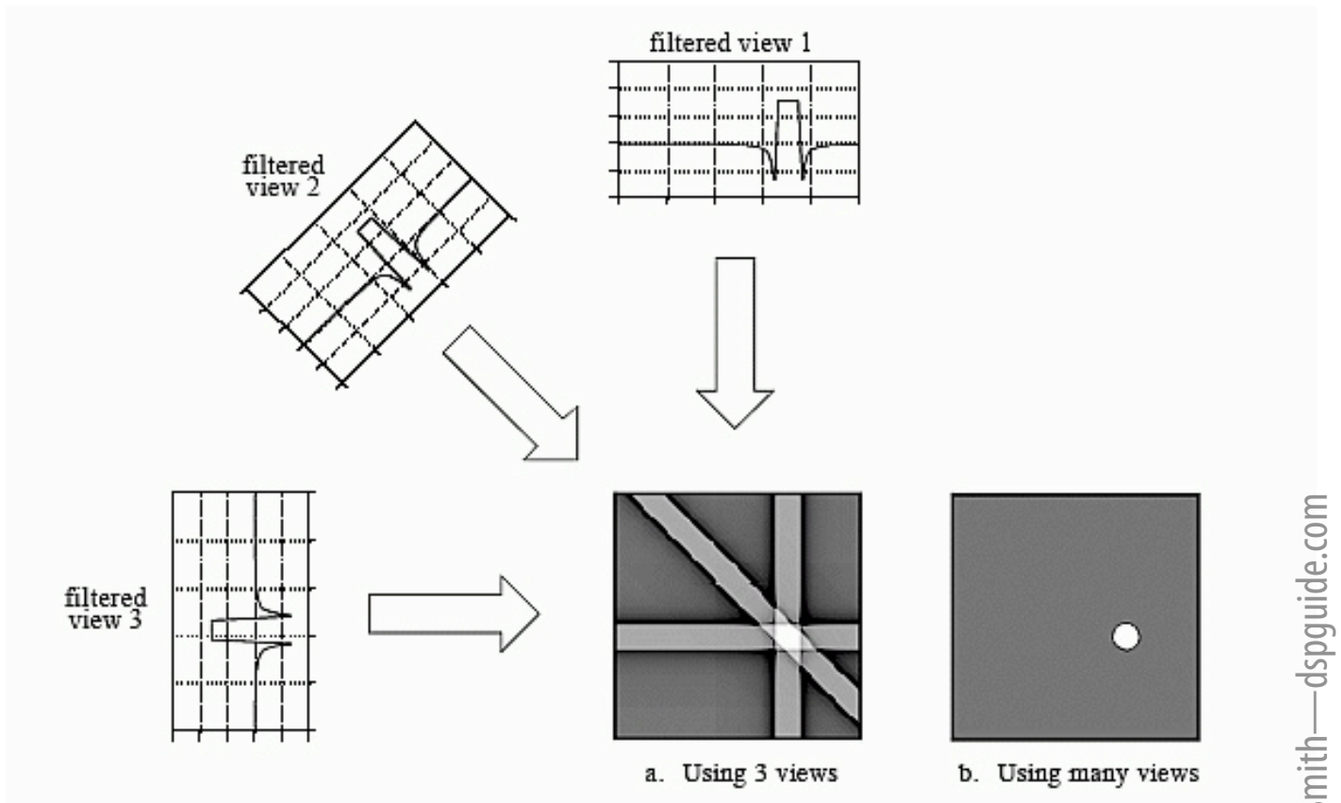

FIGURE 25-17
Filtered backprojection. Filtered backprojection reconstructs an image by filtering each view before backprojection. This removes the blurring seen in simple backprojection, and results in a mathematically exact reconstruction of the image. Filtered backprojection is the most commonly used algorithm for computed tomography systems.

Steven W. Smith—dspguide.com

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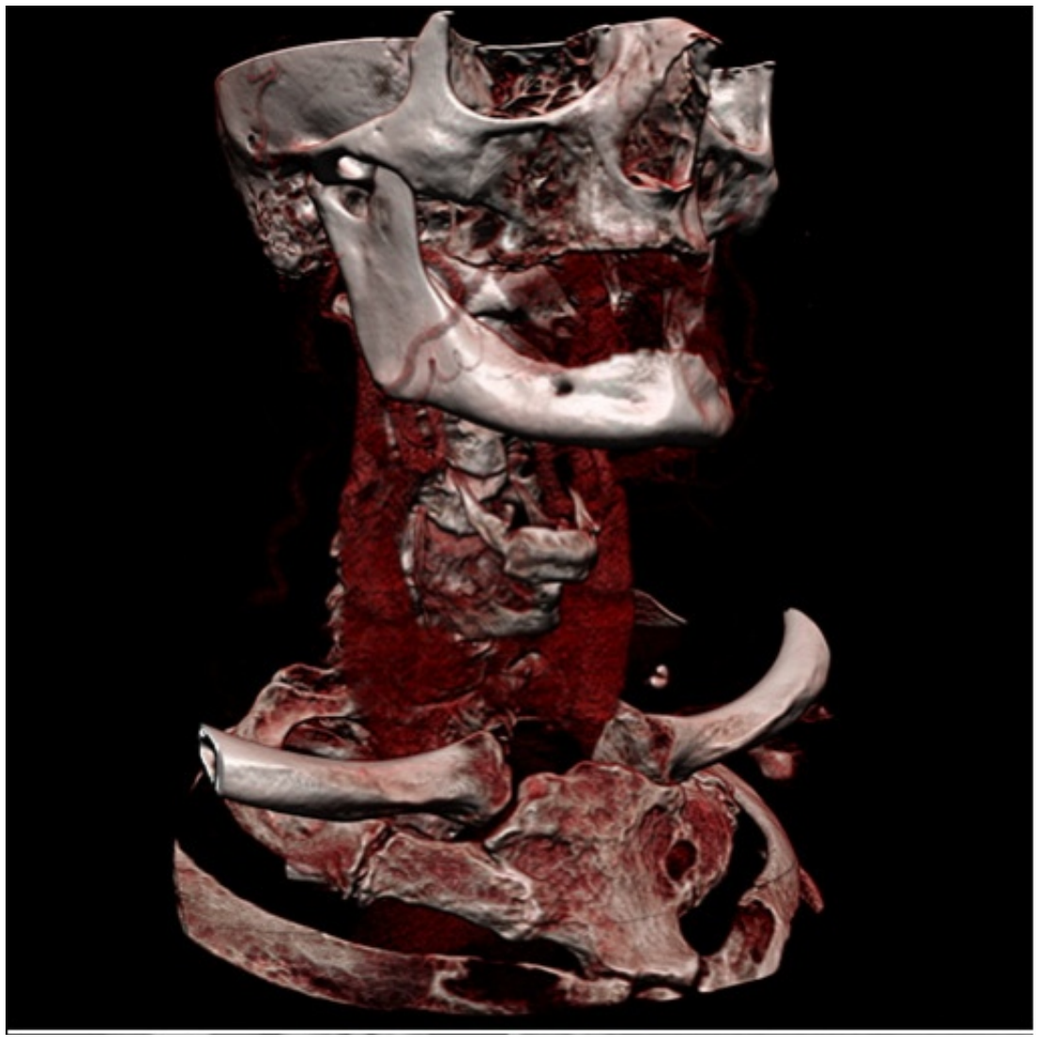

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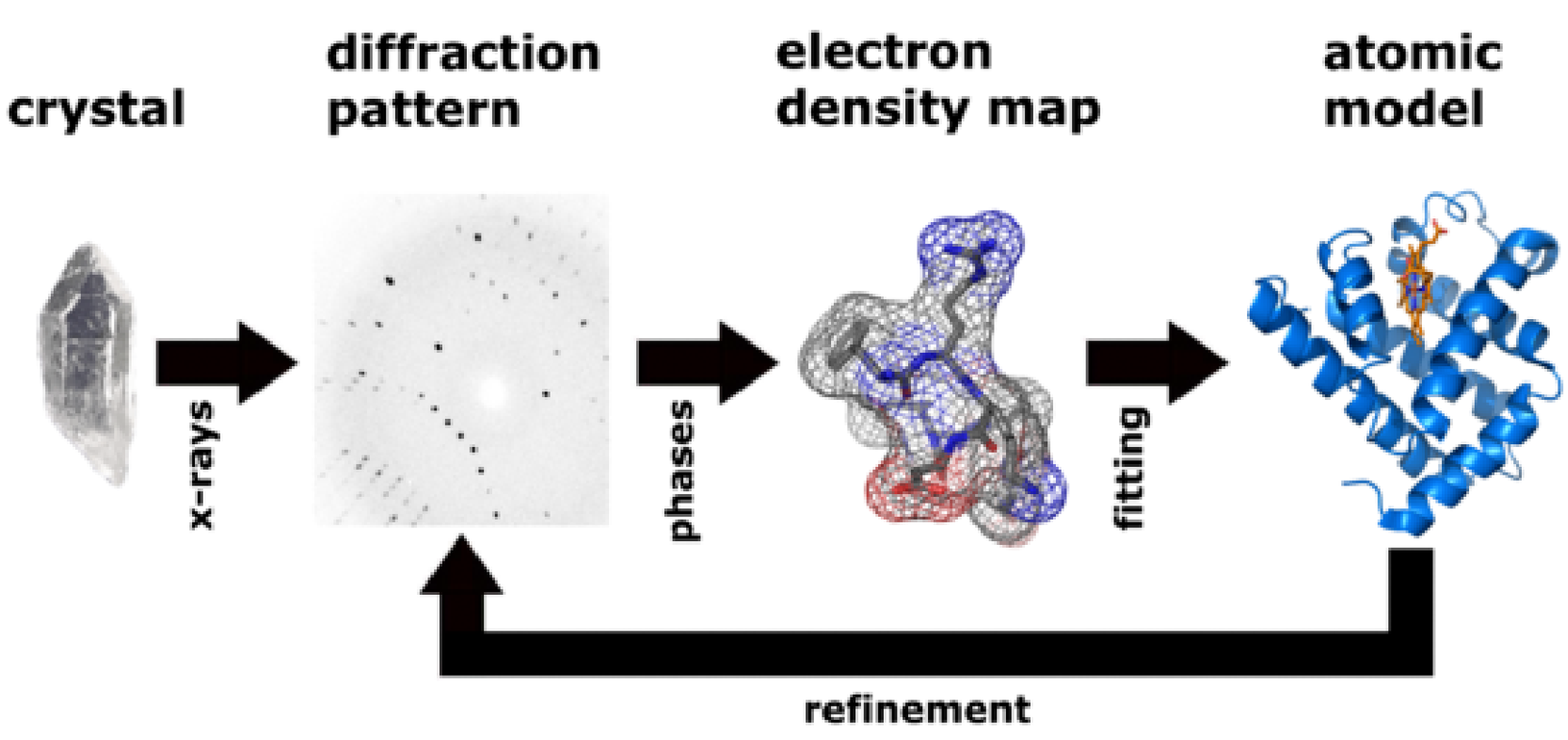

Thomas Splettstoesser—Wikimedia Commons

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Simulated deformation of citrate synthase during substrate binding

Kalju Kahn, UCSB

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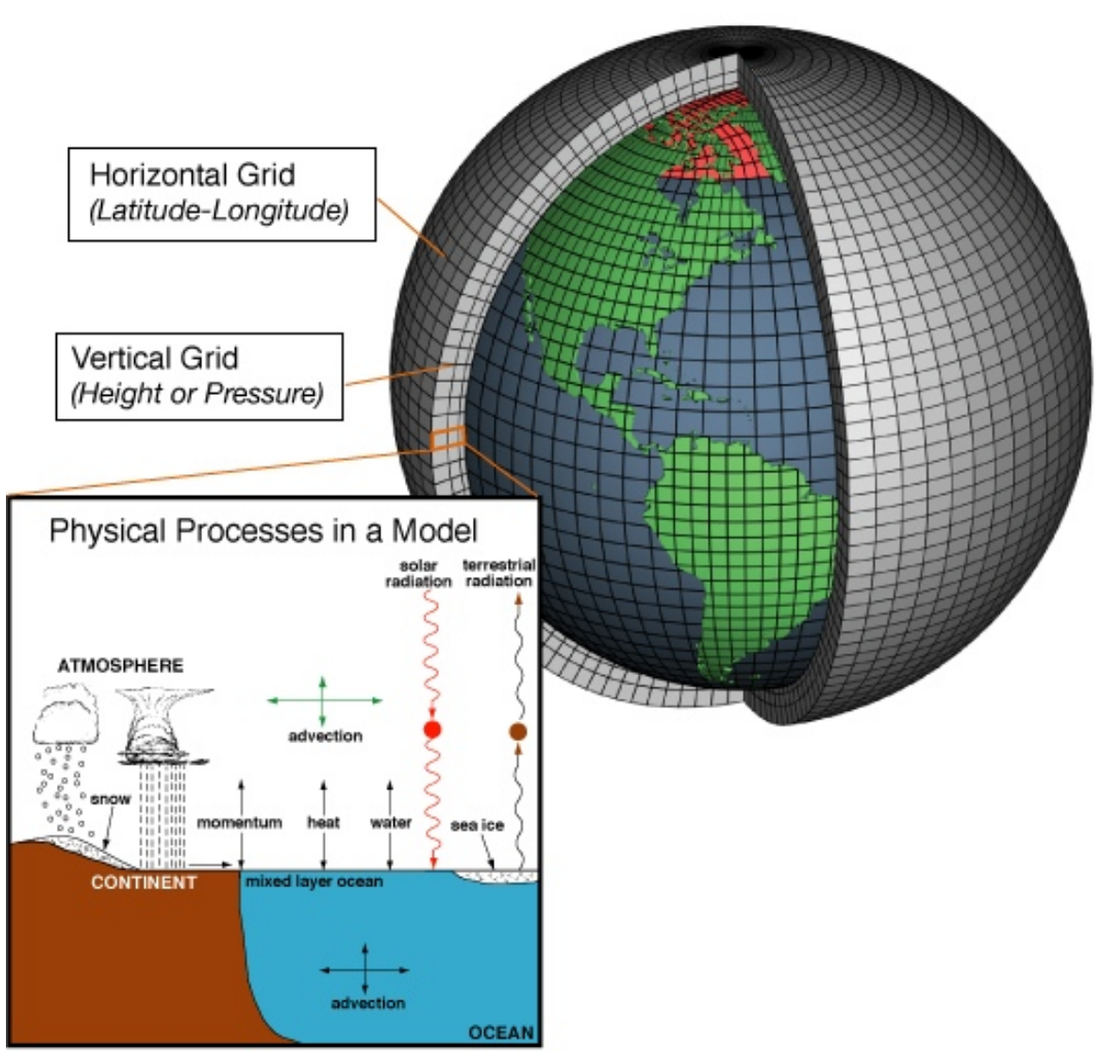

NOAA

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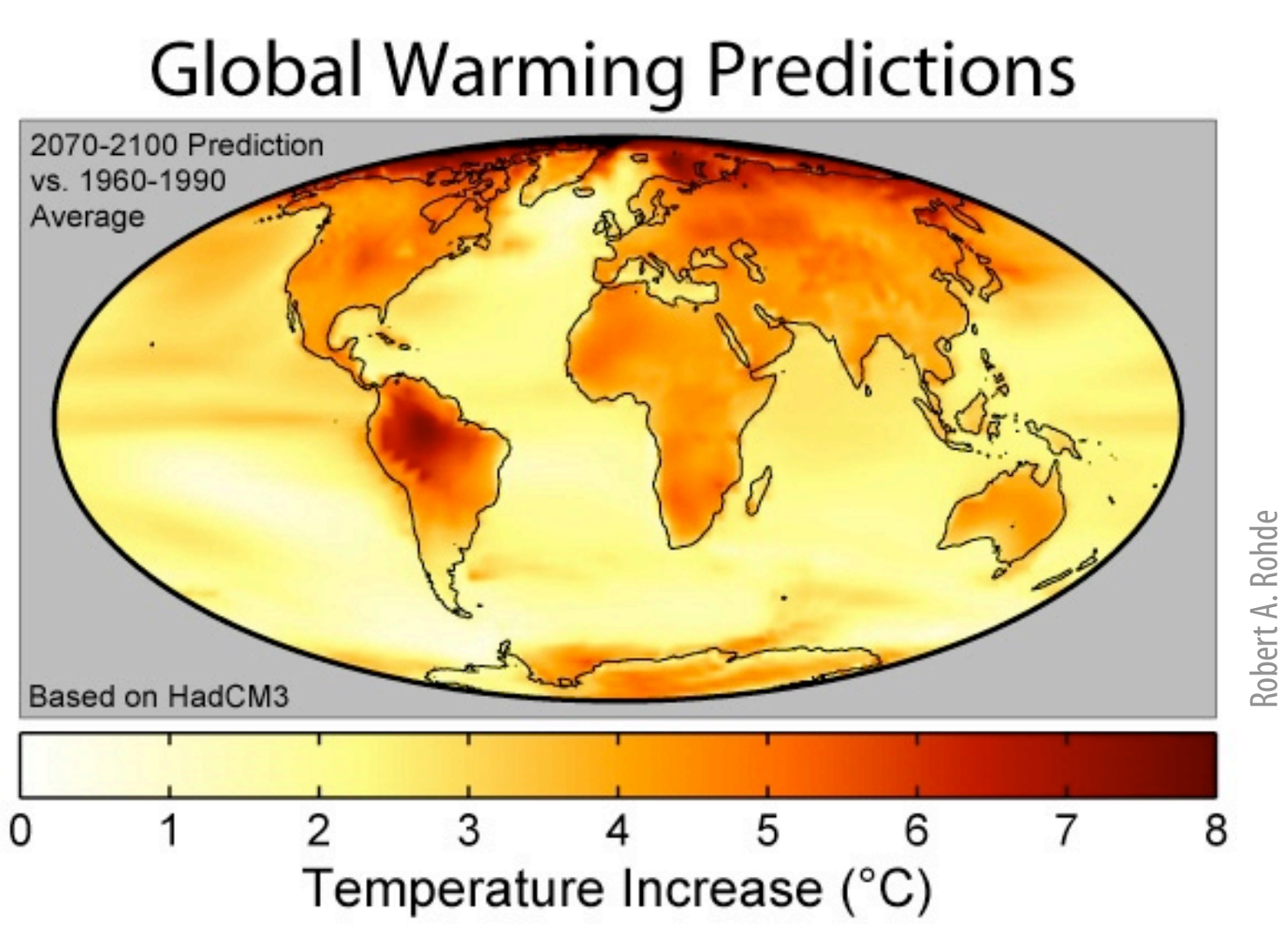

Numerical computing in automotive engineering

Safe cars: electronic stability control

Autonomous vehicles: path planning

Numerical computing in automotive engineering

Safe cars: electronic stability control

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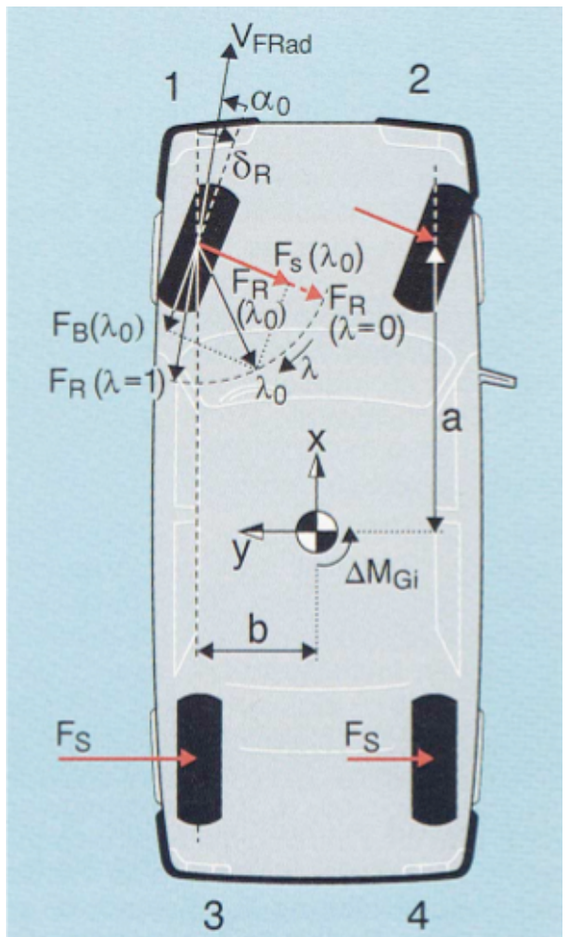
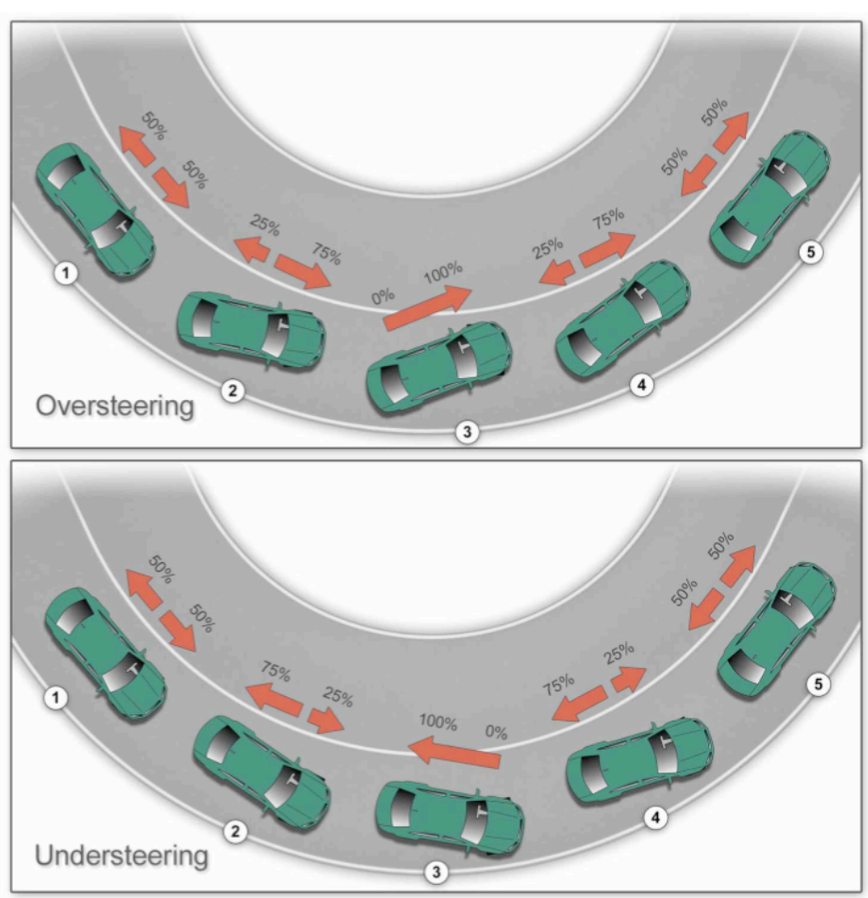
images from:
Liebemann et al. "Safety and Performance Enhancement: The Bosch Electronic Stability Control (ESP)" in *The 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV)*





Yaw rate control at work

Fifth Gear—demo of Bosch ESP system

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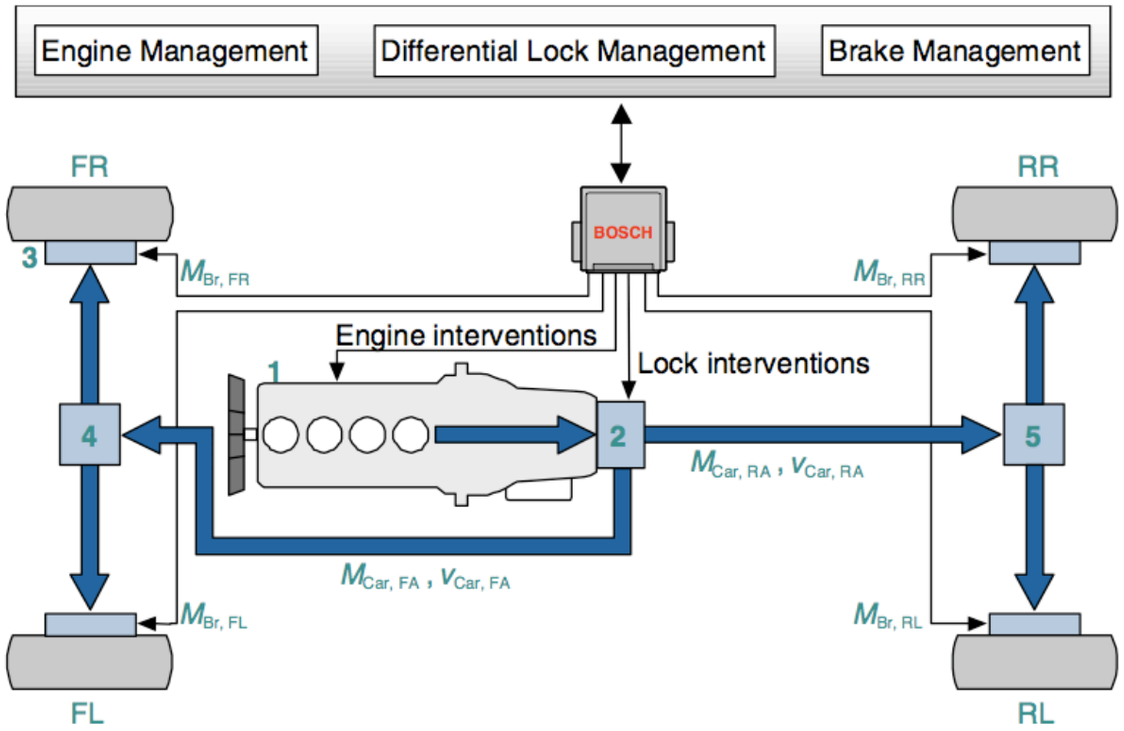
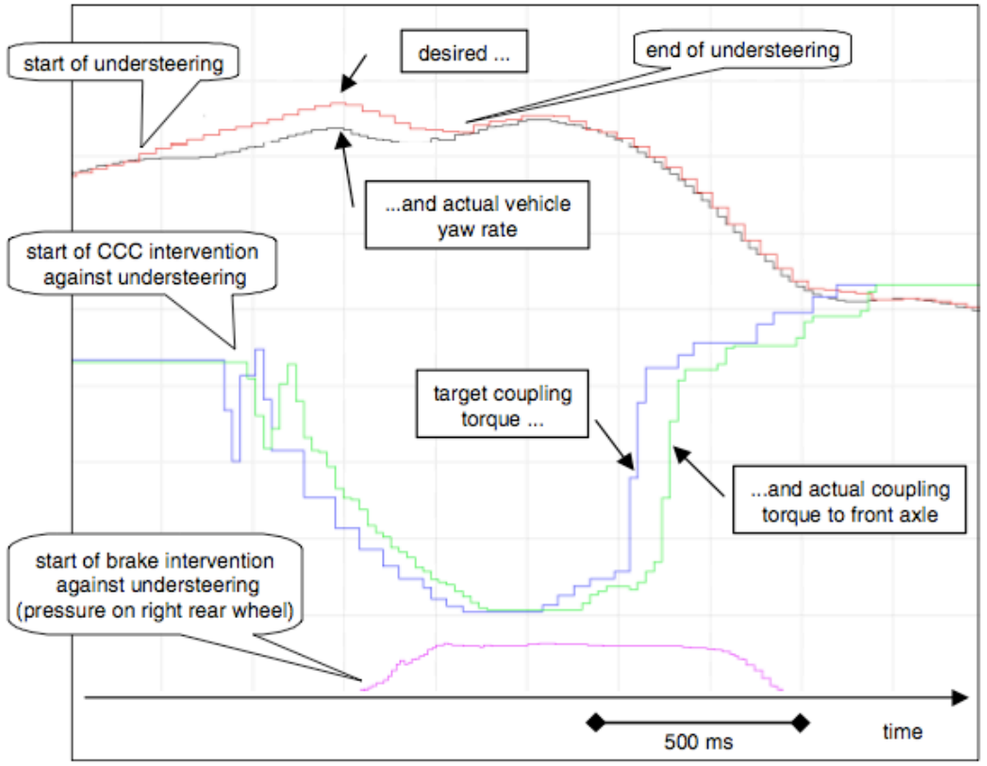


Liebemann et al.



Liebemann et al.

Yaw rate control by braking

Fifth Gear—demo of Bosch ESP system

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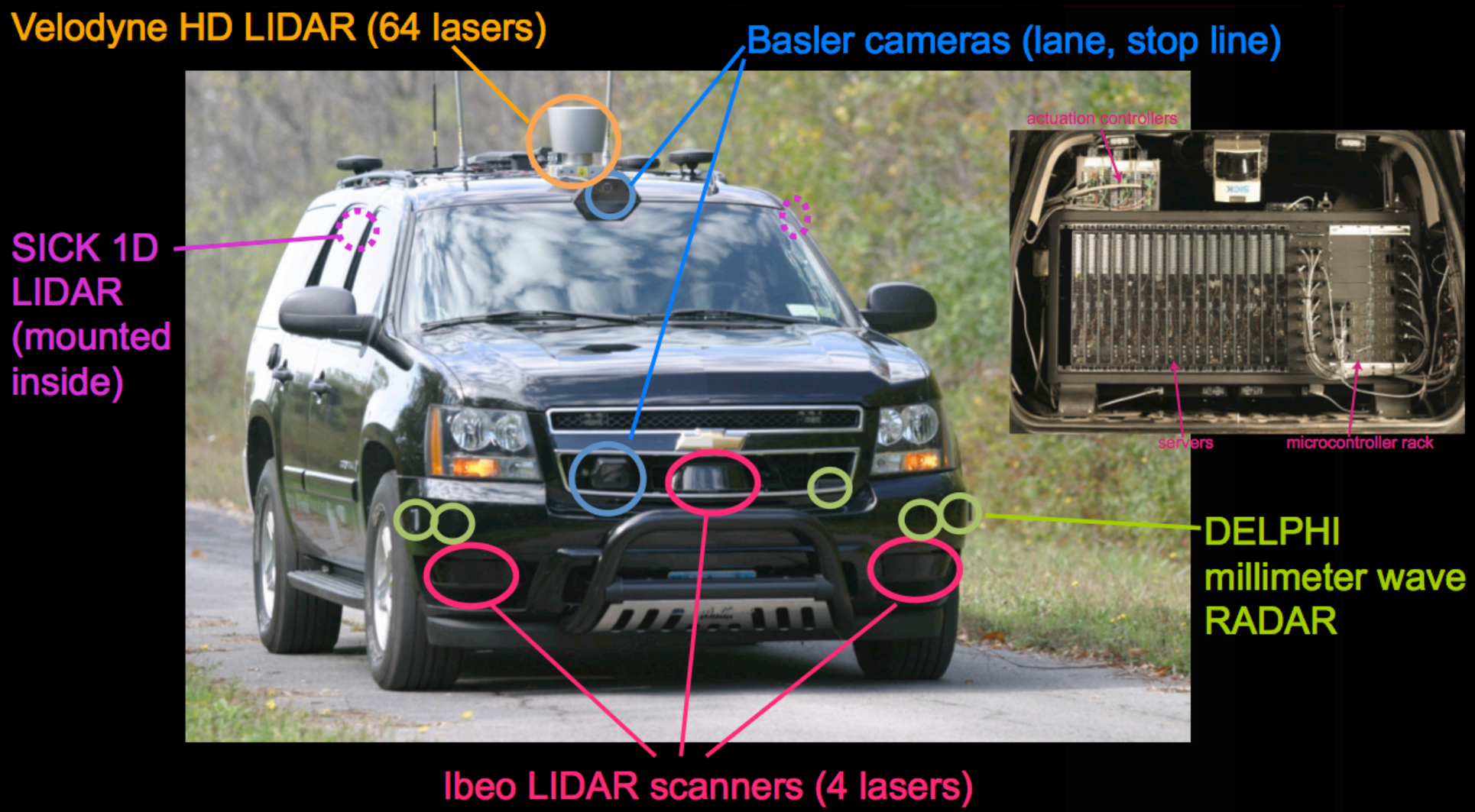

Mark Campbell—Cornell DARPA Urban Challenge team

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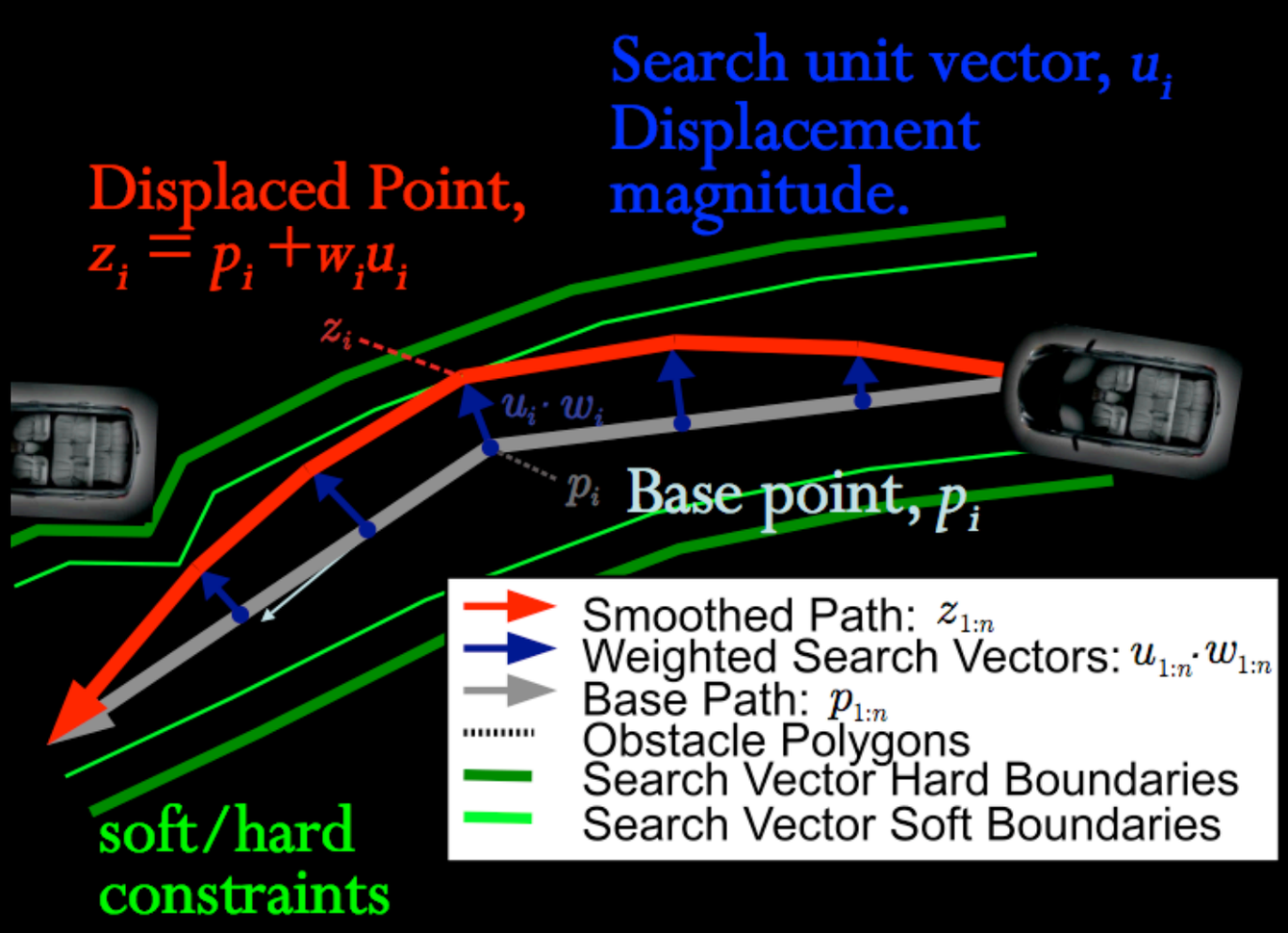
Autonomous vehicles: path planning



Individual costs:
- path curvature
- distance from base
- obstacle spacing

tuning weights

$$J(w_i) = \sum_j \alpha_j J_j$$

$$c(x) = 0$$

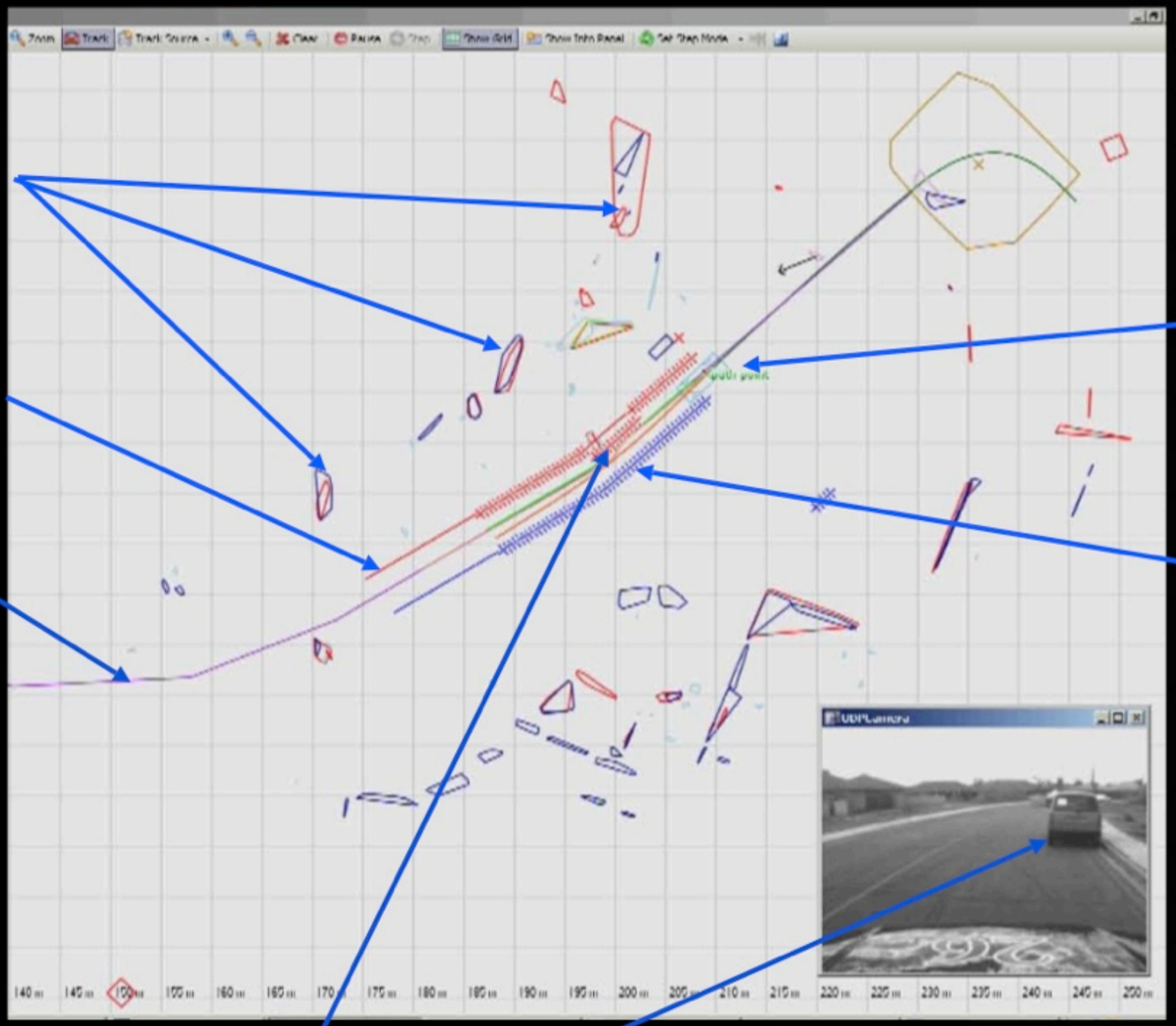
Constraints:
- lane width
- obstacle spacing

Mark Campbell—Cornell DARPA Urban Challenge team

convex hulls of obstacles

lane boundaries

RNDF (map)

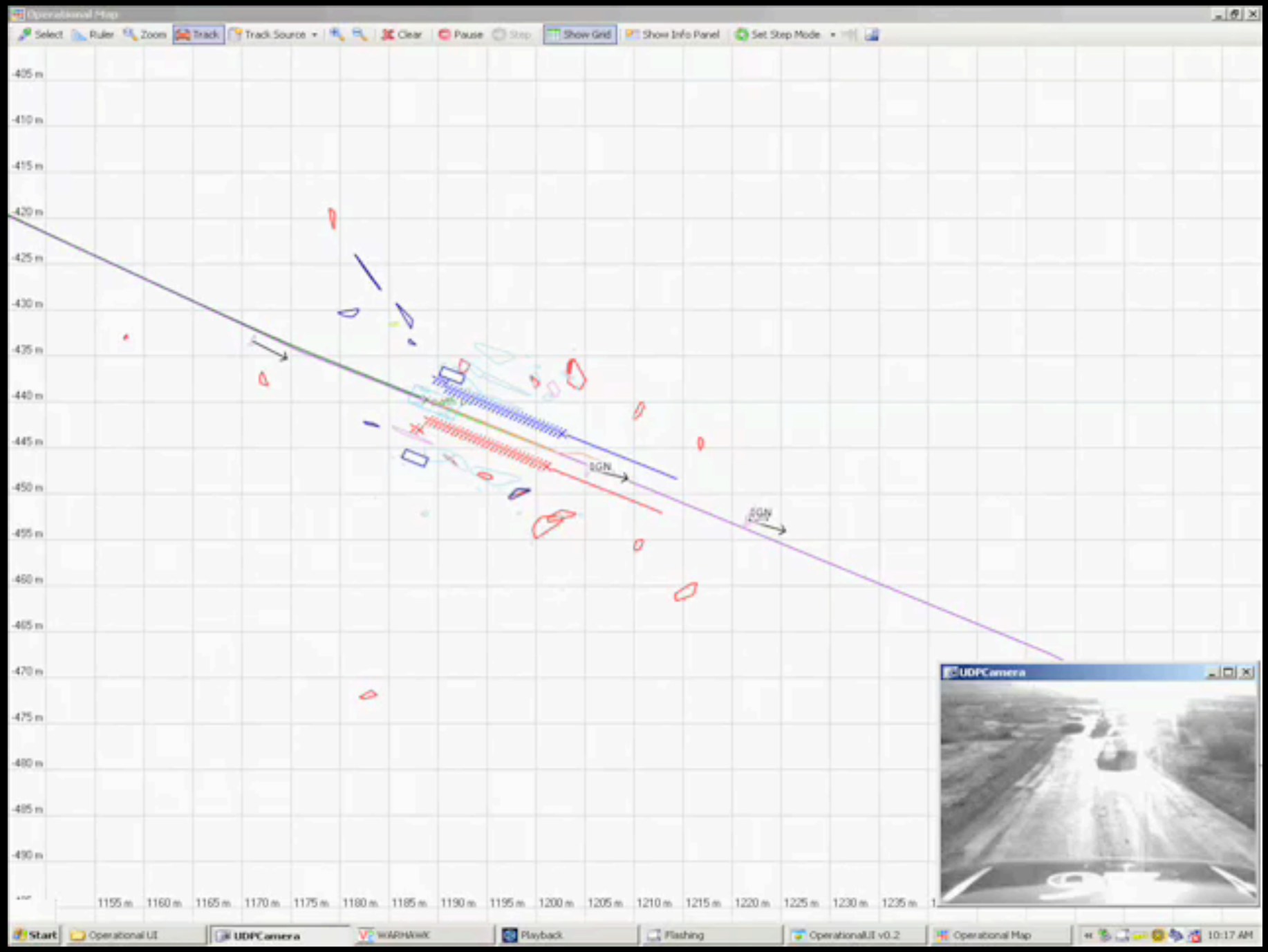


Ego-vehicle

planner constraints

constraints around parked car

Mark Campbell—Cornell DARPA Urban Challenge team



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Numerical computing in entertainment

Game physics: new kinds of gameplay

Movie graphics: realistic lighting

Movie vision: camera tracking, or “matchmove”

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Crytek GmBH—advertisement for CryEngine 2 game engine

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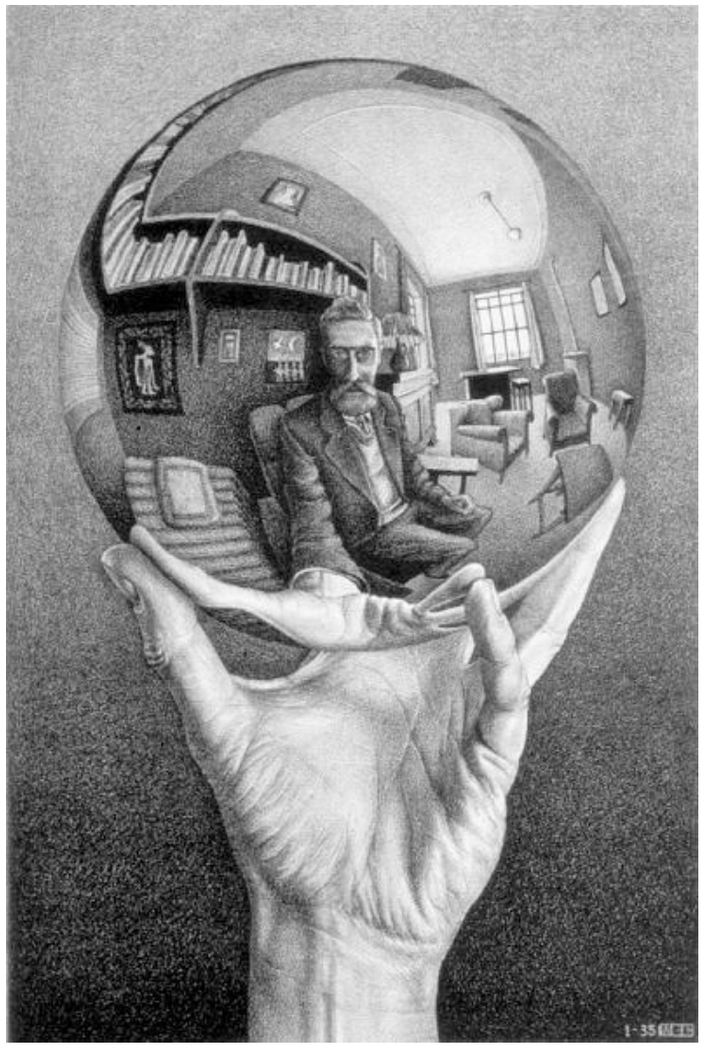

Hand with Reflecting Sphere. M. C. Escher, 1935. lithograph

Gene Miller & Ken Perlin, 1982

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Game physics: new kinds of gameplay

Movie graphics: realistic lighting

Movie vision: camera tracking, or "matchmove"

Real environment, computed objects

Jonas Unger

KING KONG
© 2005 Universal Studios. Used With Permission.

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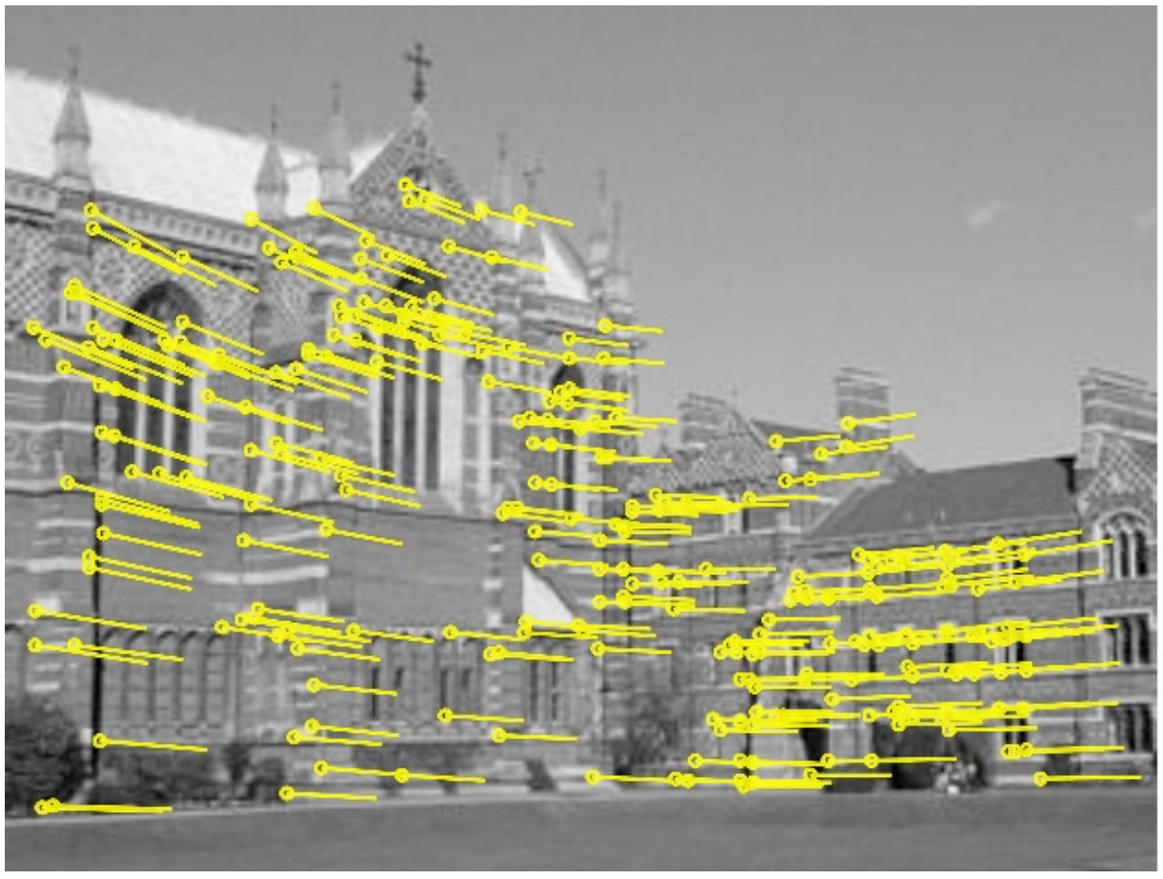
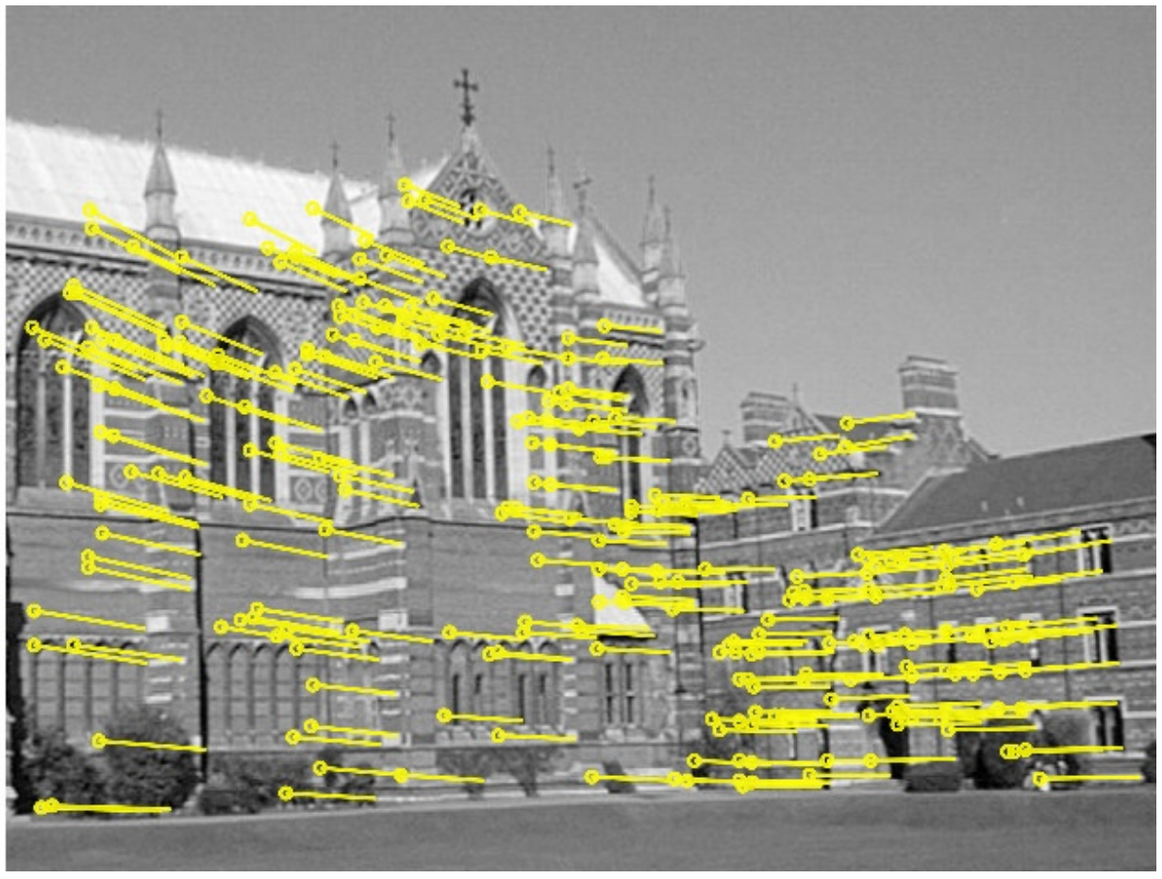




Torr & Zisserman, in *Vision Algorithms: Theory and Practice*, 2000

Rendered model added

Camera footage

Scenespector Systems—VooCAT product demo
Zaha Hadid Architects—proposed Guggenheim Vilnius museum

Numerical computing in "non-numerical" applications

Information retrieval: Google's PageRank

Numerical computing in "non-numerical" applications

Information retrieval: Google's PageRank

Idea 1: **importance = citation count** — simple integer exact answer

Idea 2: **importance = citation count weighted by importance** — now it is a self-referencing definition for a real-valued quantity (and it must be approximated numerically)

Computing PageRank works out to be a linear algebra problem: finding the largest eigenvalue of a matrix.

Problem taxonomy

linear or nonlinear?

how many unknowns?

what kind of equations?

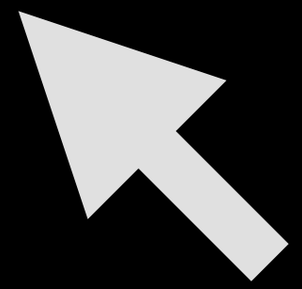
LINEAR

	solve	minimize	diff. eq.
1-D	(arithmetic)	(projection)	linear ODEs
n-D	linear systems	linear least squares	linear PDEs

NONLINEAR

	solve	minimize	diff. eq.
1-D	root finding	minimum searching	ODEs
n-D	nonlinear equations	optimization	PDEs

It's all about converting hard problems to easier ones.



go that way!

Method characteristics

accuracy

stability

robustness

“Never in the history of mankind has it been possible to produce so many wrong answers so quickly!”

—Carl-Erik Fröberg

prerequisites

calculus, linear algebra

some programming experience

Matlab

CS1132: Transition to Matlab
A one-credit course for students who know another language (e.g. Java) and need to map the ideas over to Matlab.

Informational meetings:

Tuesday (1/26) 3:35 Phillips 219
Thursday (1/28) 4:40 Thurston 205

course mechanics

http://www.cs.cornell.edu/Courses/cs3220