KAOS
Compilers
Hardware
Architectures
Operating
Systems

Aggregate.Org
UNBRIDLED COMPUTING

CPE200
Oct. 27, 2021

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Electrical & Computer Engineering

University of Kentucky

What Do We Do?

- KAOS: Compilers, Hardware Architectures, and Operating Systems
- Aggregate.Org (UNBRIDLED COMPUTING):
  - Aggregate Function Networks (AFNs)… in 1st Linux PC Cluster Supercomputer
  - Make the components of a computing system work better together, improving performance & gaining new abilities

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You are what you eat...

- I am a computer engineer / systems guy
- Background in CS, EE, ME, Math, & Econ
- From 1983, parallel processing researcher
- In 1970s, photo editor of various school pubs and a published professional photographer
- From birth, trained to know how everything in Dad's manufacturing company worked

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Supercomputers

Computers that can solve big problems
and can scale to solve bigger problems.

- Mostly about parallel processing
- Need not be huge, expensive, etc.
- We make them cheap
- We also make them able to do new things

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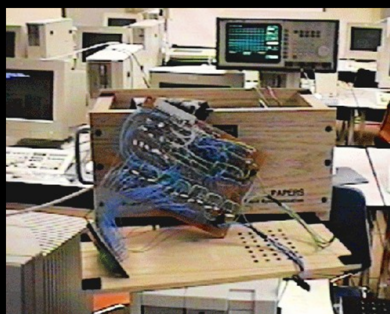
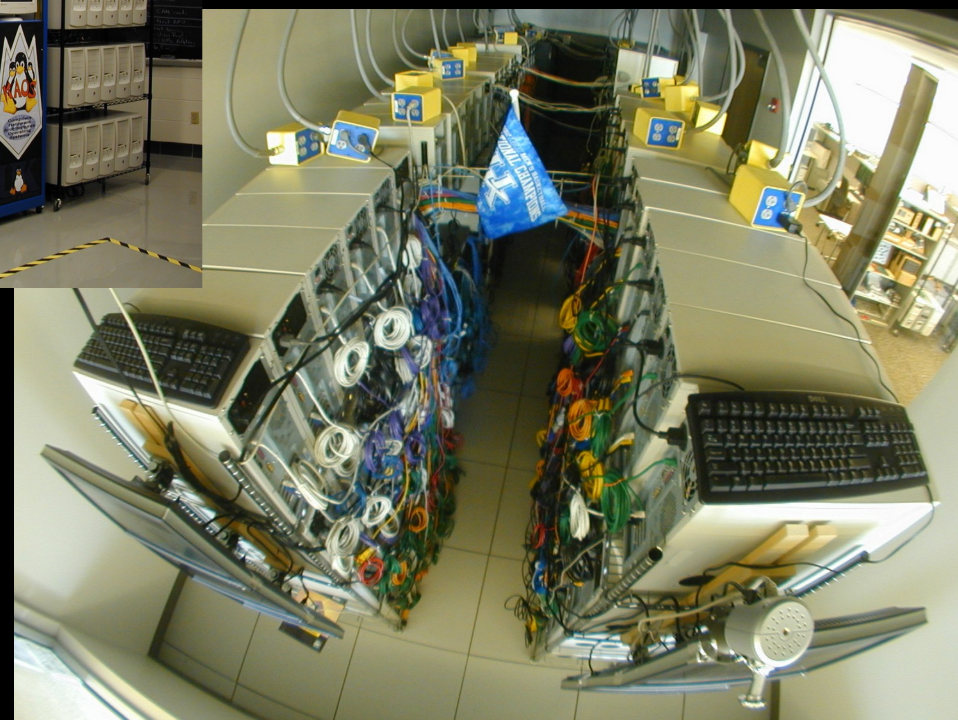
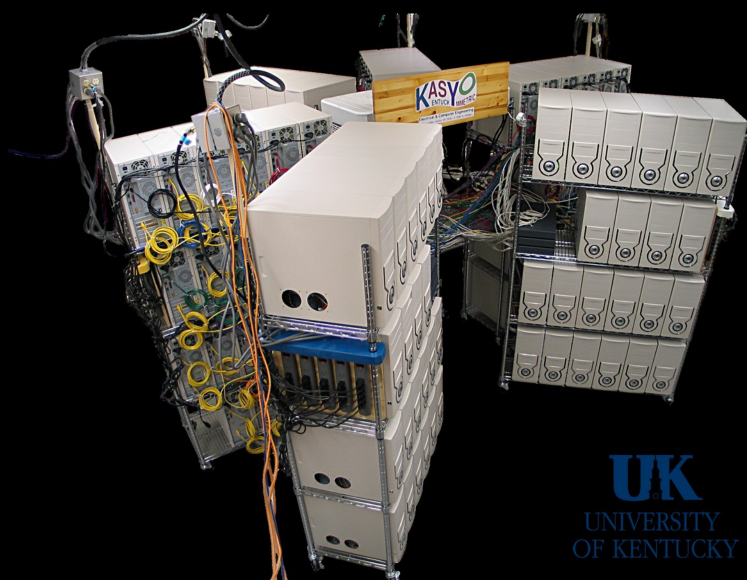
(Old) Cheap Supercomputers







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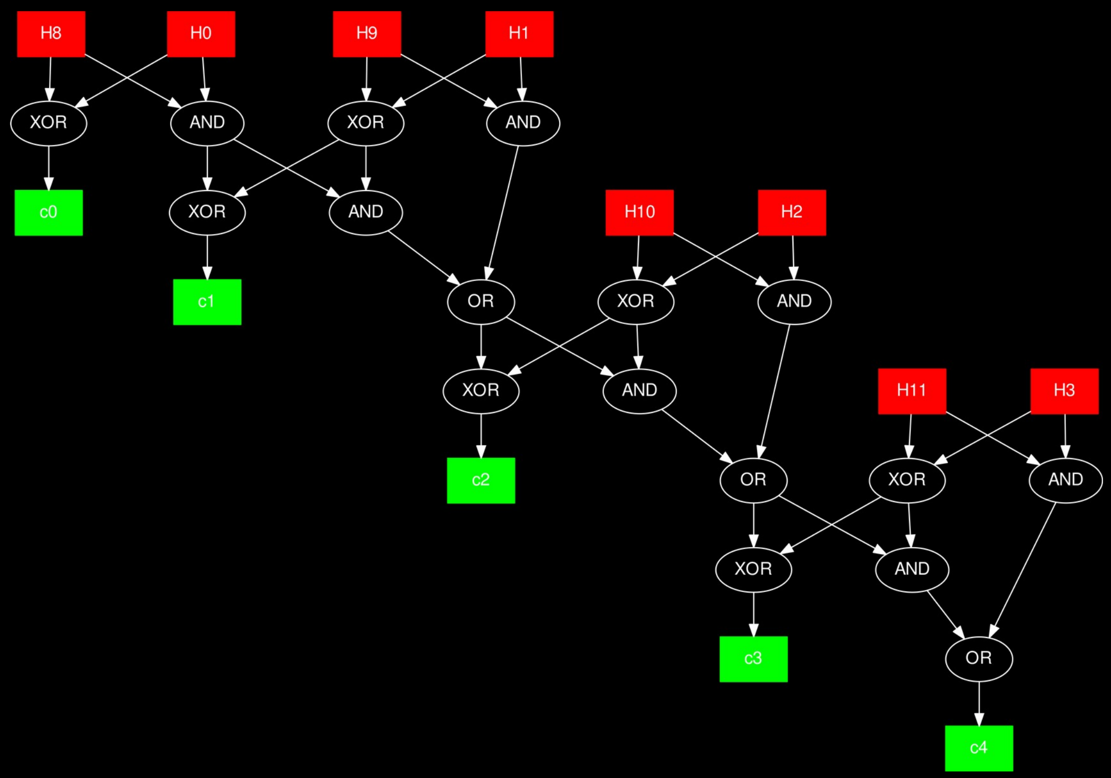
Current Supercomputing Research

- I'm one of the folks who started the cluster supercomputing revolution...
- Several years ago, I realized:
  - My lab has 168kW power, 30 tons cooling
  - My lab heats half the Marksbury building
  - My lab could **not** power **1 high-end rack**!
  - Big systems have **thousands of racks**
- It's really all about power / computation

```
int:4 a, b;
c = a + b;
```

- Optimized, **17** single-gate operations:



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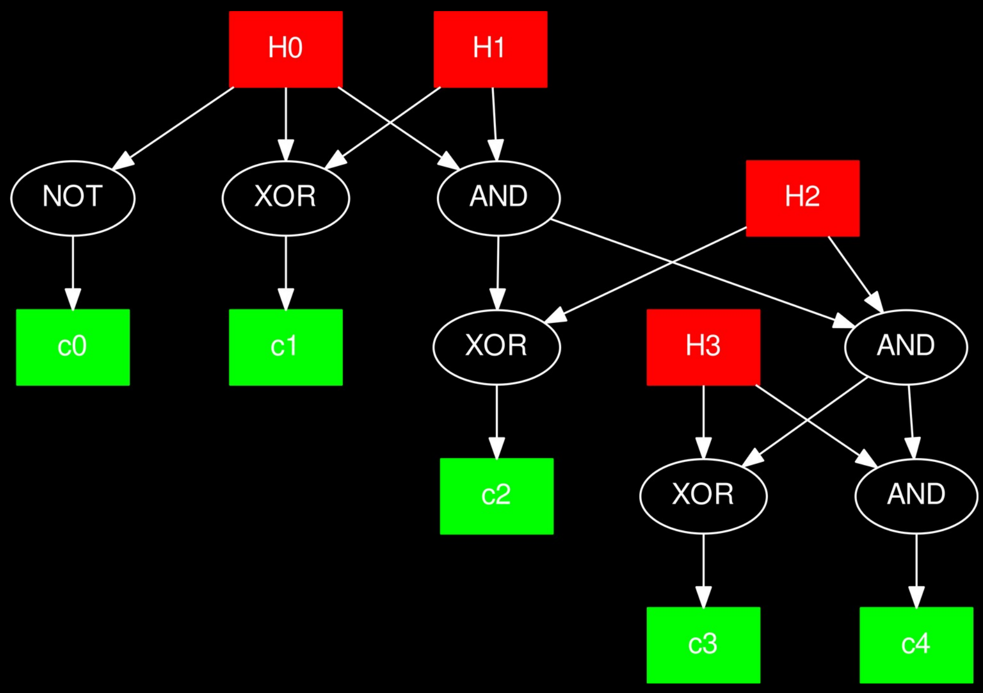
```
int:4 a, b;
b = 1; c = a + b;
```

- Optimized, **7** single-gate operations:



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```
int:8 a, b, c;
a = (c * c) ^ 70;
a = ((a >> 1) & 1);
a = b + (c * b) + a;
a = a + ~(b * (c + 1));
```

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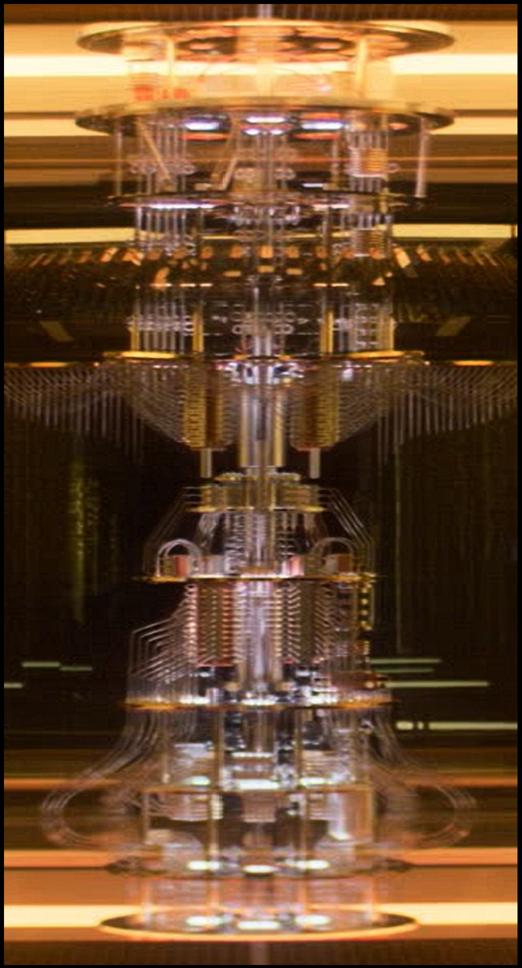
```
int:8 a, b, c;
a = (c * c) ^ 70;
a = ((a >> 1) & 1);
a = b + (c * b) + a;
a = a + ~(b * (c + 1));
```

- About **206,669 gates** unoptimized
- Optimized, it's just `a = 0;`

Quantum Computers?



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Quantum Computing

Parallel processing ***without*** parallel hardware.

- **Qubits** instead of bits
  - Each qubit can be 0, 1, or ***superposed***
  - A “gate” operates on superposed values
  - ***Entangled*** qubits maintain values together
  - Measuring a qubit’s value picks 0 or 1
- Quantum computers are **not** the only way to do that: Parallel Bit Pattern computing

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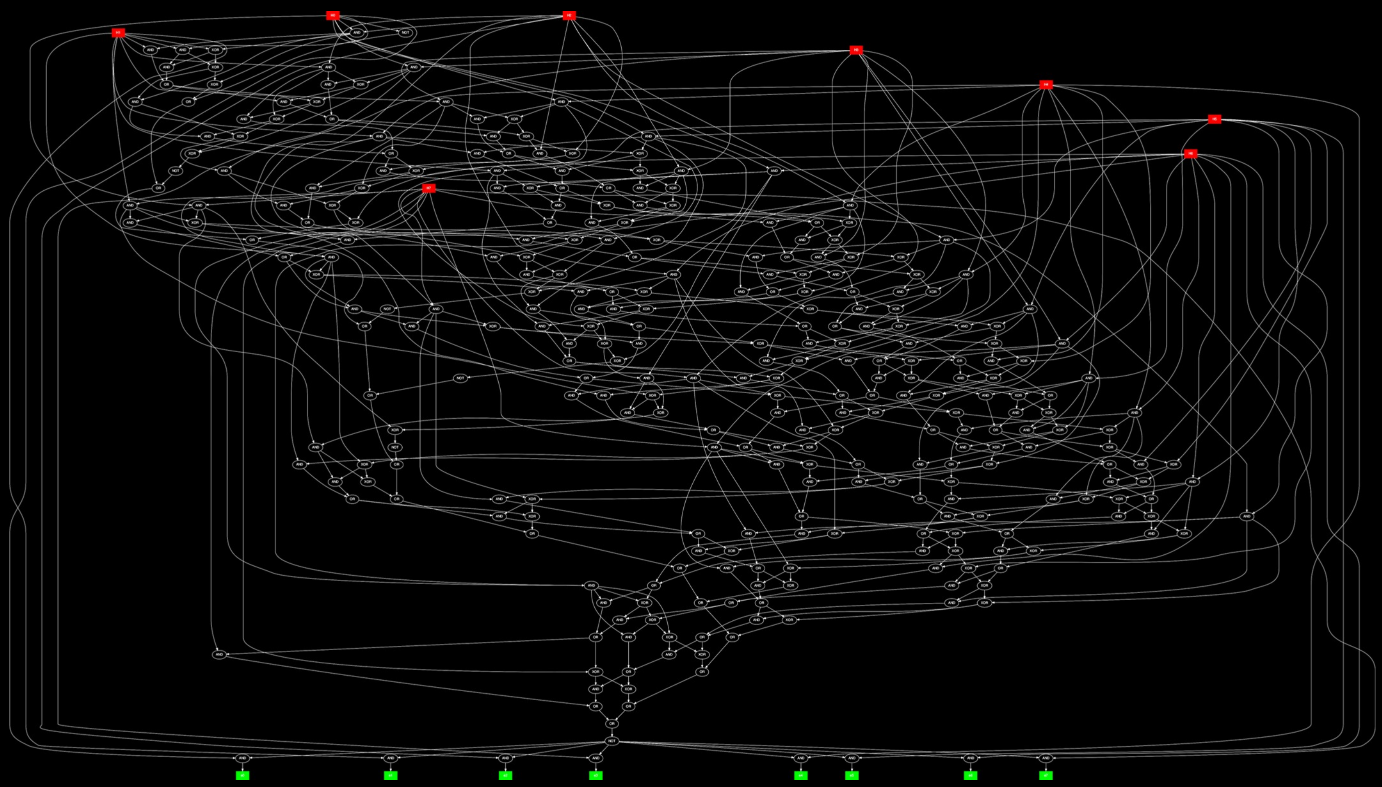
An Example: Find `sqrt(29929)`

- **310** single-gate operations:



An Example: Find `sqrt(29929)`

- The complete C program, prints `0 173`

```
int main(int argc, char **argv) {
  pbit_init();
  pint a = pint_mk(16, 29929);
  pint b = pint_h(8, 0xff);
  pint c = pint_mul(b, b);
  pint d = pint_eq(c, a);
  pint e = pint_mul(d, b);
  pint_measure(e);
}
```

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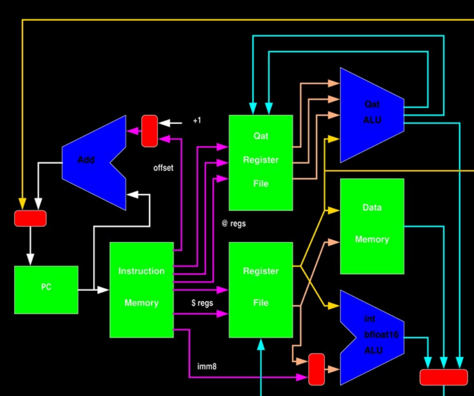
An Example: factor 15

```
had @0,3
had @1,5
and @2,@0,@1
had @3,4
and @4,@0,@3
had @5,2
and @6,@5,@1
and @7,@4,@6
and @8,@5,@3
had @9,1
and @10,@9,@1
and @11,@8,@10
and @12,@9,@3
had @13,0
and @14,@13,@1
and @15,@12,@14
xor @16,@8,@10
and @17,@15,@16
or  @18,@11,@17
xor @19,@4,@6
and @20,@18,@19
or  @21,@7,@20
and @22,@2,@21
had @23,6
and @24,@0,@23
and @25,@22,@24
xor @26,@2,@21
and @27,@5,@23
and @28,@26,@27
xor @29,@18,@19
and @30,@9,@23
and @31,@29,@30
xor @32,@15,@16
and @33,@13,@23
and @34,@32,@33
xor @35,@29,@30
and @36,@34,@35
or  @37,@31,@36
xor @38,@26,@27
and @39,@37,@38
or  @40,@28,@39
xor @41,@22,@24
and @42,@40,@41
or  @43,@25,@42
had @44,7
and @45,@0,@44
and @46,@43,@45
xor @47,@40,@41
and @48,@5,@44
and @49,@47,@48
xor @50,@37,@38
and @51,@9,@44
and @52,@50,@51
xor @53,@34,@35
and @54,@13,@44
and @55,@53,@54
xor @56,@50,@51
and @57,@55,@56
or  @58,@52,@57
xor @59,@47,@48
and  @60,@58,@59
or   @61,@49,@60
xor  @62,@43,@45
and  @63,@61,@62
or   @64,@46,@63
xor  @65,@61,@62
xor  @66,@58,@59
xor  @67,@55,@56
xor  @68,@53,@54
xor  @69,@32,@33
and  @70,@13,@3
xor  @71,@12,@14
and  @72,@70,@71
and  @73,@69,@72
and  @74,@68,@73
or   @75,@74,@74
not  @75
or   @76,@67,@75
or   @77,@66,@76
or   @78,@65,@77
or   @79,@64,@78
or   @80,@79,@79
not  @80
lex  $0,31
next $0,@80
copy $1,$0
next $1,@80
lex  $2,15
and  $0,$2 ;5
and  $1,$2 ;3
```

Figure 10: Code prime factoring 15 (3 columns).

```
pint a = pint_mk(4, 15);  // a=15
pint b = pint_h(4, 0x0f); // b=0..15
pint c = pint_h(4, 0xf0); // c=0..15
pint d = pint_mul(b, c);  // d=b*c
pint e = pint_eq(d, a);   // e=(d==a)
pint f = pint_mul(e, b);  // make non-factors 0
pint_measure(f);          // prints 0, 1, 3, 5, 15
```

Figure 9: Word-level prime factoring of 15.



Tangled

(no, not that one)

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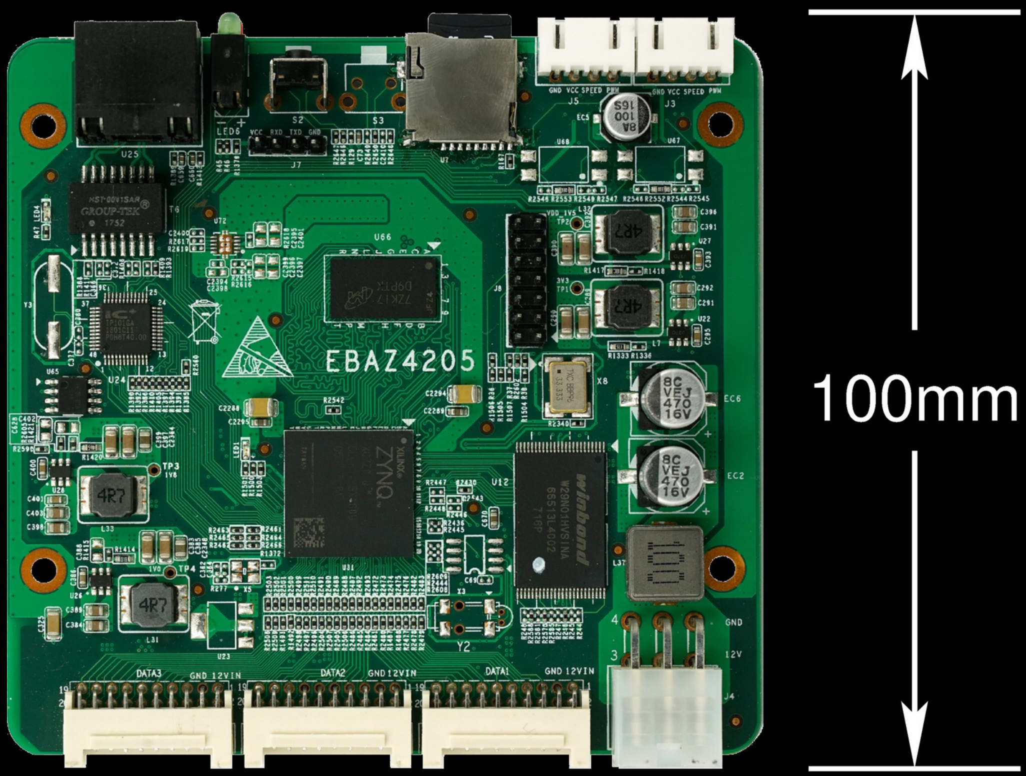
Our next superccomputer...



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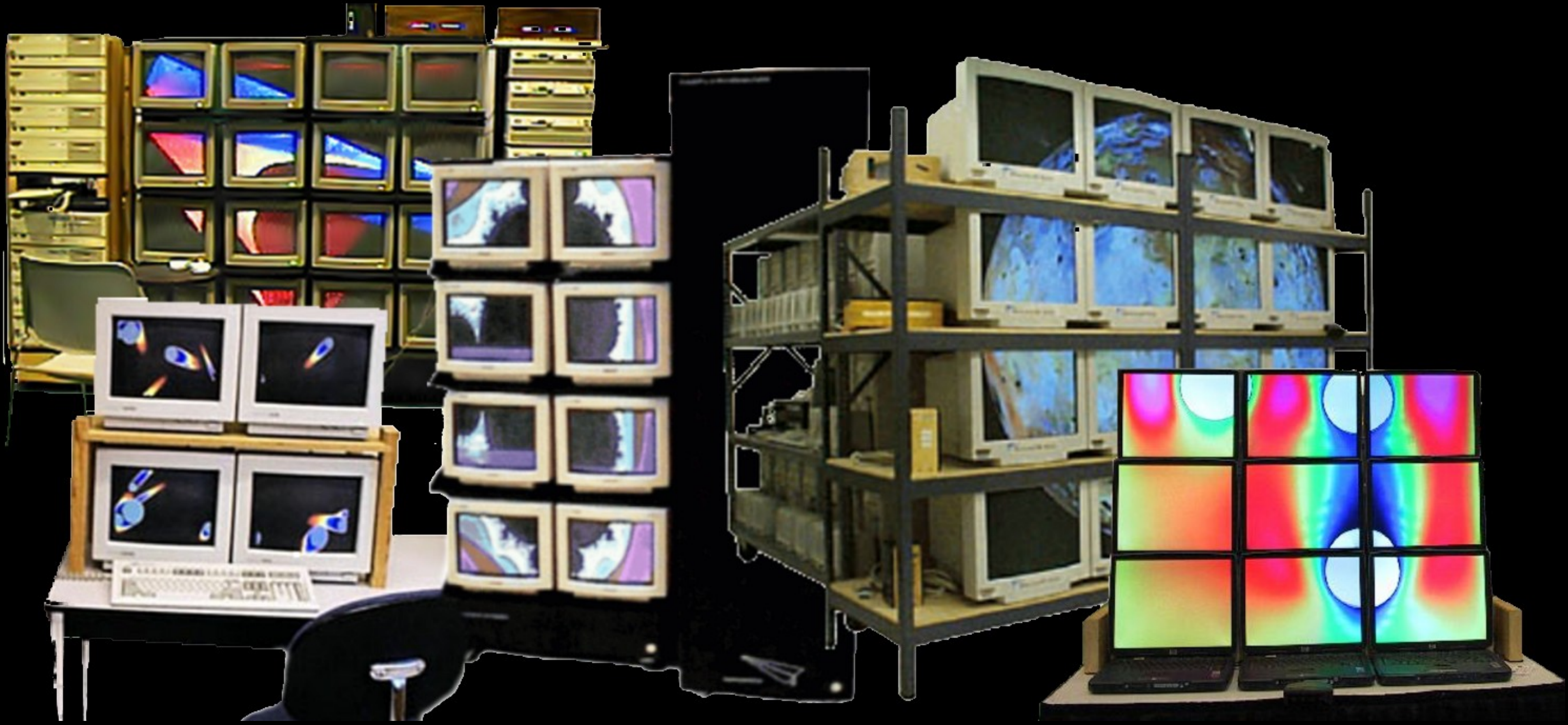
Supercomputers Doing New Things



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Computational Photography

Cameras as computing systems;
using computation to enhance camera abilities
and / or to process the data captured

- New camera / sensor / processing models
- Intelligent computer control of capture
- Detection / manipulation of image properties

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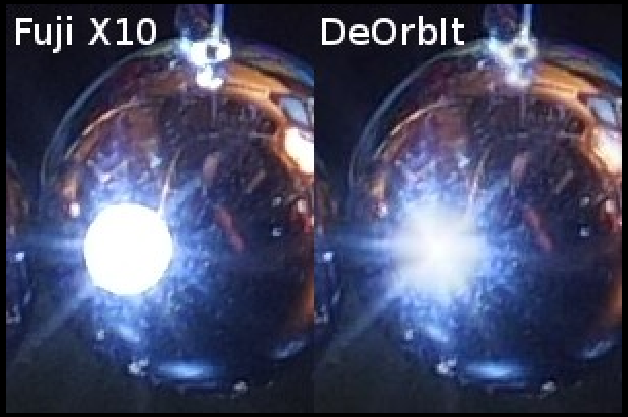
“Raw” Repair



- “Raw” means “uncooked” or “unprocessed”
- Can *credibly* **repair** corrupted data
  - Fuji X10 “white orbs” blooming ⇒ **DeOrbIt**
  - Sony ARW compression artifacts ⇒ **KARWY**
  - Sony ARW PDAF artifacts ⇒ **KARWY-SR**

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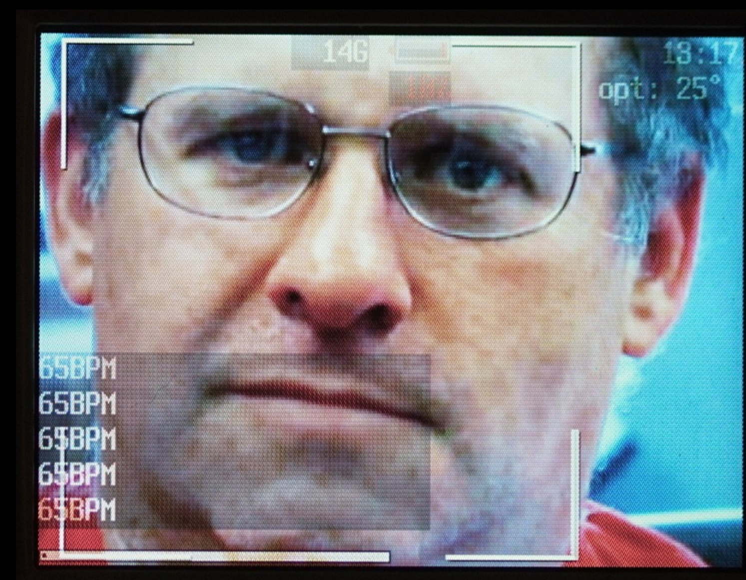
Photoplethysmography



- Reprogrammed a $100 camera to detect heartbeats by detecting color change

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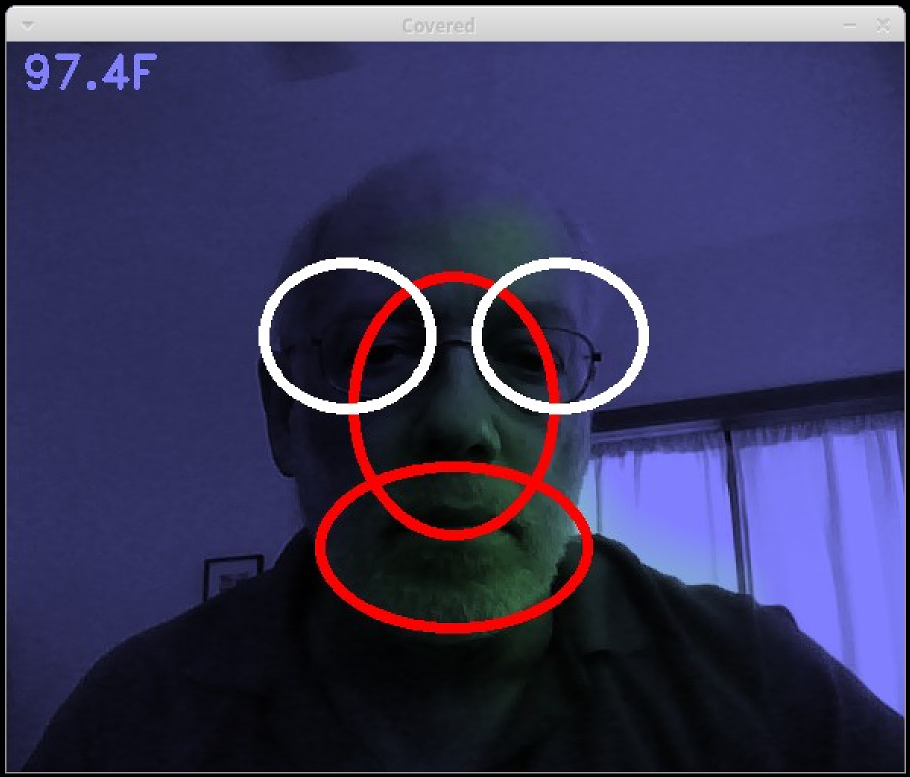
Covered Safe Entry Scanner



- Detect when a mask is being properly worn
- Also thermal imager & contact tracing

TDCI: Time Domain Continuous Imaging

- TDCI representation: a continuous waveform per pixel, compressed (mostly) in time domain
- TDCI processing enables:
  - High dynamic range (HDR), improved SNR
  - Rendering a virtual exposure for any time interval (start time, shutter speed)
  - Rendering a conventional video at any FPS and shutter angle (temporal weighting)

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TDCI Example

- Video is converted to TDCI, then new frames synthesized... with significantly better quality

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FourSee TDCI Camera

- Syncs four reprogrammed PowerShots
- 3D-printed structure for alignment, etc.

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A Custom 3D-Printed Adapter With M42-Compatible Thread

Lens adapter
M42 x 1mm pitch
to Sony E

On $180 printer,
0.25mm layers!

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Some of our latest work...

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Design For Manufacturability (DFM)

Design product so that it is easy to manufacture.

- E.g., Lego doesn’t easily do curves… and most 3D printers don’t do unsupported spans
- How is this computer engineering?
  - A design is a parametric program (parameterized by machine characteristics)
  - Compiler technology optimizes for DFM

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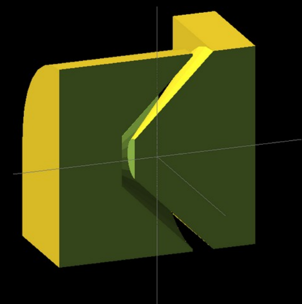
3D-Printed Spanless Hinges



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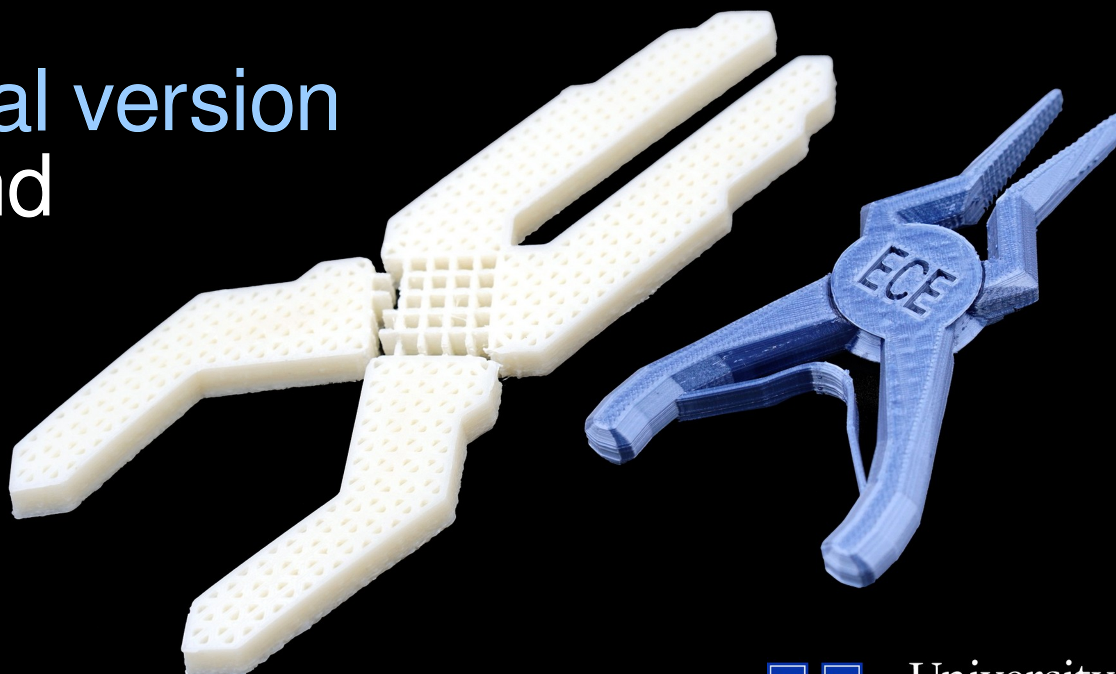
A Fancier DFM Example

- In 2016, researchers at the *Hasso Plattner Institute* made "metamaterial pliers": a single part with stiffness, spring, & bending hinge
- Our metamaterial version has a **spring** and a **spanless hinge** and it works…



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You Can Get Involved

- Talk to me, or Paul Eberhart, etc.
- Most stuff is posted at `AGGREGATE.ORG`
- **Q**uantum computing **E**ducation & **R**esearch In **K**entucky