“Digital Twins of Physical Reality”

Future in Review

FireSide Remote Presentation

May 27, 2021

Dr. Larry Smarr

Director, California Institute for Telecommunications and Information Technology

Harry E. Gruber Professor,

Dept. of Computer Science and Engineering

Jacobs School of Engineering, UCSD

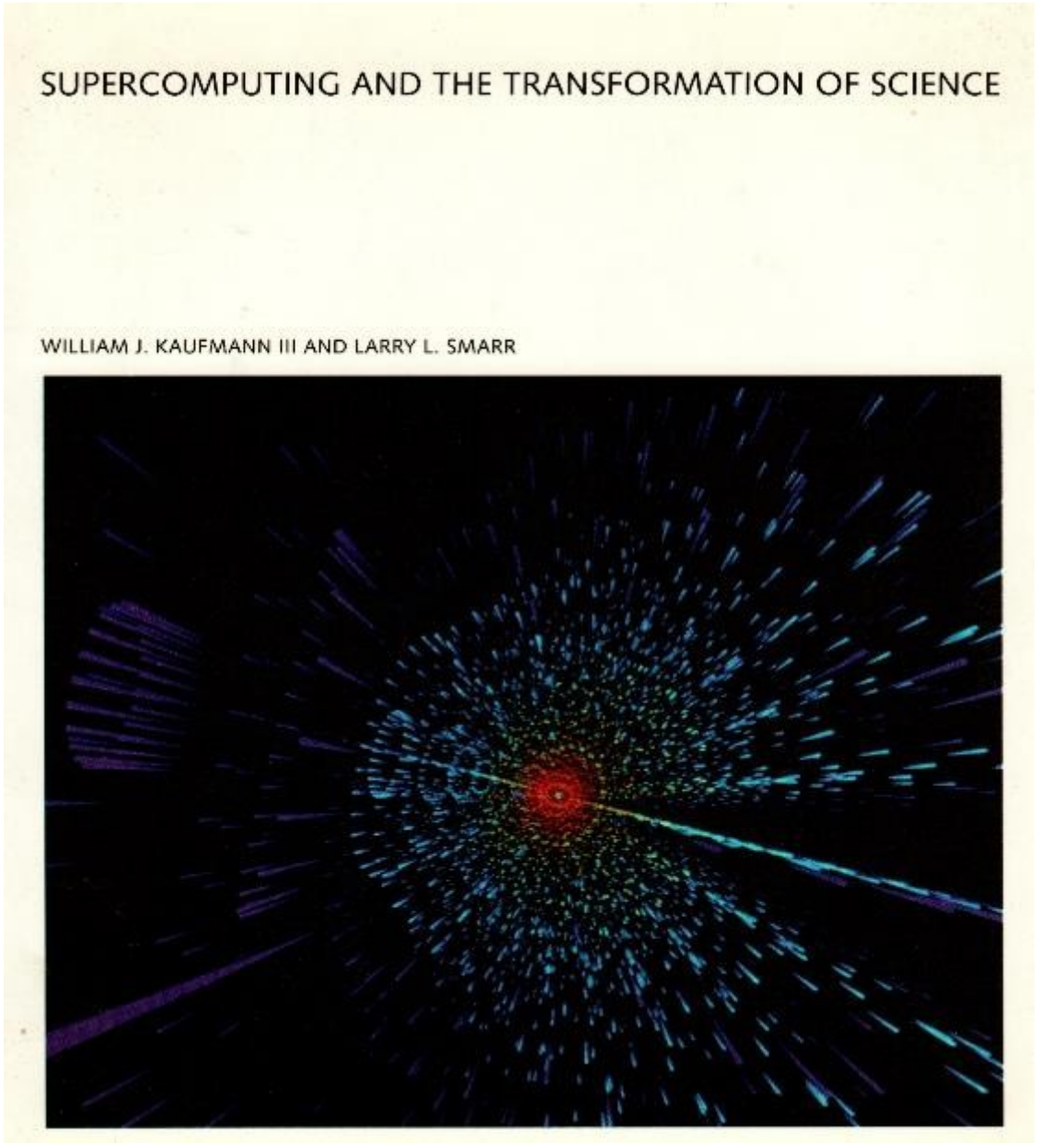
http://lsmarr.calit2.net

Supercomputers Enabled Solution of the Laws of Physics to Create the First “Mirror Worlds” of Physical Systems



National Center for Supercomputing Applications (NCSA)
1986 Cray XMP2/4

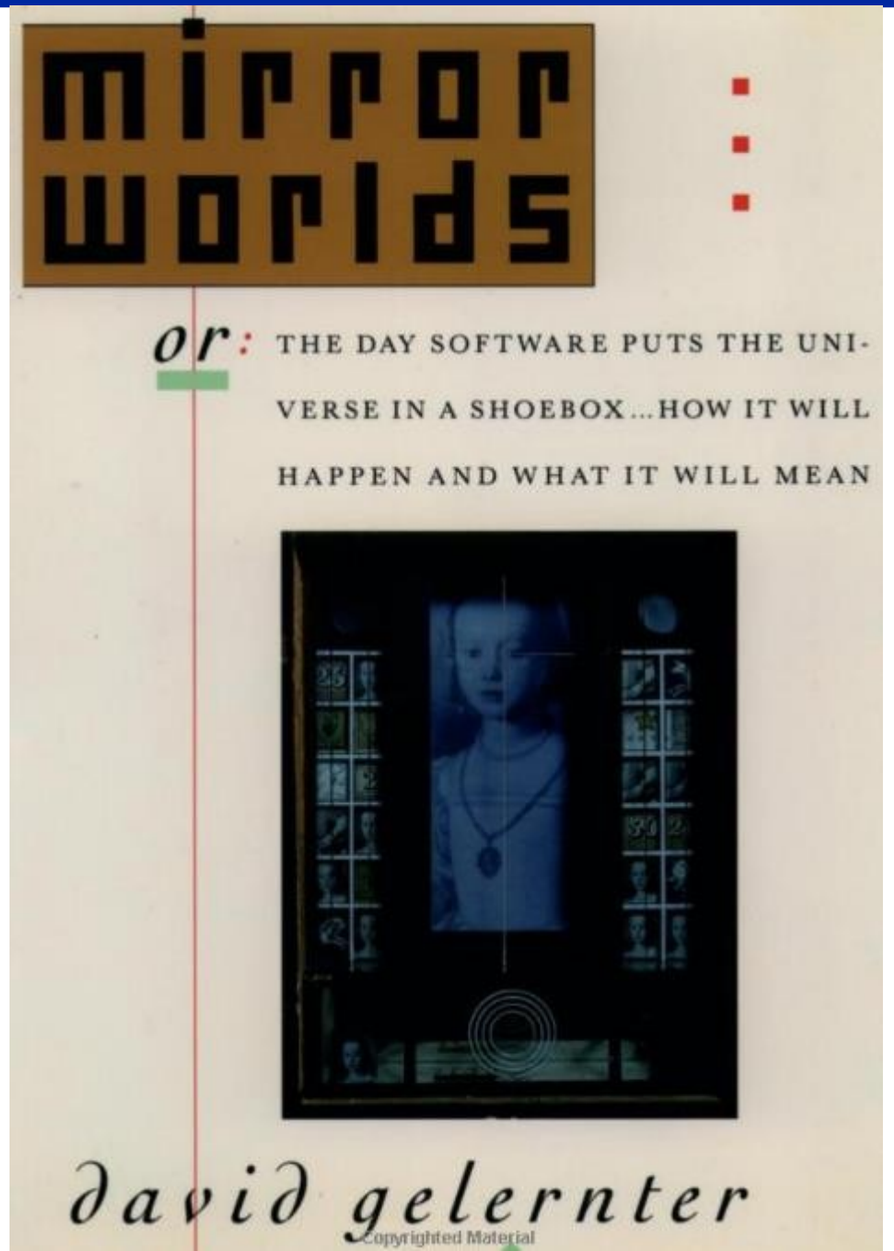
Today’s iPhone is 200x Faster!



W H Freeman & Co (1993)

In 1992 Computer Scientist David Gelernter Published a General Theory of Mirror Worlds

Our Current Era is Experiencing an Unrelenting Exponential Increase of Data Creation From A Wide Range of "Chunks of Reality"



"Mirror Worlds are software models of some chunk of reality...

Oceans of information pour endlessly into the model…

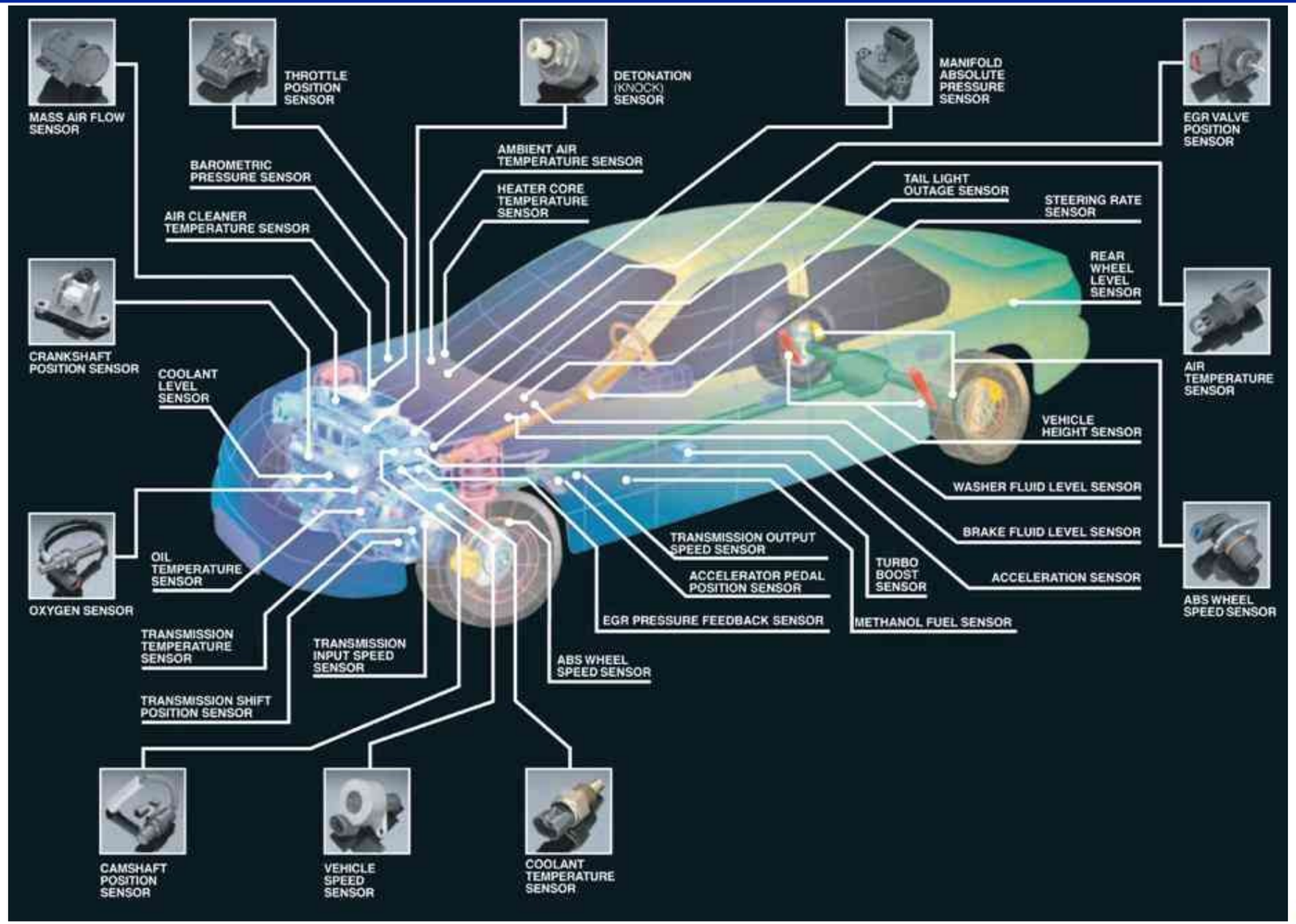
So much information that the model can mimic the reality's every move, moment-by-moment."

Modern Cars Have Massive Sensor Arrays Which Record Time Series Enabling Computer Diagnostics For Early Warning

From Mirror Worlds To Digital Twins

Before the computer diagnostics technology, most car owners did not know something was wrong with the engine until something drastic happened, such as overheating or running out of gas.

www.thepeoplehistory.com/carelectronics.html



http://blog.asautoparts.com/5-common-symptoms-of-faulty-car-sensors/

The Transition from Car “Sickcare” to Car “Healthcare” Was Enabled by Pattern Recognition Using Big Data Analytics

BMW Using IBM Predictive Analytics in Auto Production, Repairs

By Darryl K. Taft | Posted 2014-03-12 Print

eWEEK®

**“… using IBM big data and analytics technology,
all available data sources can be analyzed
to discover patterns and anomalies
to predict and anticipate maintenance needs.**

Digital Twins of Manufactured Products Are Becoming the New Normal for Large Companies

www.ibm.com/internet-of-things/trending/digital-twin

"A digital twin is a virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning."

IBM

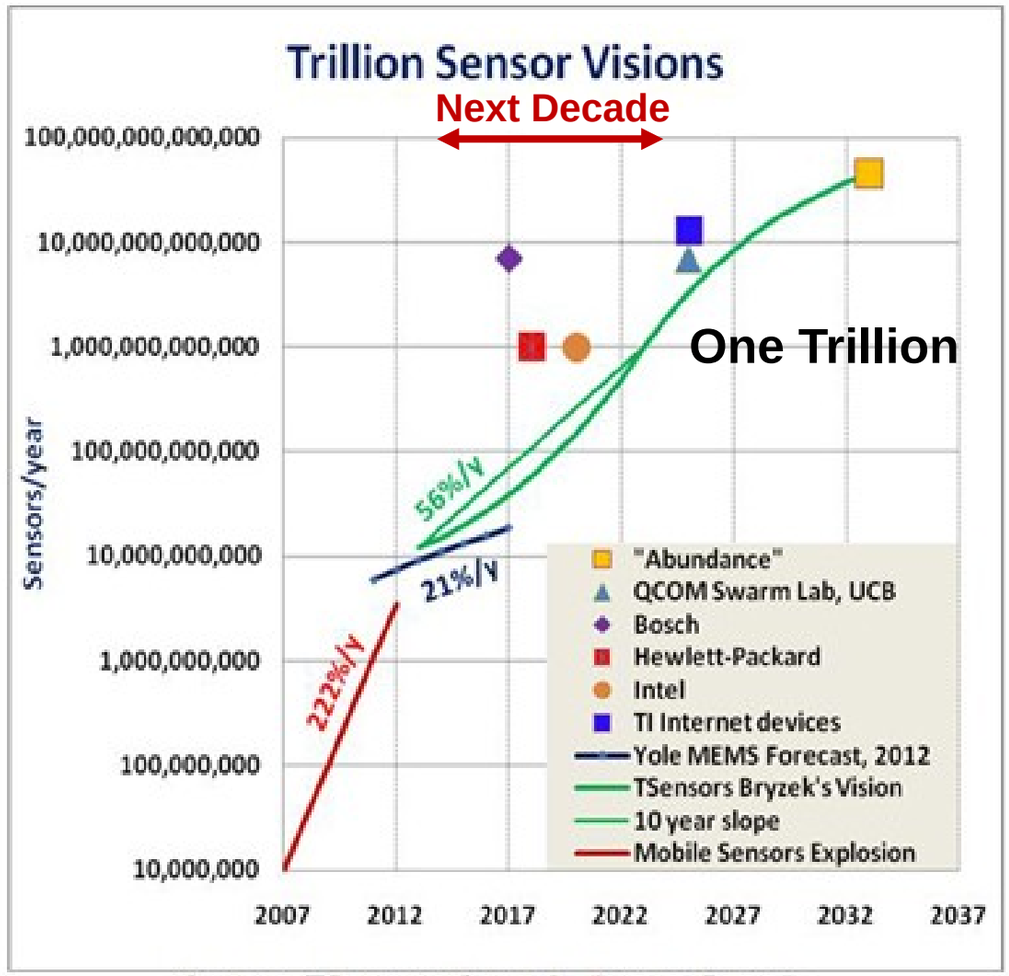
"The whole Tesla fleet operates as a network. When one car learns something, they all learn it. Each driver using the autopilot system becomes an expert trainer for how the autopilot should work."
-Elon Musk, CEO Tesla



https://fortune.com/2015/10/16/how-tesla-autopilot-learns/

The Planetary Computer, Computing Digital Twins of Manufactured Objects, Fed by a Trillion Sensors, Will Drive a Global Industrial Internet

T SENSORS SUMMIT™ FOR TRILLION SENSOR ROADMAP



Source: TSensors Summit, Janusz Bryzek



www.tsensorssummit.org

"Within the next 20 years the Industrial Internet will have added to the global economy an additional $15 trillion."
--General Electric

www.ge.com/docs/chapters/Industrial_Internet.pdf

www-bsac.eecs.berkeley.edu/frontpagefiles/BSACGrowingMEMS_Markets_%20SEMI.ORG.html

The Industrial Internet's Digital Twins Are Essential for Optimal Performance of Complex Machines



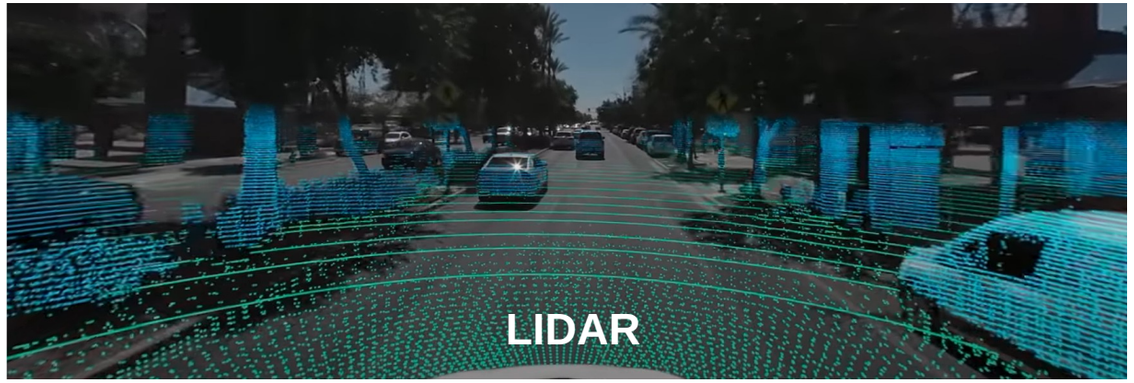
Each of General Electric's 22,000 wind turbines is continually streaming operational data to the cloud, where GE analysts can tweak the direction & pitch of the blades to ensure as much energy is being captured as possible.

Intelligent learning algorithms allow each individual turbine to adapt its behavior to mimic other nearby turbines that are operating more efficiently.

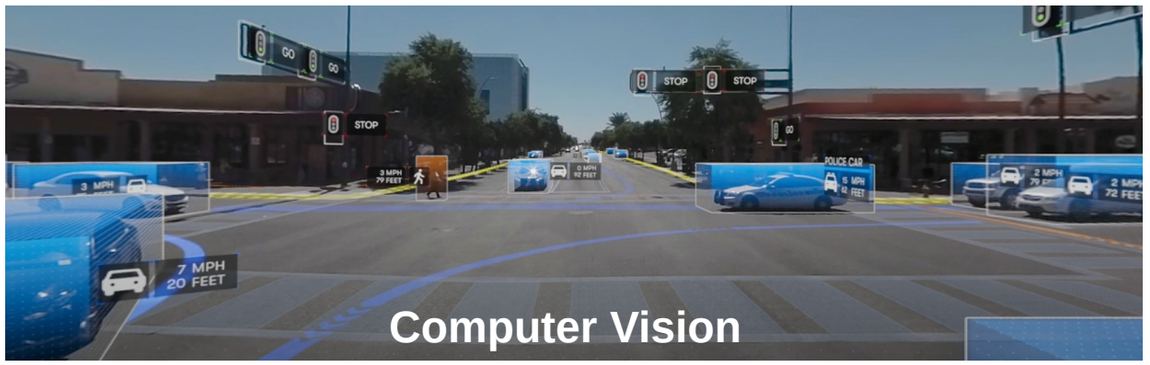
Each turbine generates around 500 Gigabytes of data a day. Forbes

Alphabet's Waymo
Using Sensor Fusion to Create a Digital Twin World and Drive Through It

https://waymo.com/360experience/

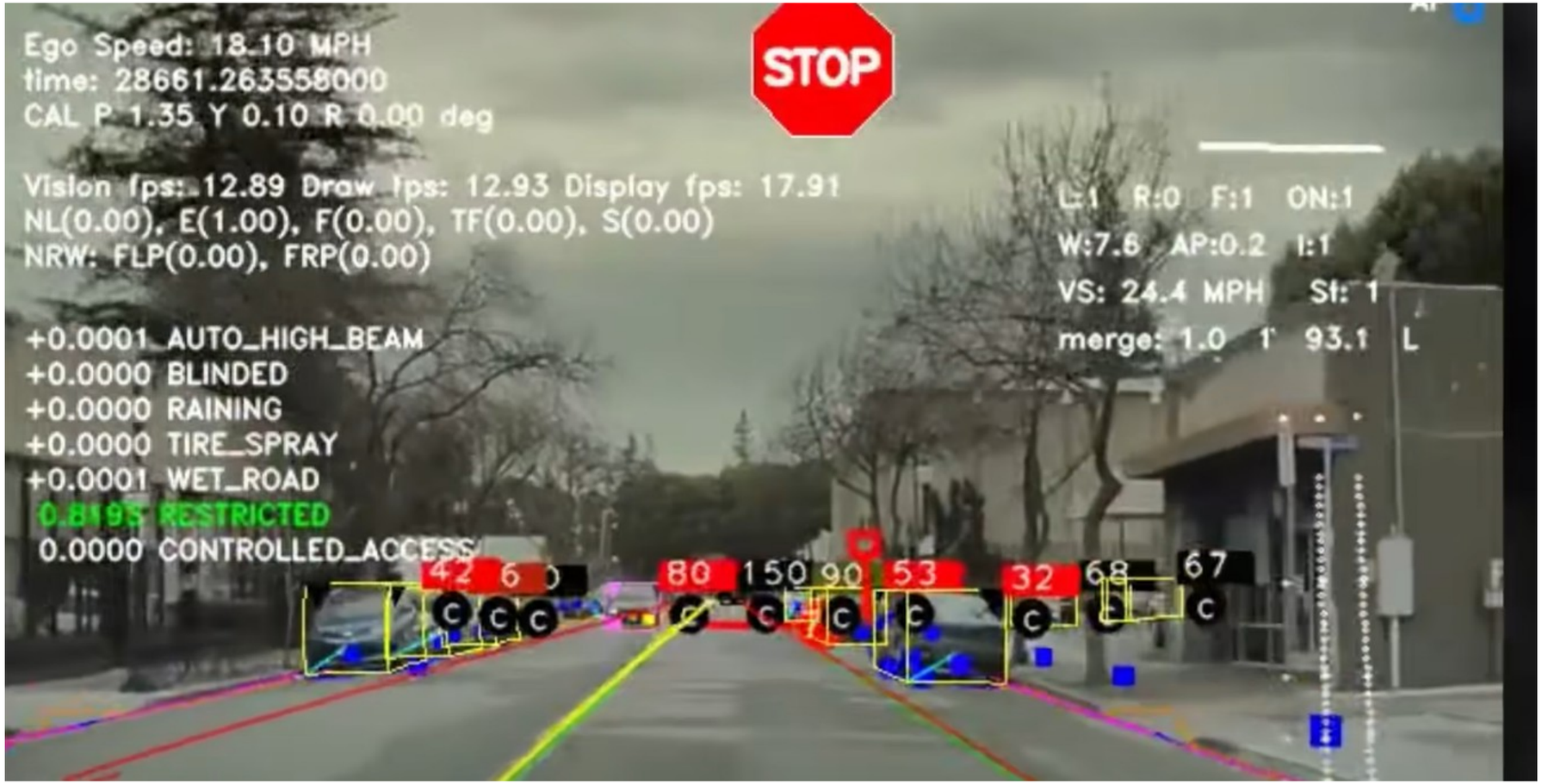






Tesla Using Human’s to Label Reality

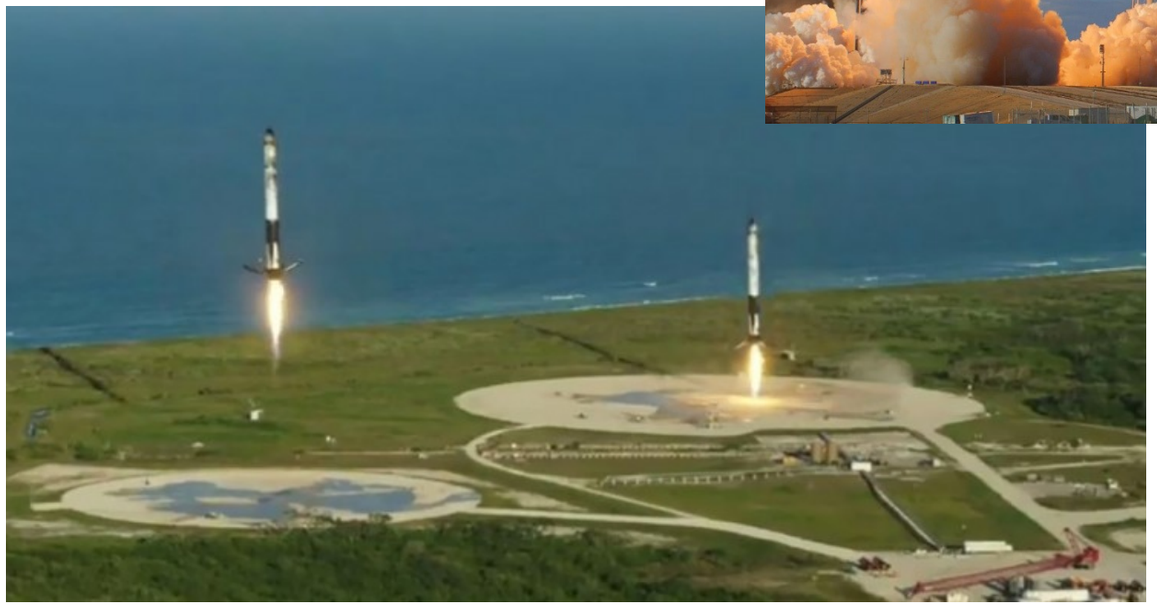
- Supervised Autonomous Driving
- Goal: Collecting Data at 1 Billion Intersections Per Month
- Camera Computer Vision
- Fleet Learning



Digital Twins Is What Allows SpaceX to Have Just Had the 100th Straight Falcon Launch

And 85th Straight Successful Booster Recovery

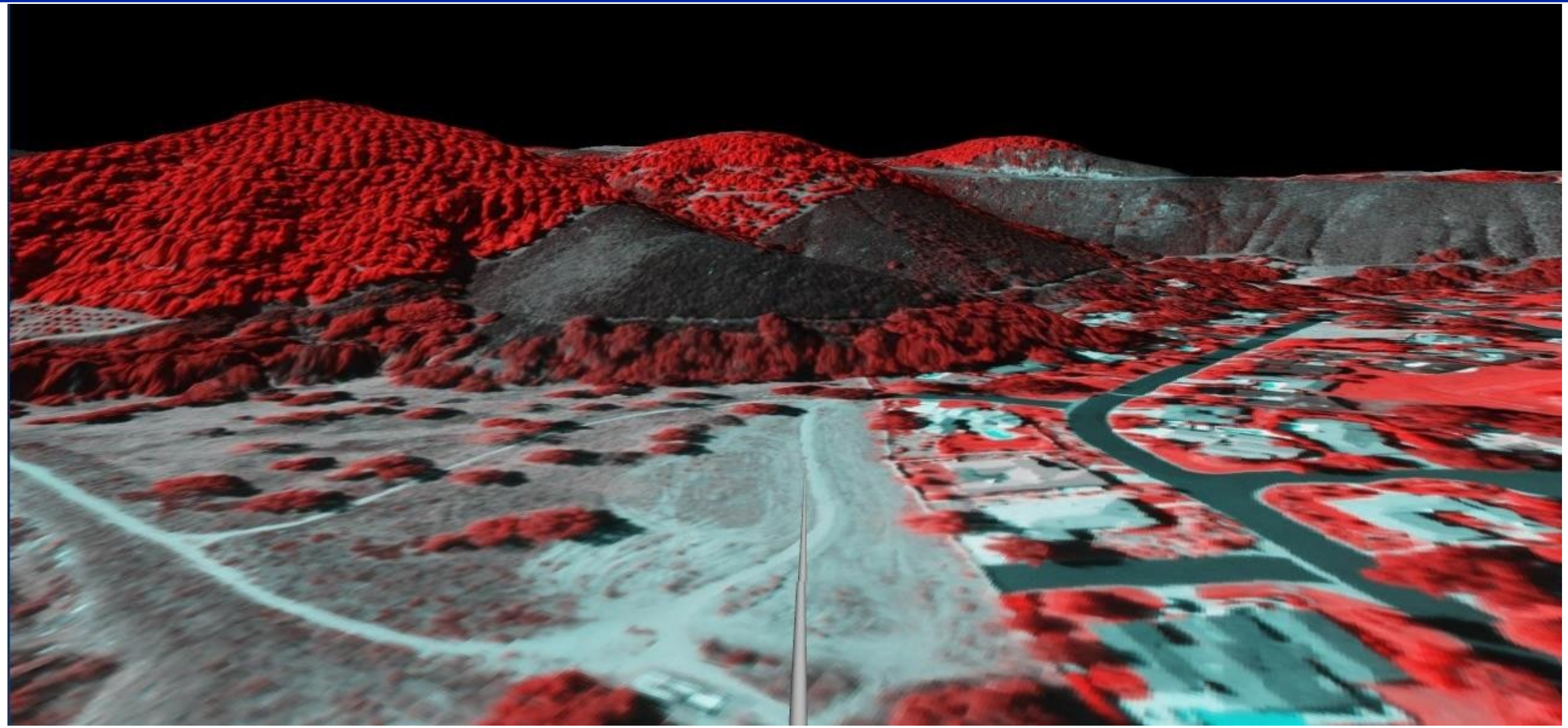






Successful Falcon Heavy Central Core and Two Side Boosters Recovery
April 11, 2019

Calit2 Has Created a Digital "Digital Twin" of San Diego County



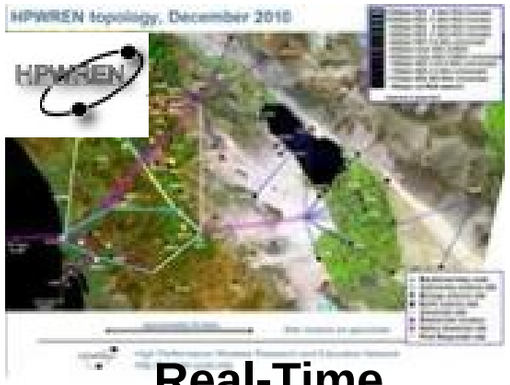
0.5 meter Image Resolution
2 meter Elevation Resolution

Interactive Virtual Reality Viewing of San Diego County “Digital Twin” Includes Live Feeds From 200 Meteorological Stations



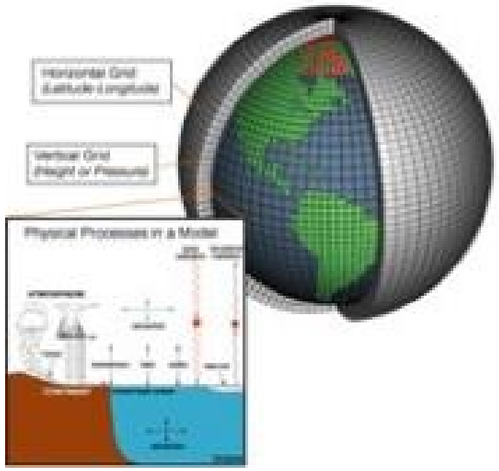
Jessica Block at Calit2’s Qualcomm Institute

Supercomputers Use Satellite & Weather Sensors to Feed a “Digital Twin” of Wildfire Evolution



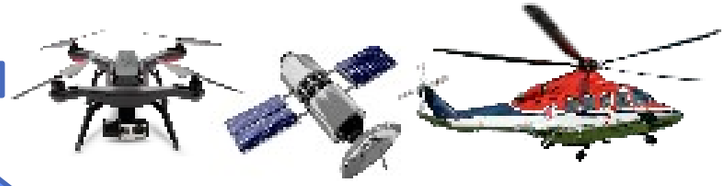
Real-Time Meteorological Sensors

Weather Forecast

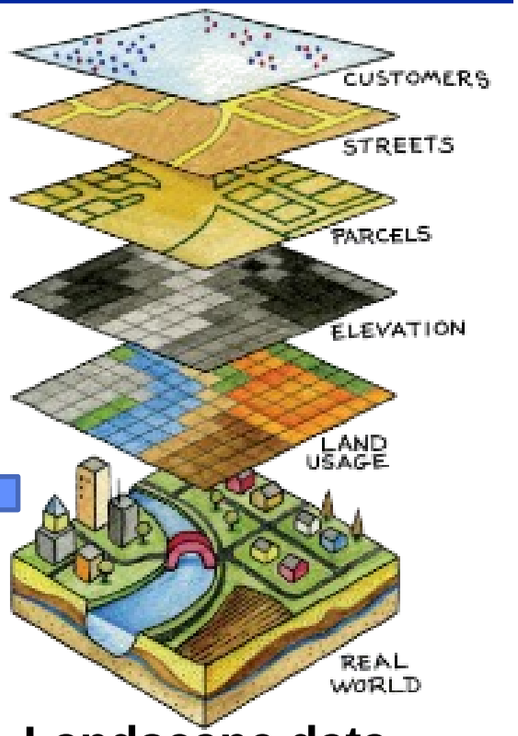




Source: Ilkay Altintas, SDSC



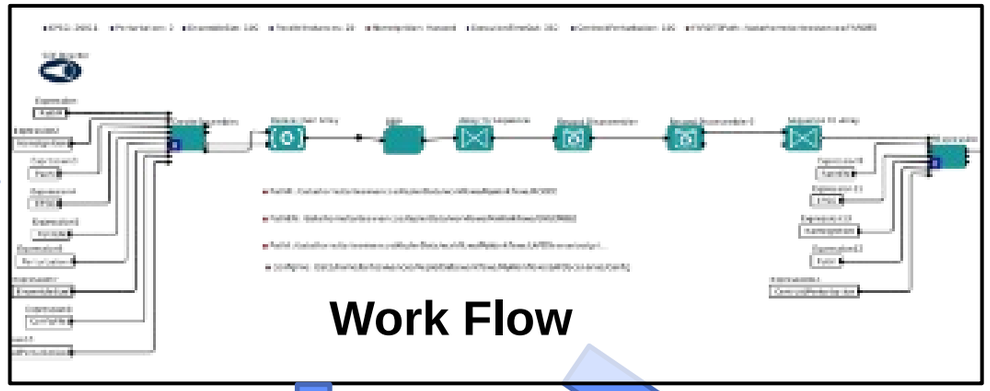
WIFIRE



Landscape data

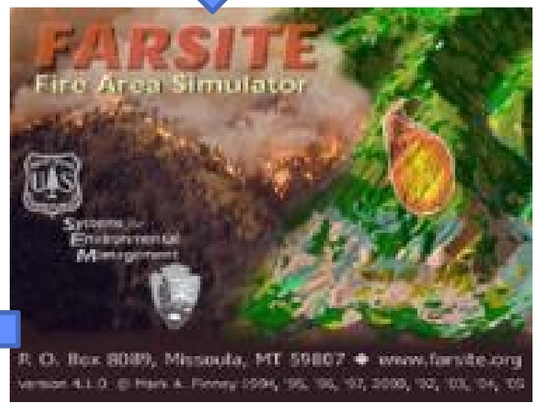
PRP

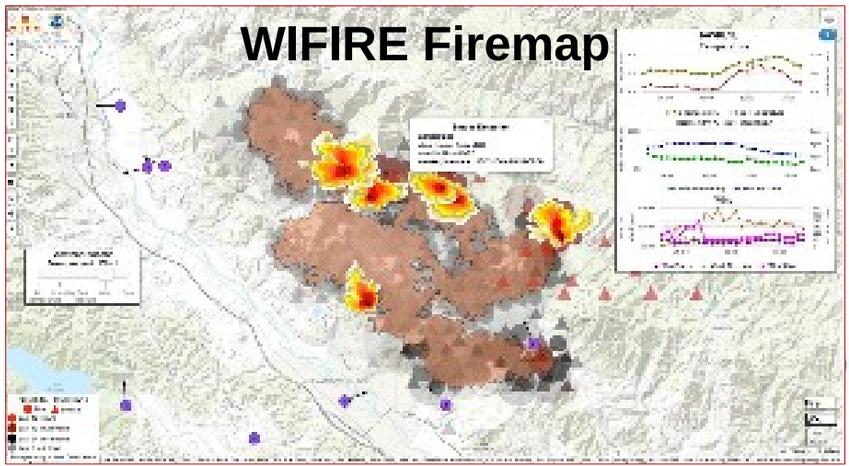




Work Flow







San Diego Airborne Intelligence Reconnaissance System (SDAIRS) – San Diego County Lilac Fire (Dec 7-16, 2017)

1. SDAIRS team at work at the SDFD Emergency Command and Dispatch Center





2. Lilac Fire Perimeter Capture through the GA Aircraft and Assimilation of Perimeters into WIFIRE Fire Models



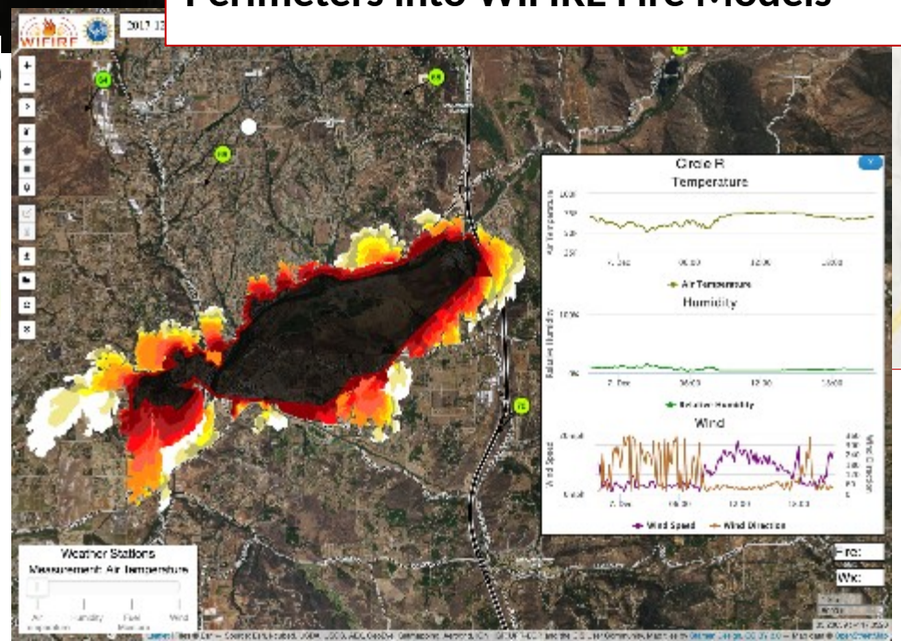
GENERAL ATOMICS AERONAUTICAL

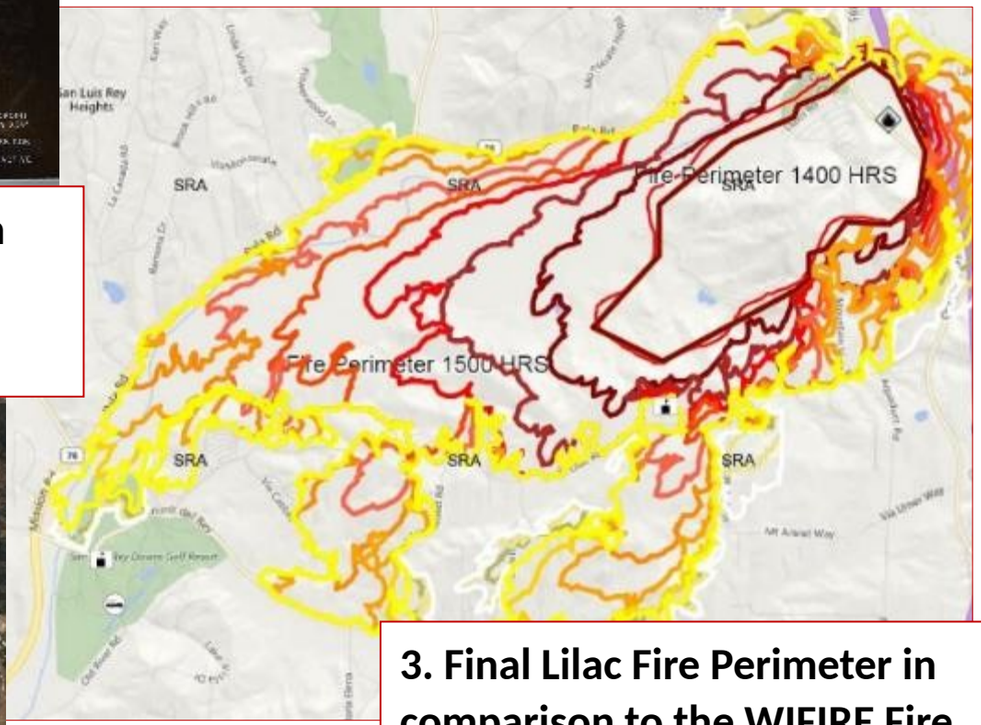
SCOUT SITUATION AWARENESS & COLLABORATION TOOL

CITY of SAN DIEGO FIRE-RESCUE

WIFIRE

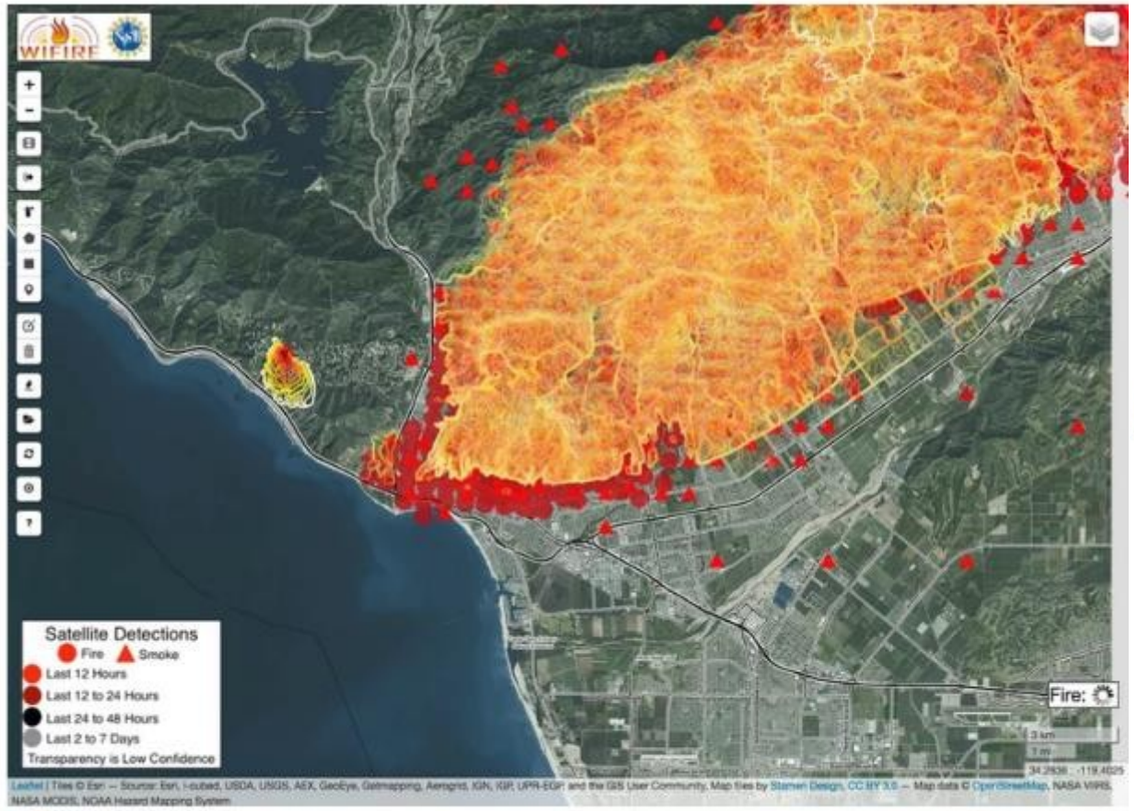
UNIVERSITY OF CALIFORNIA SAN DIEGO





3. Final Lilac Fire Perimeter in comparison to the WIFIRE Fire Progression Model in SCOUT

NSF-Funded WIFIRE Project Has Reached a National Audience



A WIFIRE display showing the Thomas Fire that ignited in Dec. 2017. University of California San Diego

TIME

TECH • WILDFIRES

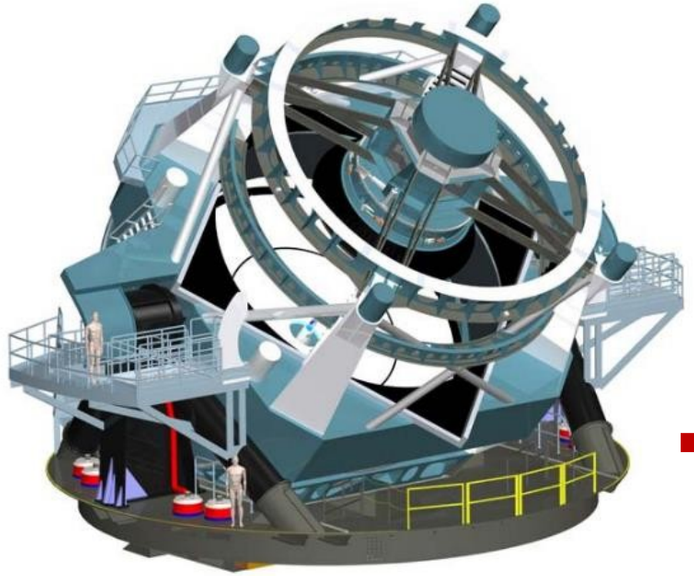
AI Is Helping Fight Wildfires Before They Start

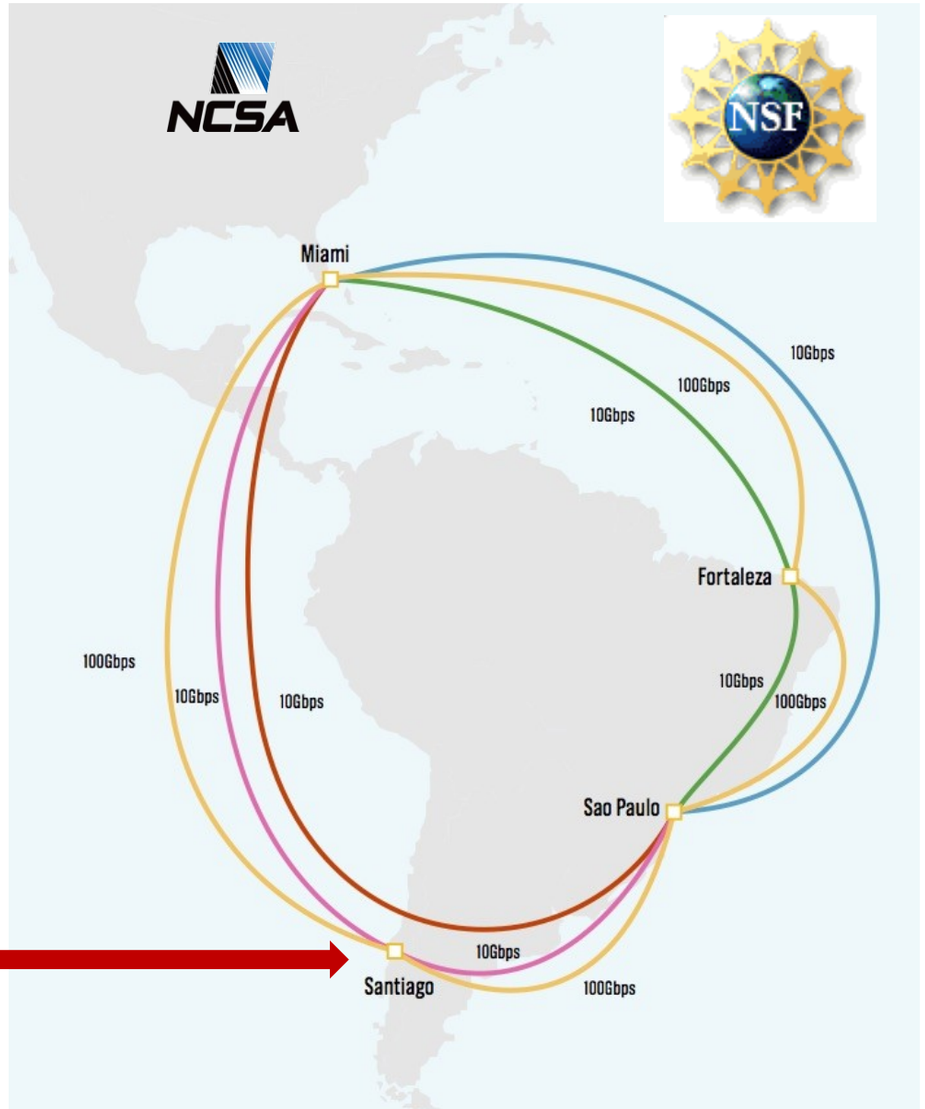
BY ALEJANDRO DE LA GARZA JANUARY 21, 2019

Next Generation Telescopes Will Produce Ultralarge Datasets Continuously Creating a “Digital Twin” of the Observable Universe

Large Synoptic Survey Telescope (LSST) – Vera Rubin Observatory

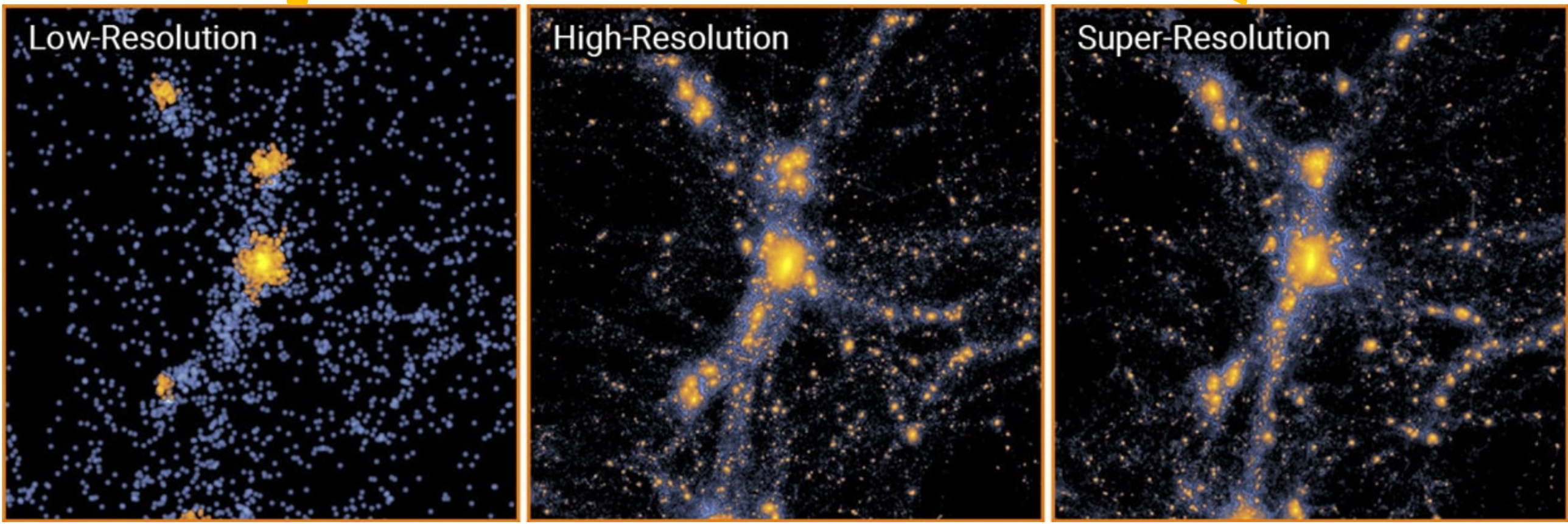
3.2 Gpixel Camera, 8.4-meter optical telescope
50x Moon Area Field of View
20,000GB/Night
Tracks ~40B Objects (Half Stars, Half Galaxies)
6M orbits of solar system bodies, 100,000 NEOs
Creates 1-10M Alerts/Night
Within 1 Minute of Observing
1000 Supernovas Discovered/Night





AI Can Accelerate Cosmological Simulations - Which Are the Models Into Which Vera Rubin Observational Data Streams

AI

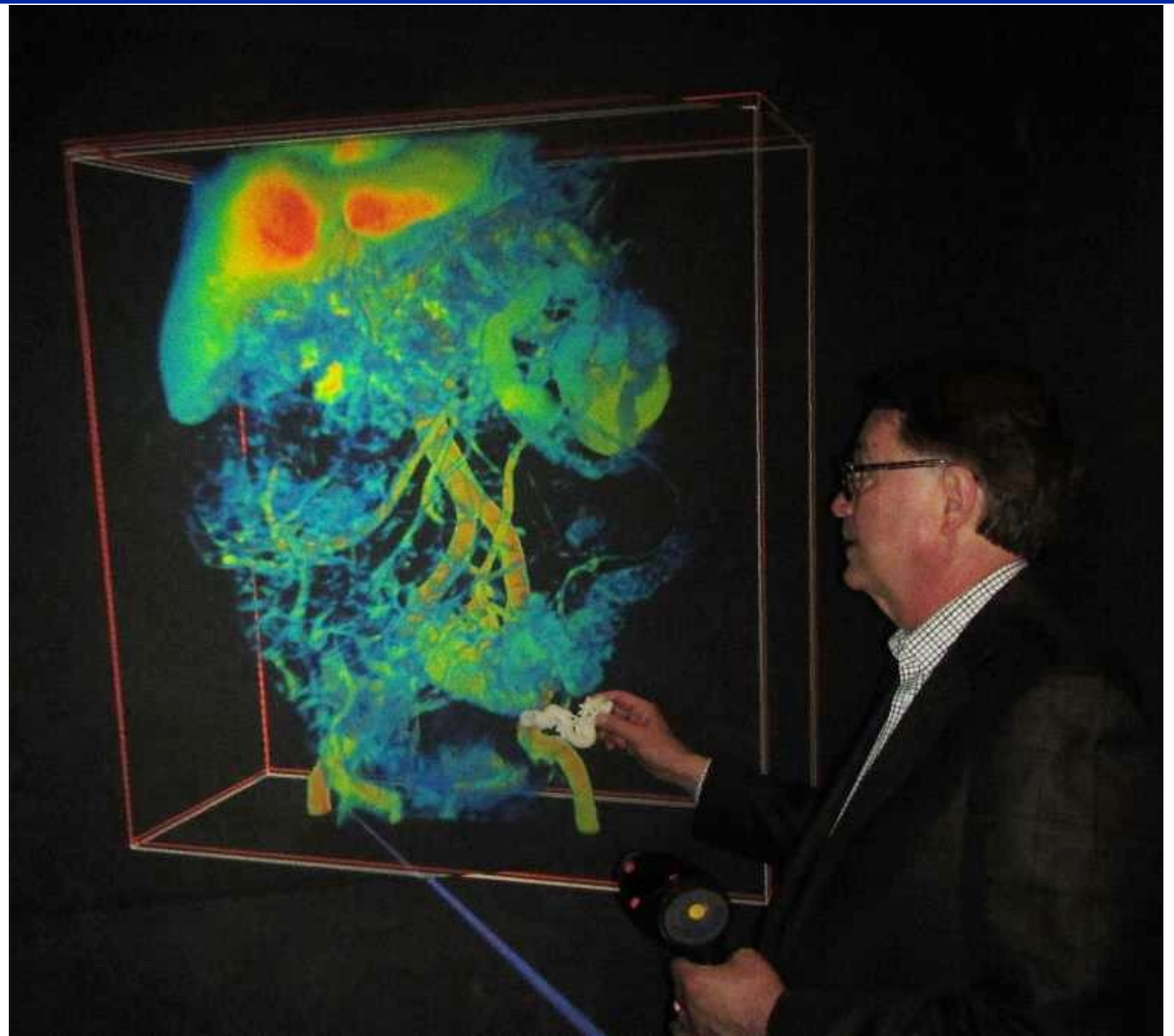


For a universe with 134 billion particles, the new method took 16 hours on a single GPU. This would take a dedicated supercomputer months to complete. (Carnegie Mellon Univ.)

“This new result is a good example of how AI is transforming cosmology.“ - NSF

3D Volumetric Visualization From 150 MRI Slices Creates a Transparent Larry “Digital Twin”

Calit2’s Jurgen Schulze from January 2012 MRI



Pre-Surgical Planning in Virtual Reality:
From Digitally-Enabled Future Patient to Digitally-Enabled Future Doctor





Colon visualization by Jurgen Schulze, Calit2;
Photo credit Tom DeFanti, Calit2

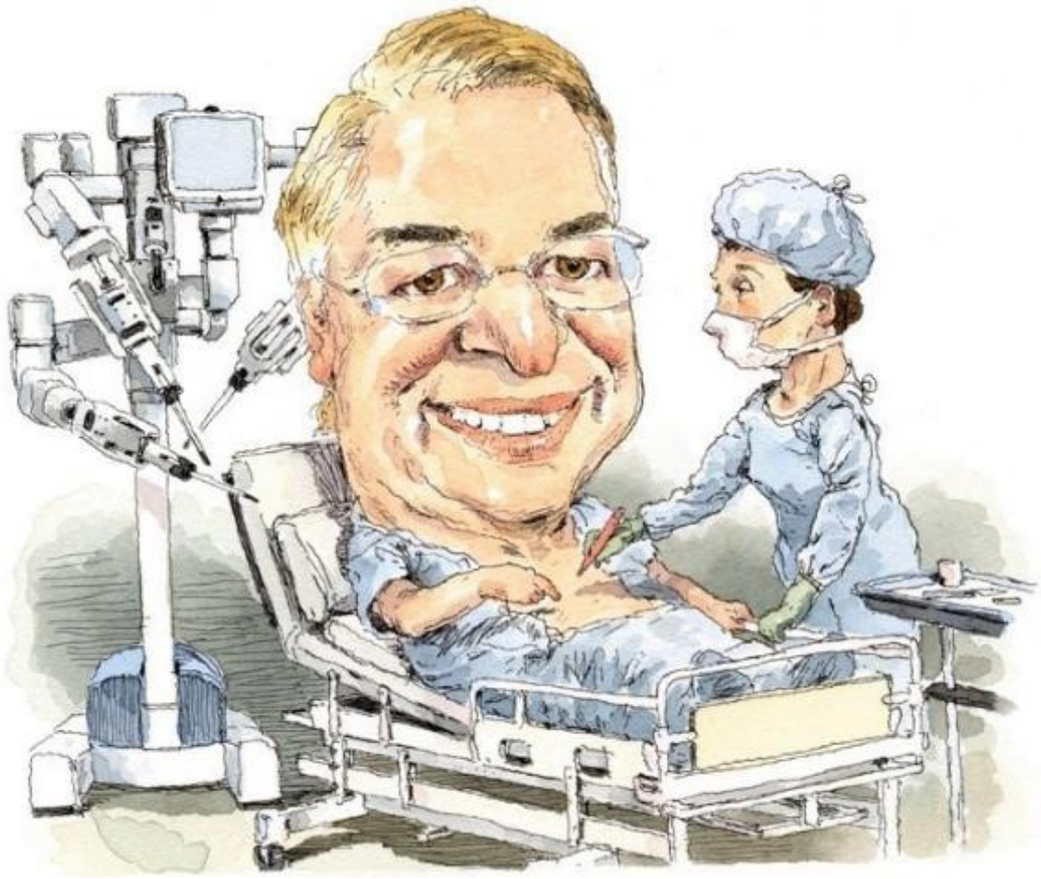
The Ability to See Inside Myself Led to My Co-Planning My Own Surgery

The Atlantic

The Man Who Saw Inside Himself

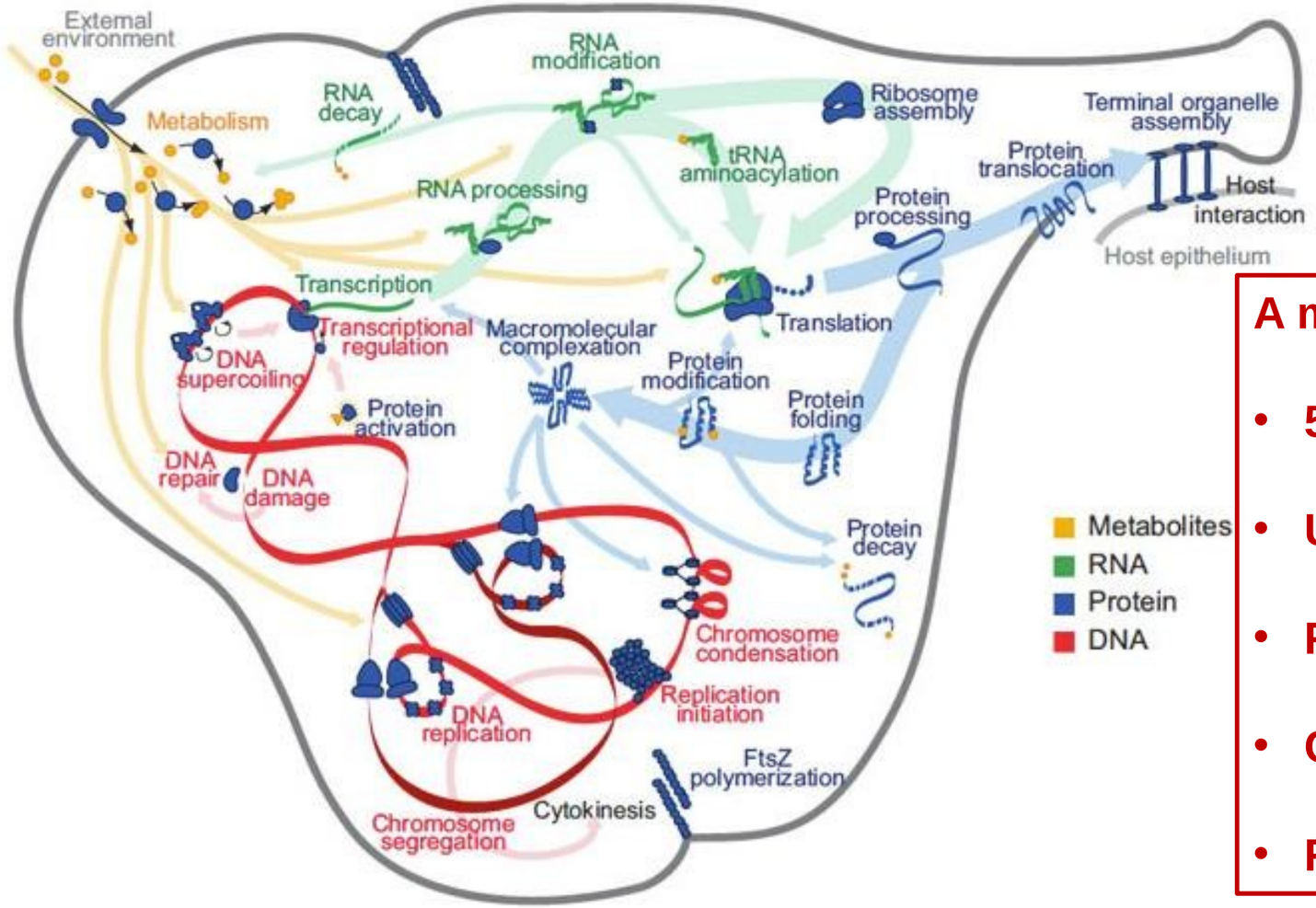
For years, Larry Smarr has used a supercomputer to monitor his health and peer at his organs. Recently, he used his knowledge to help direct his own surgery.

MARK BOWDEN | MARCH 2018 ISSUE | HEALTH



10 More Patients Analyzed in 3D
Helmsley Charitable Trust Grant

Digital Twins of Whole Living Cells
"A Computational Model Predicts Phenotype from Genotype"



Cell

Cell *150*, 389–401, July 20, 2012

A model of *Mycoplasma genitalium,*

- **525 Genes**
- **Using 1,900 Experimental Observations**
- **From 900 Published Studies,**
- **Created a Software Model,**
- **Requires 128 Computers to Run**

Jonathan R. Karr,[1,4] Jayodita C. Sanghvi,[2,4] Derek N. Macklin,[2] Miriam V. Gutschow,[2] Jared M. Jacobs,[2] Benjamin Bolival, Jr.,[2] Nacyra Assad-Garcia,[3] John I. Glass,[3] and Markus W. Covert[2,*]

[1]Graduate Program in Biophysics
[2]Department of Bioengineering
Stanford University, Stanford, CA 94305, USA
[3]J. Craig Venter Institute, Rockville, MD 20850, USA

The Dawn of Virtual Cell Biology

I Use Many Personal Sensors, Which Stream My Data to Clouds, To Quantify My Body, Detect Changes, & Drive Behavioral Change



MyCircadian Clock-
Food & Drink



FitBit -
Daily Steps,
Heart Rate, Sleep



Withings/iPhone-
Blood Pressure





Abbott Libre -
Continuous Glucose



Withings WiFi Scale -
Daily Weight

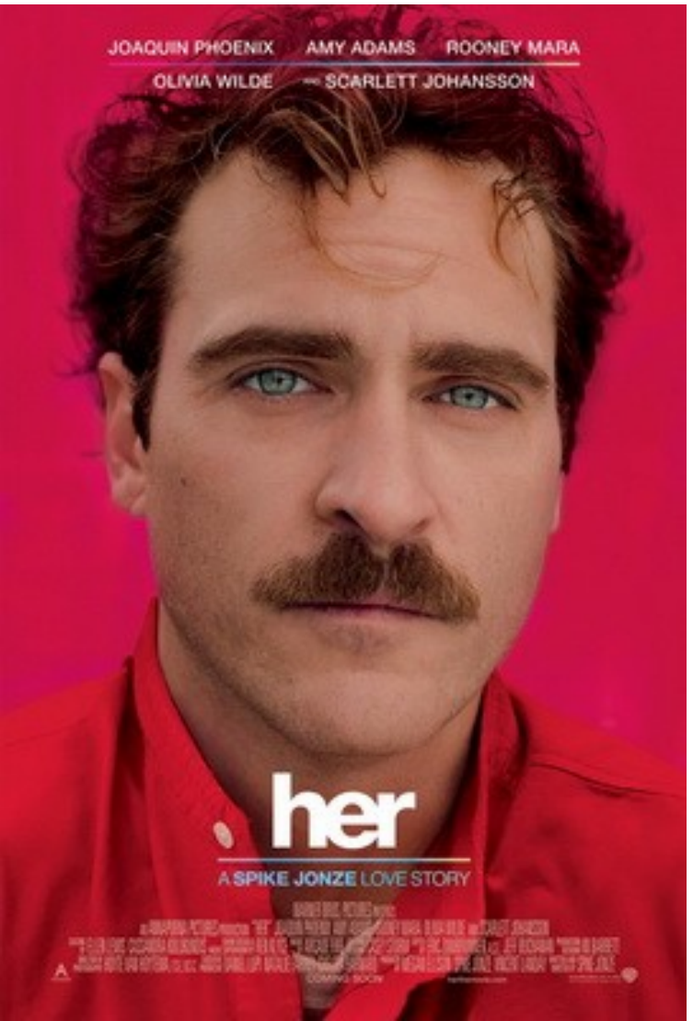


Apple Watch 5 -
Heart Rhythm



Oura Ring -
Temperature,
Sleep, HRV

A Vision for Healthcare in the Coming Decades



Using this data, the planetary computer will be able to build a computational model of your body and compare your sensor stream with millions of others. Besides providing early detection of internal changes that could lead to disease, cloud-powered voice-recognition wellness coaches could provide continual personalized support on lifestyle choices, potentially staving off disease and making health care affordable for everyone.

ESSAY | The New York Times | Science

An Evolution Toward a Programmable Universe

By LARRY SMARR

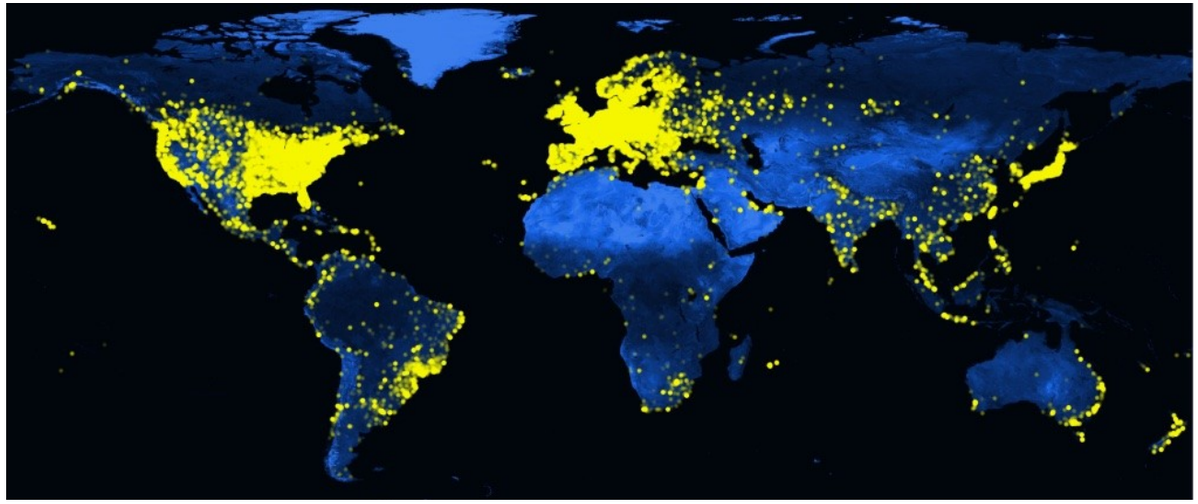
Published: December 5, 2011

COVID Molecular Simulations Drove the Most Rapid Creation of a Planetary-Scale Distributed Computer in History

April 15, 2020

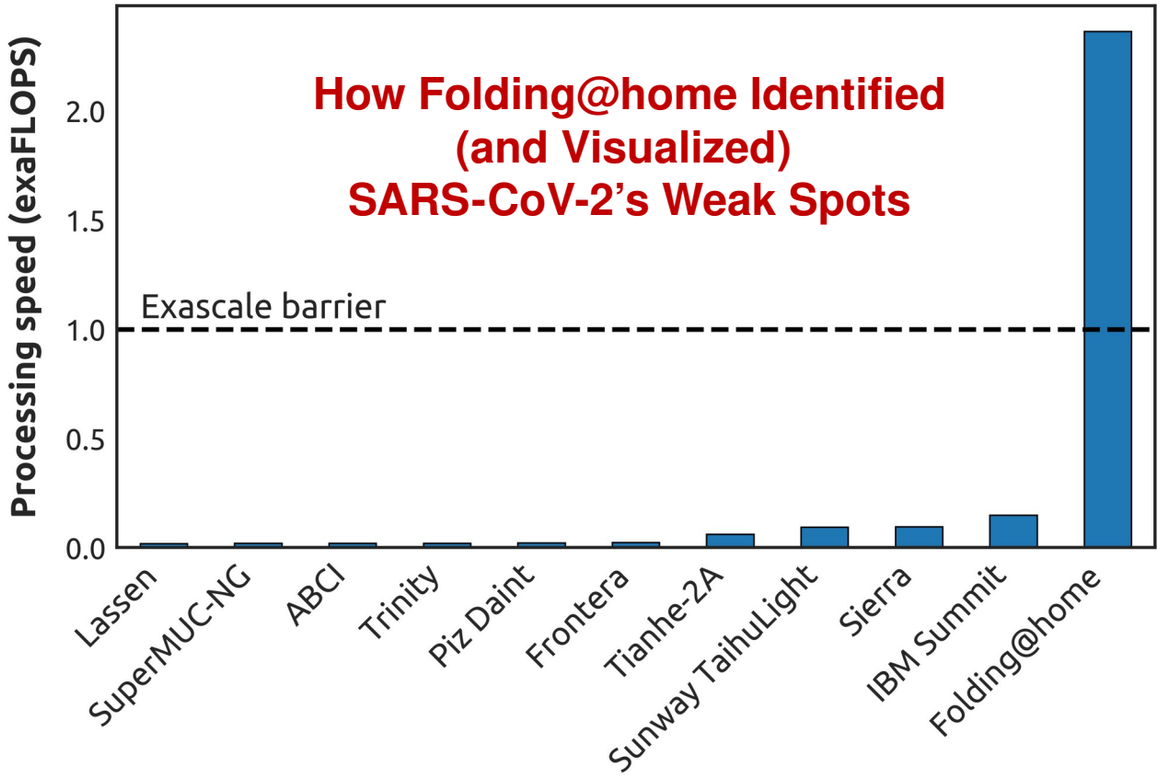
Folding@Home Now More Powerful Than Top 500 Supercomputers Combined

690K GPUs and 12M CPU cores



“Never in human history — not with the human genome, or AIDS, or SARS, or even cancer research — has so much horsepower been so unilaterally focused on a single goal.”

Folding@home is 15X faster than any current supercomputer



“Digital Twins” Are Coming to Consumer Business, Economics, and Perhaps Social Systems

- **“Digital Twins” of Hundreds of Millions of Consumers:**
  - **Apple ($2.1 Trillion)**
    - **More Than 100 Million Apple Watches Sold to Date**
  - **Microsoft ($1.9 Trillion)**
    - **Over 1 Billion Devices Run Windows 10**
  - **Alphabet (Google) ($1.6 Trillion)**
    - **3.5 Billion Searches/Day**
  - **Amazon ($1.6 Trillion)**
    - **Ships 2 Million Packages/Day**
  - **Facebook ($0.9 Trillion)**
    - **2 Billion People Update/Day**
- **IoT Smart Homes and Cities**
- **China's Surveillance State**
- **Agent-Based Computational Economics**
- **Asimov’s Psychohistory?**