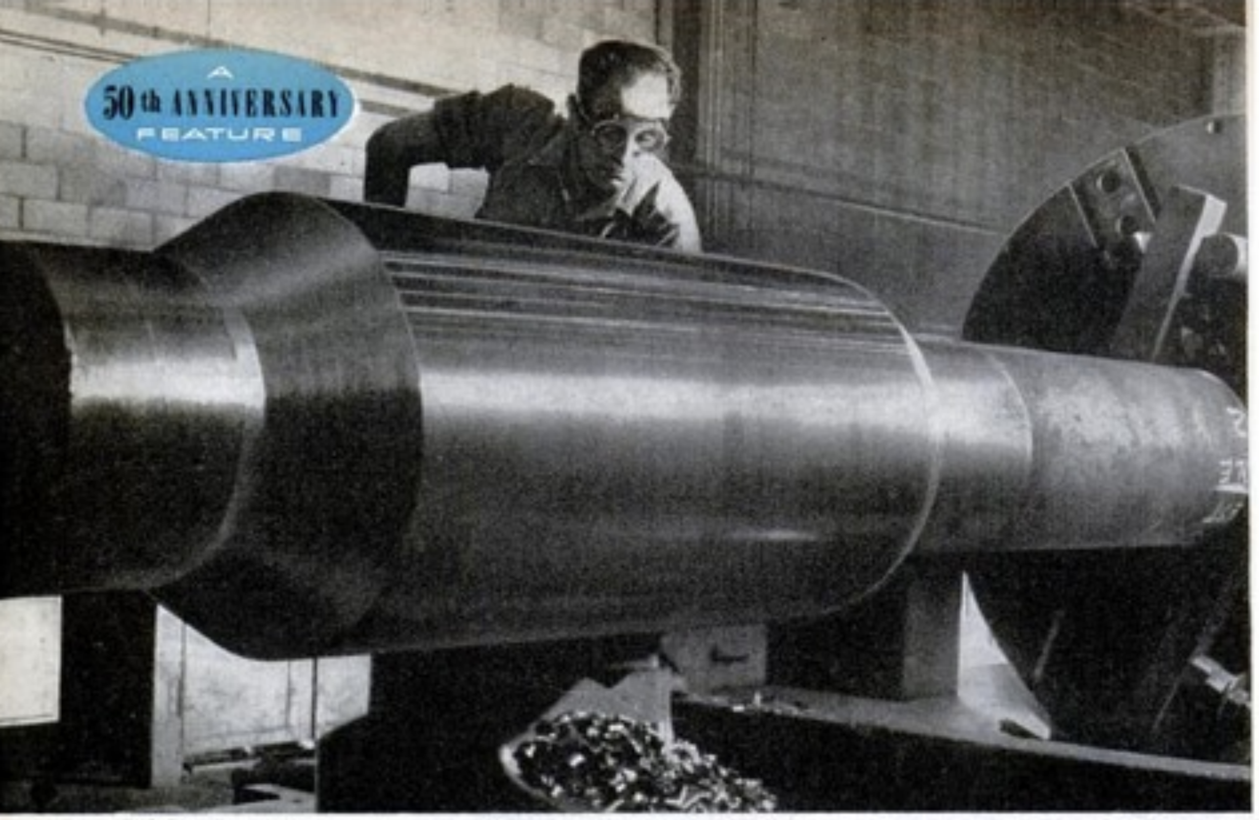
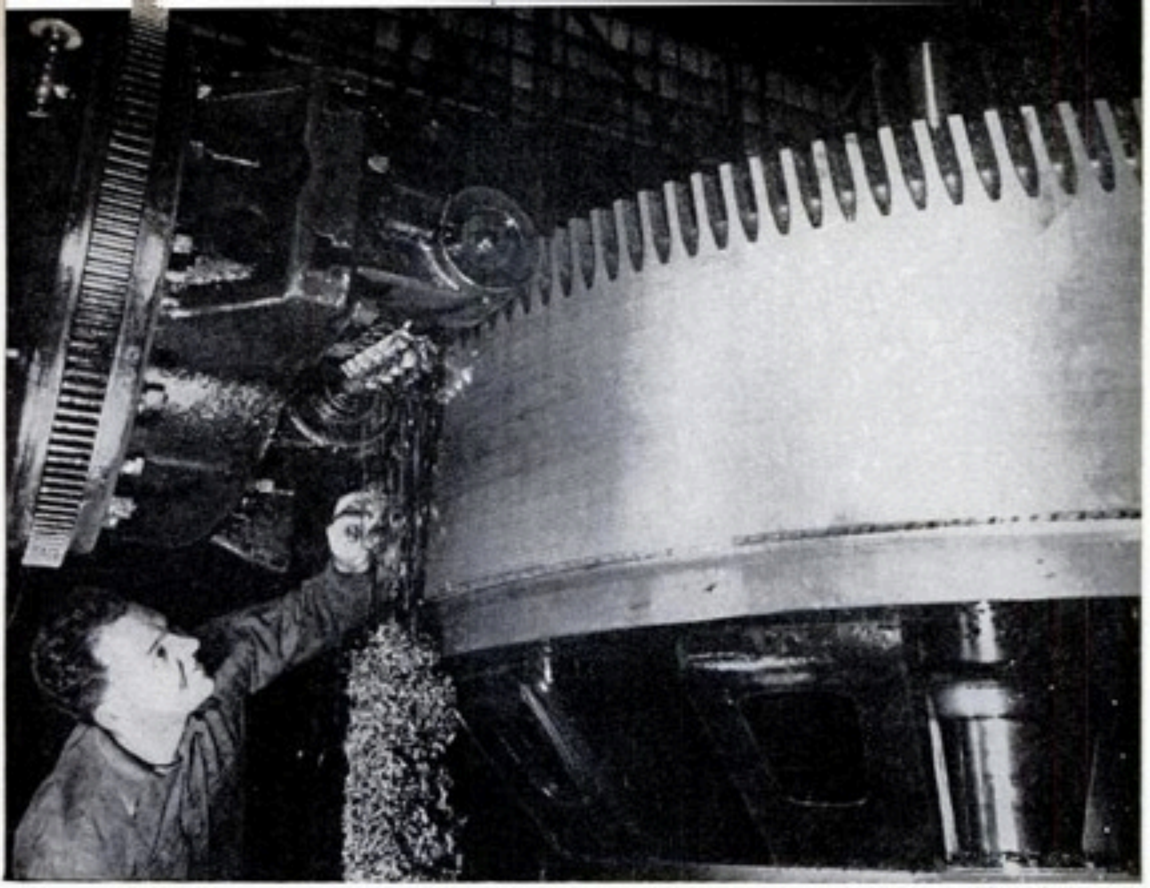
Why do we use digital fabrication machines by presenting them with oddly formatted files?

A 50th ANNIVERSARY FEATURE



U. S. Steel Corp. photo

Giant steel roll soon to take its place in a U. S. Steel rolling mill is machined on a 60-inch lathe in the forging shop at the firm's Homestead District works



Westinghouse photo

Hobbing machine cuts teeth in a gear over eight feet in diameter; chips pile up beneath the cutting tool

By George Scullin

The jet engine and the wrist watch, the power saw and the 1952 automobile— all are products of those modern wonders—

THE TOOLS THAT MAKE TOOLS

AROUND early March this year, a few newspapers announced casually that the Air Force had been given the green light on the purchase of 20 machine tools. It was just a small story and the editors couldn't get too excited about it. Not even at the size of the machines, four stories high; or their cost, $389,000,000! Stories like that are routine in this year of 1952.

But what if that story, through some slip in the time machine, had appeared before the young editors preparing the first issues of *Popular Mechanics* in 1902? What about it would be strange?

Not the words "Air Force," though man had yet to fly a power-driven aircraft. These farseeing young men were already convinced that man *would* fly, and soon, and that there would be an Air Force. Not the size of the machines. These editors were dedicating their magazine to the conviction that the years to come would produce mechanical wonders beyond anything even dreamed of at the turn of the century. To anticipate these marvels and explain them in words and pictures their readers could [illegible] was [illegible] job [illegible] created for themselves. But we do think they would have been stunned by the $389,000,000.

In 1902 that sum would have bought the year's output of the entire machine-tool industry, would have bought the industry as well, and there would have been enough left over to put a little white fence around the whole thing. In fact, the industry was so small that few people had ever heard of it, and fewer still knew what it was.

Yet this is the tiny industry that has made possible our entire way of life. Without it, we would be living on the products of our bare hands, with a standard of living approaching that of Colonial days.

What are these machines that produce all this magic? Well, they are a weird family. They are the tools that make the tools that make everything else. But, being a family, they also make each other. This makes them the only self-procreating race in the machine world.

To understand the huge, fantastic, almost-human machine tools of today, let's take a look at their ancestors as the first [illegible] Popular [illegible] A lot of selective breeding has gone into them since, but basically they remain unchanged. In 1902 a machine tool was described as a nonportable, power-driven tool that shaped metal by removing surplus material in the form of chips.

The first and oldest of these tools was the lathe. By 1902 a more flexible version called the turret lathe was coming into popularity. The next was the drill, which was fine for drilling holes in metal but not always accurate enough for some of the close-tolerance work required in 1902. For tolerances of .001 inch, a boring machine was used. Today drilling and boring are words often used interchangeably, but to the

Machine-tool shop of 50 years ago presented maze of overhead pulleys. [illegible] National Acme Company

Popular Mechanics September 1952

In an electronic lab at MIT, engineers now are

Teaching Power Tools to Run Themselves

By Hartley E. Howe

SO JOE WORKSHOPPER figures he'd like to turn out a set of dining-room chairs—and at the same time break in his new Model 100 Super Tapemaster. Joe whips down to the hardware store and looks over photographs of different designs. He settles on a Swedish pattern popular 'way back in 1955—delicate and handsome, but full of difficult reverse curves.

That doesn't worry Joe. He plunks down $10 for a week's rental of a batch of tapes—one each for legs, arms, back and seat.

That night, he clamps a nice piece of birch into his Tapemaster, slips the tape into the control box, flips the switch, and sits back with his pipe and the new issue of *Outdoor Life*.

Forty minutes later, the rumble of the Tapemaster stops and Joe takes a look. One leg is finished. So he clamps on another piece of birch . . .

Sure it's a dream—in 1955. But the engineering basis for Joe's Tapemaster exists right now. Sitting up in the Servomechanisms Laboratory of the Massachusetts Institute of Technology in Cambridge, Mass., is a milling machine that will turn out any metal part at the command of a little roll of tape. Originally a standard, vertical 28" Cincinnati Hydro-Tel, it now has hitched to it $50,000 worth of electronics.

To conceive, design and build the MIT machine took some quarter-million

Punches in tape code size and time of each cut.

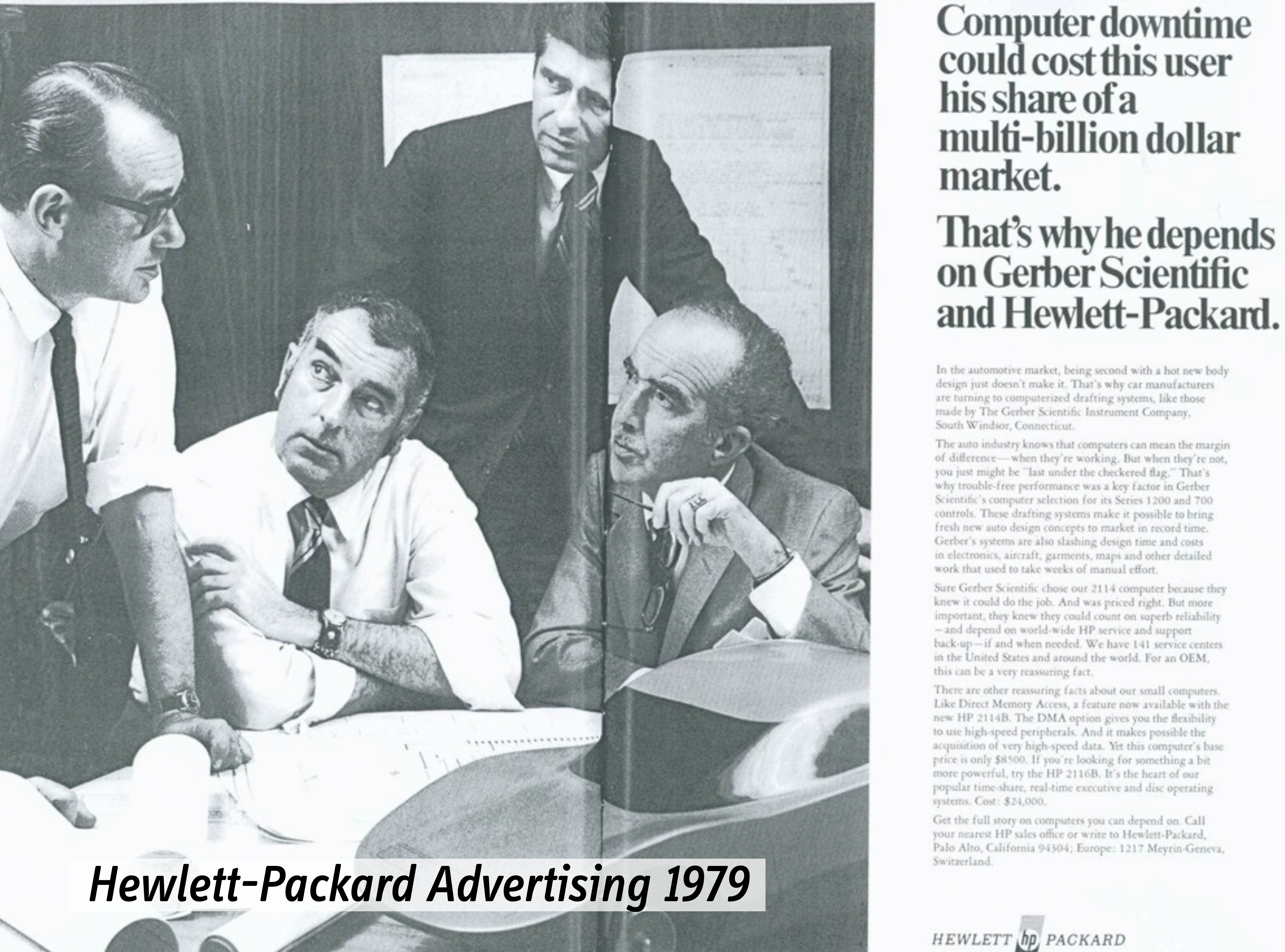
Tape is fed into computer where code is converted to electric signals.

Too big yet for home shop, this MIT milling machine is run by computer-control at left.

Signals control three-dimensional movement of cutter head, time each cut.

Popular Science August 1955

Gerber Scientific Variable Scale 1945



Hewlett-Packard Advertising 1979

Computer downtime could cost this user his share of a multi-billion dollar market.

That's why he depends on Gerber Scientific and Hewlett-Packard.

In the automotive market, being second with a hot new body design just doesn't make it. That's why car manufacturers are turning to computerized drafting systems, like those made by The Gerber Scientific Instrument Company, South Windsor, Connecticut.

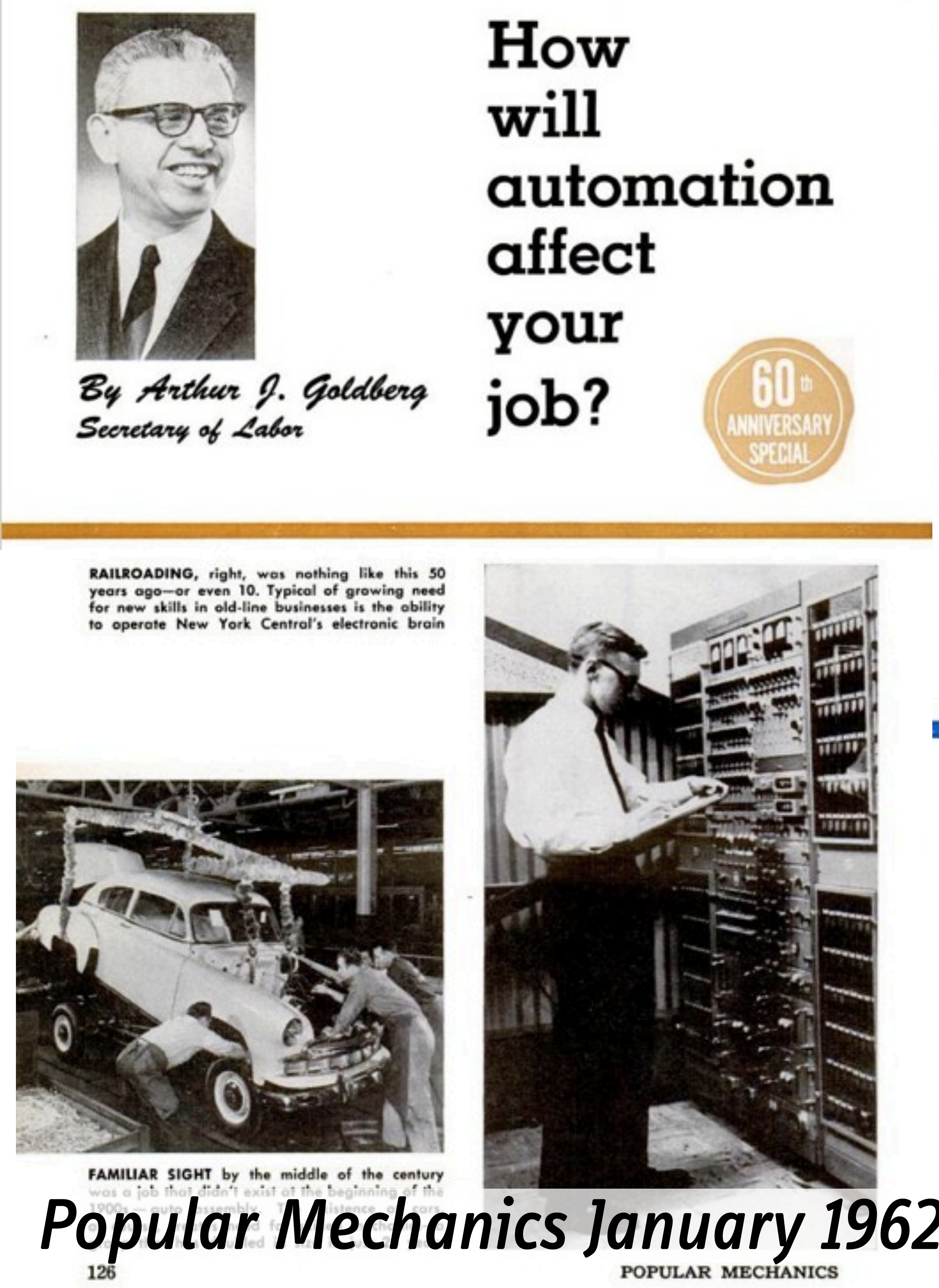
The auto industry knows that computers can mean the margin of difference—when they're working. But when they're not, you just might be "last under the checkered flag." That's why trouble-free performance was a key factor in Gerber Scientific's computer selection for its Series 1200 and 700 controls. These drafting systems make it possible to bring fresh new auto design concepts to market in record time. Gerber's systems are also slashing design time and costs in electronics, aircraft, garments, maps and other detailed work that used to take weeks of manual effort.

Sure Gerber Scientific chose our 2114 computer because they knew it could do the job. And was priced right. But more important, they knew they could count on superb reliability —and depend on world-wide HP service and support back-up—if and when needed. We have 141 service centers in the United States and around the world. For an OEM, this can be a very reassuring fact.

There are other reassuring facts about our small computers. Like Direct Memory Access, a feature now available with the new HP 2114B. The DMA option gives you the flexibility to use high-speed peripherals. And it makes possible the acquisition of very high-speed data. Yet this computer's base price is only $8500. If you're looking for something a bit more powerful, try the HP 2116B. It's the heart of our popular time-share, real-time executive and disc operating systems. Cost: $24,000.

Get the full story on computers you can depend on. Call your nearest HP sales office or write to Hewlett-Packard, Palo Alto, California 94304; Europe: 1217 Meyrin-Geneva, Switzerland.

HEWLETT hp PACKARD



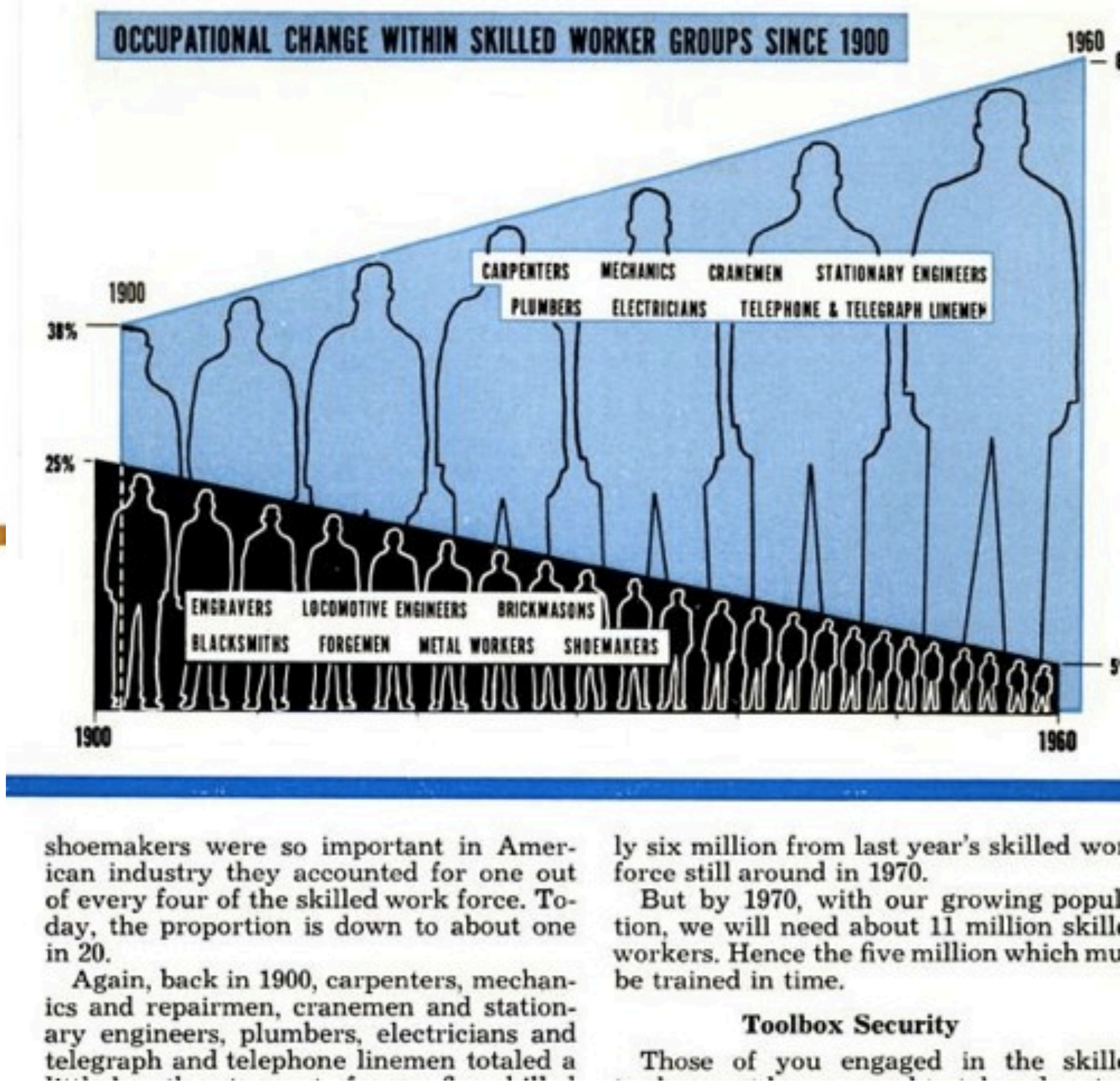
How will automation affect your job?

By Arthur J. Goldberg
Secretary of Labor

RAILROADING, right, was nothing like this 50 years ago—or even 10. Typical of growing need for new skills in old-line businesses is the ability to operate New York Central's electronic brain

FAMILIAR SIGHT by the middle of the century was a job that didn't exist at the beginning of the 1900s — auto assembly. [illegible]

Popular Mechanics January 1962



shoemakers were so important in American industry they accounted for one out of every four of the skilled work force. Today, the proportion is down to about one in 20.

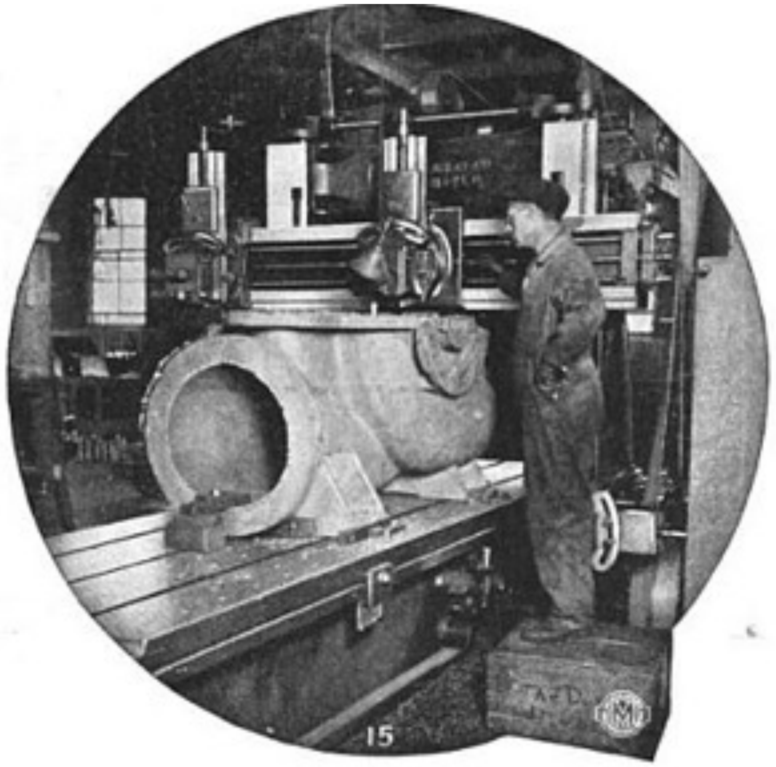
Again, back in 1900, carpenters, mechanics and repairmen, cranemen and stationary engineers, plumbers, electricians and telegraph and telephone linemen totaled a

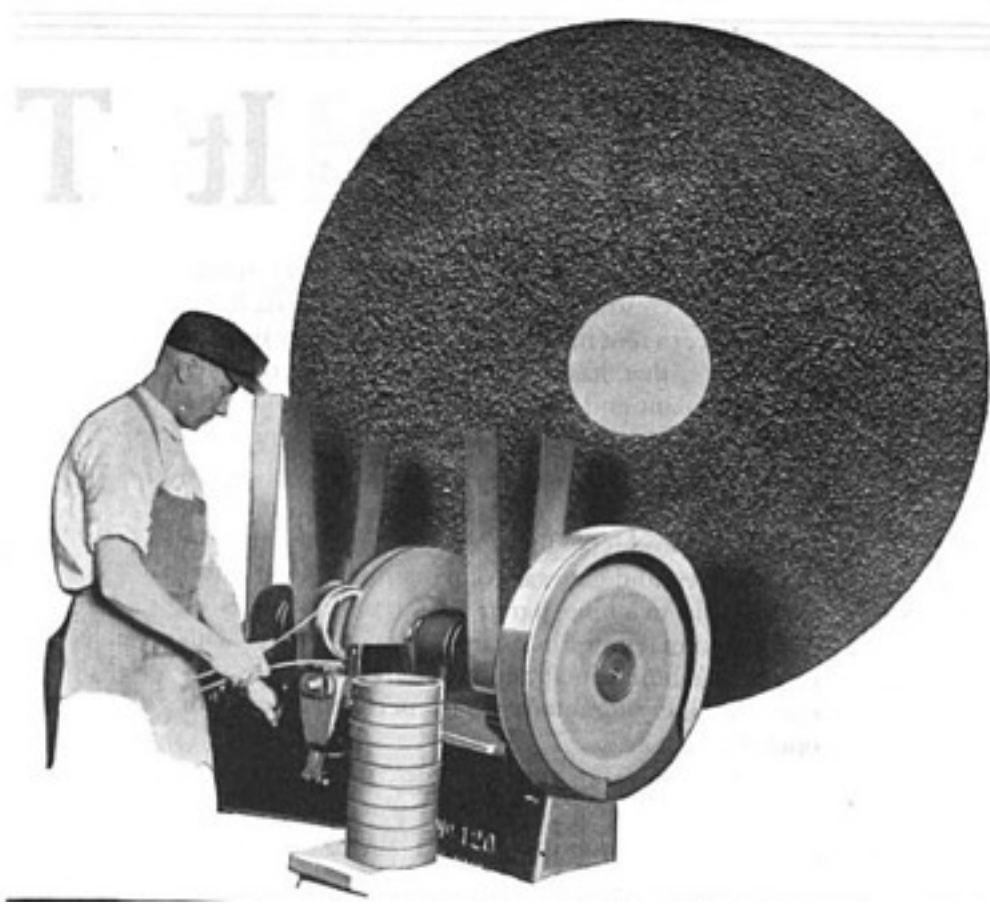
ly six million from last year's skilled wo force still around in 1970.

But by 1970, with our growing popul tion, we will need about 11 million skill workers. Hence the five million which mu be trained in time.

Toolbox Security

Those of you engaged in the skill

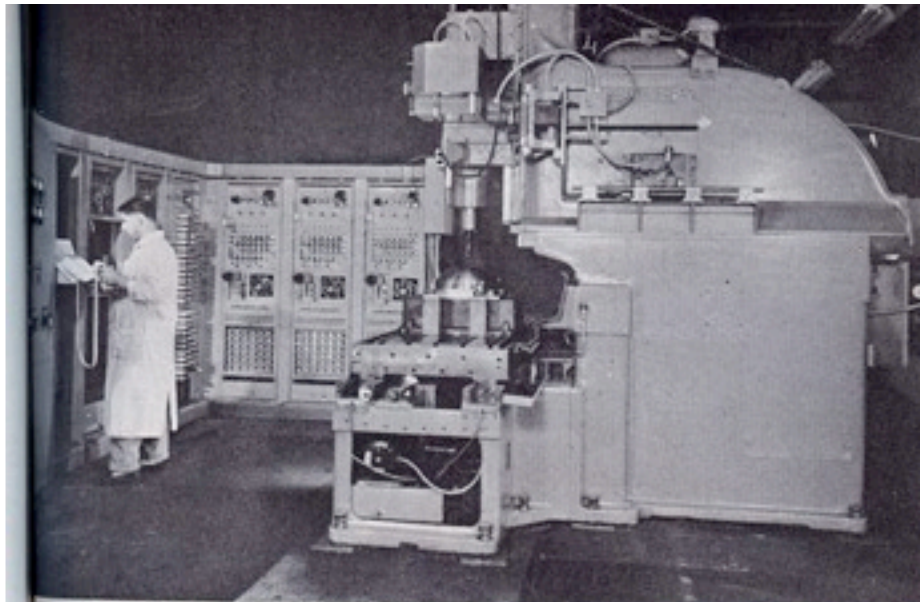




Designer

Tool path writer

Machinist

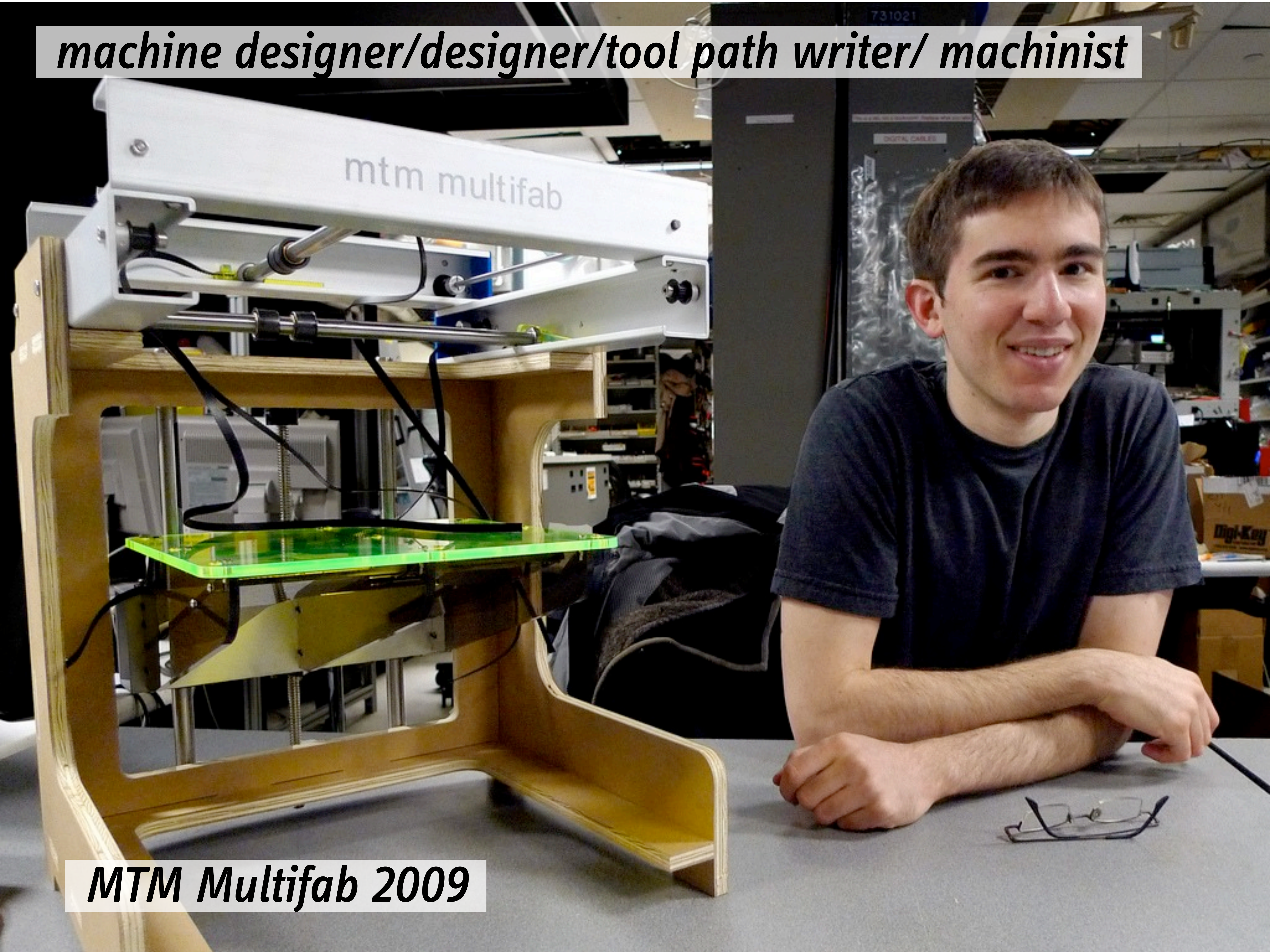


Designer/tool path writer/ machinist

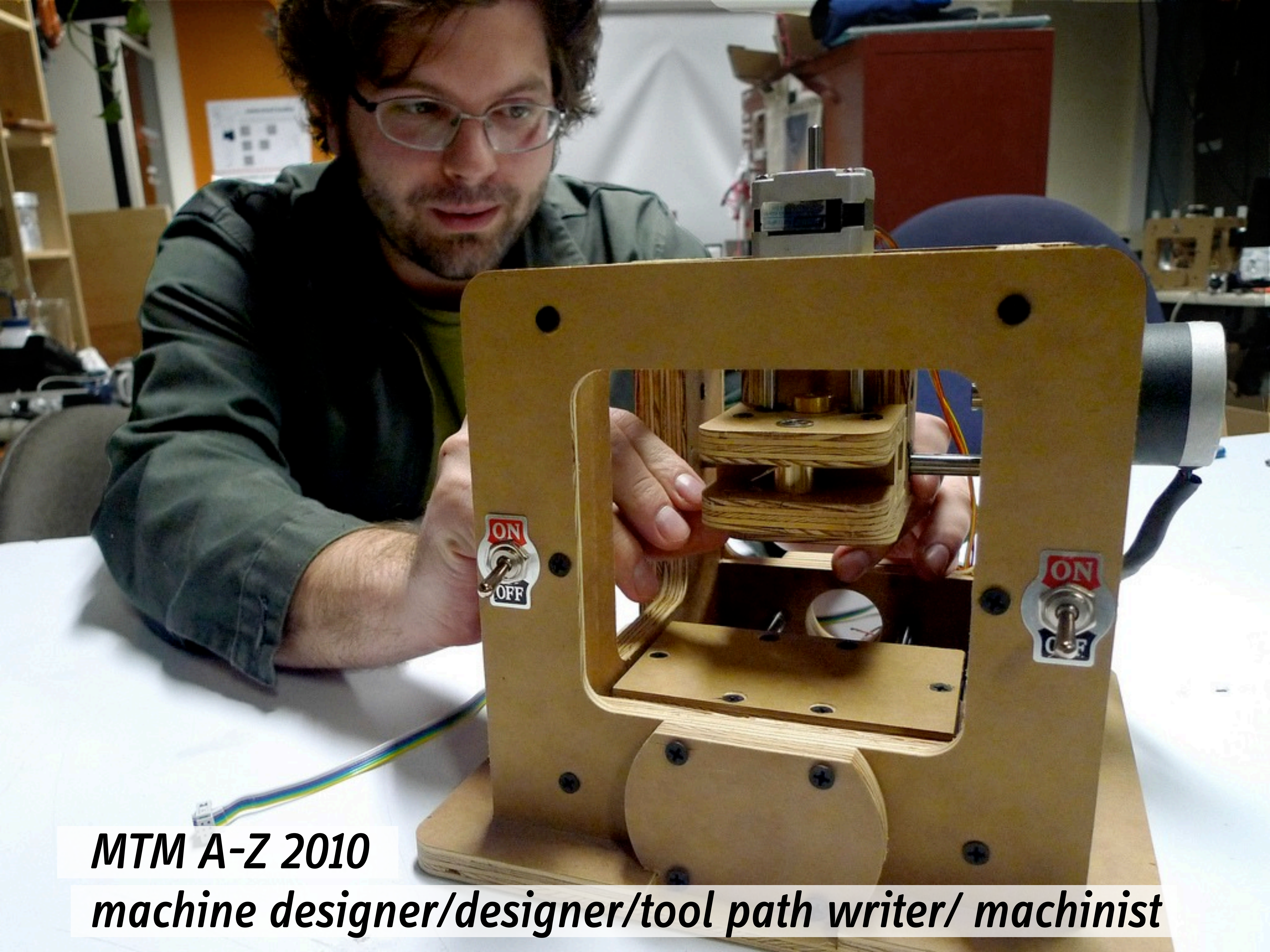
machine designer/designer/tool path writer/ machinist

Fab@Home 2006

machine designer/designer/tool path writer/ machinist



MTM Multifab 2009



MTM A-Z 2010

machine designer/designer/tool path writer/ machinist

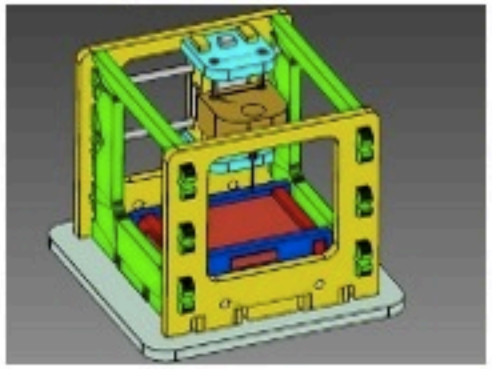
machines that make

themselves • other machines • functional parts • fun stuff

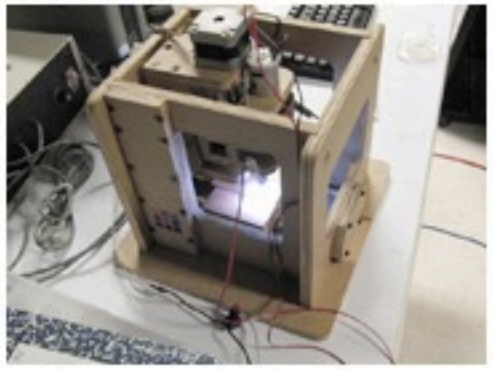
MACHINES

Fab-In-A-Box

MtM Snap-Lock



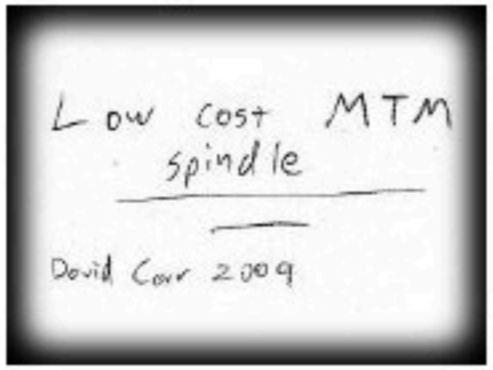
MtM A-Z



TOOLHEADS

Spindle

Low Cost Spindle

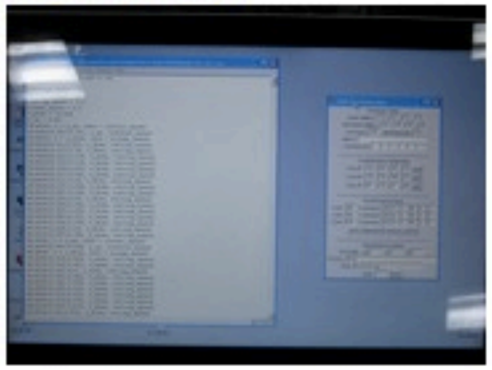


Low cost MTM
spindle

David Carr 2009

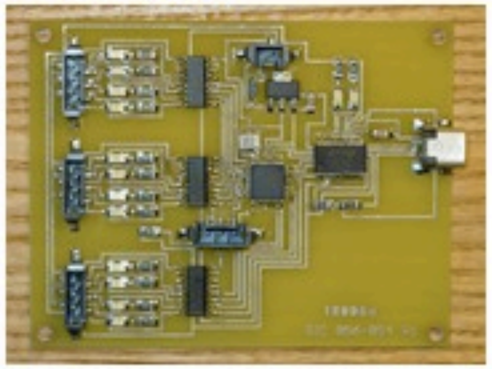
CONTROL

Virtual Machines



Internet Zero

Simple Stepper



PEOPLE

Jonathan Ward

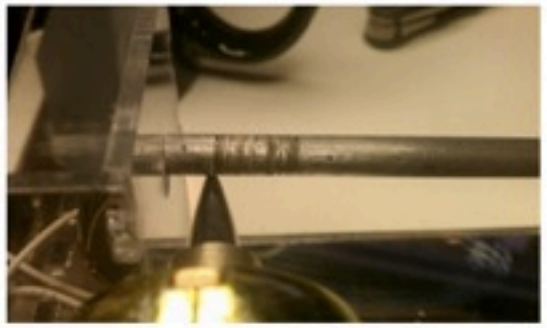
Maxim Lobovsky

Steffen Reichert

Machines that Make

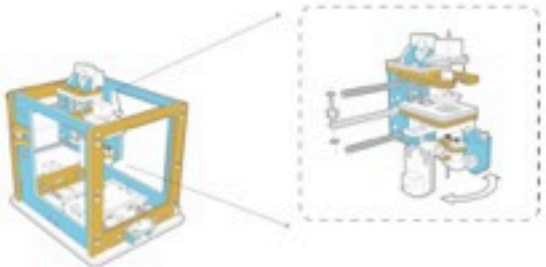
The Machine that make project at the MIT Center for Bits and Atoms seeks to develop low-cost machines that can be made using CNC equipment, like available in fab labs.

DIY EDM



An entry level (under $500) EDM machine for making carbide/HSS tooling and/or lead screws

5 Axis Timing Belt MTM

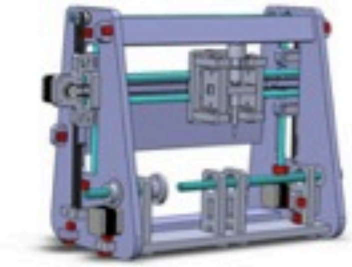


Low cost 5 axis machining.

POP Fab

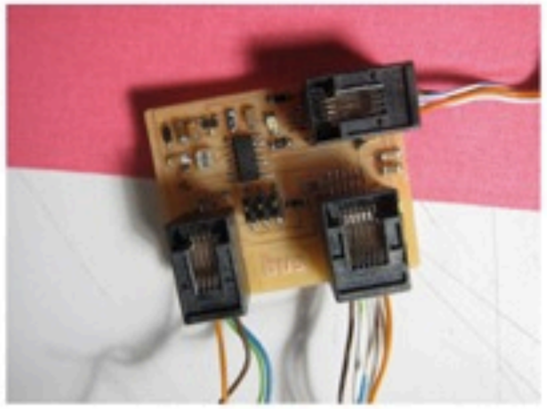
A suitcase milling machine, 3d printer, and vinyl cutter.

Multi-processes lathe



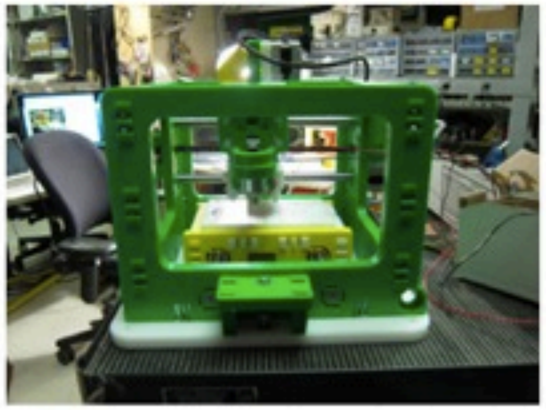
The additive lathe is a 3D printer that prints on rotation objects.

Virtual Machine Network



Modular control for the MTM project.

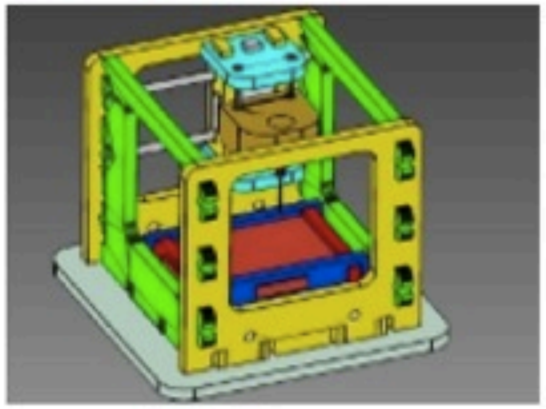
Timing Belt MTM

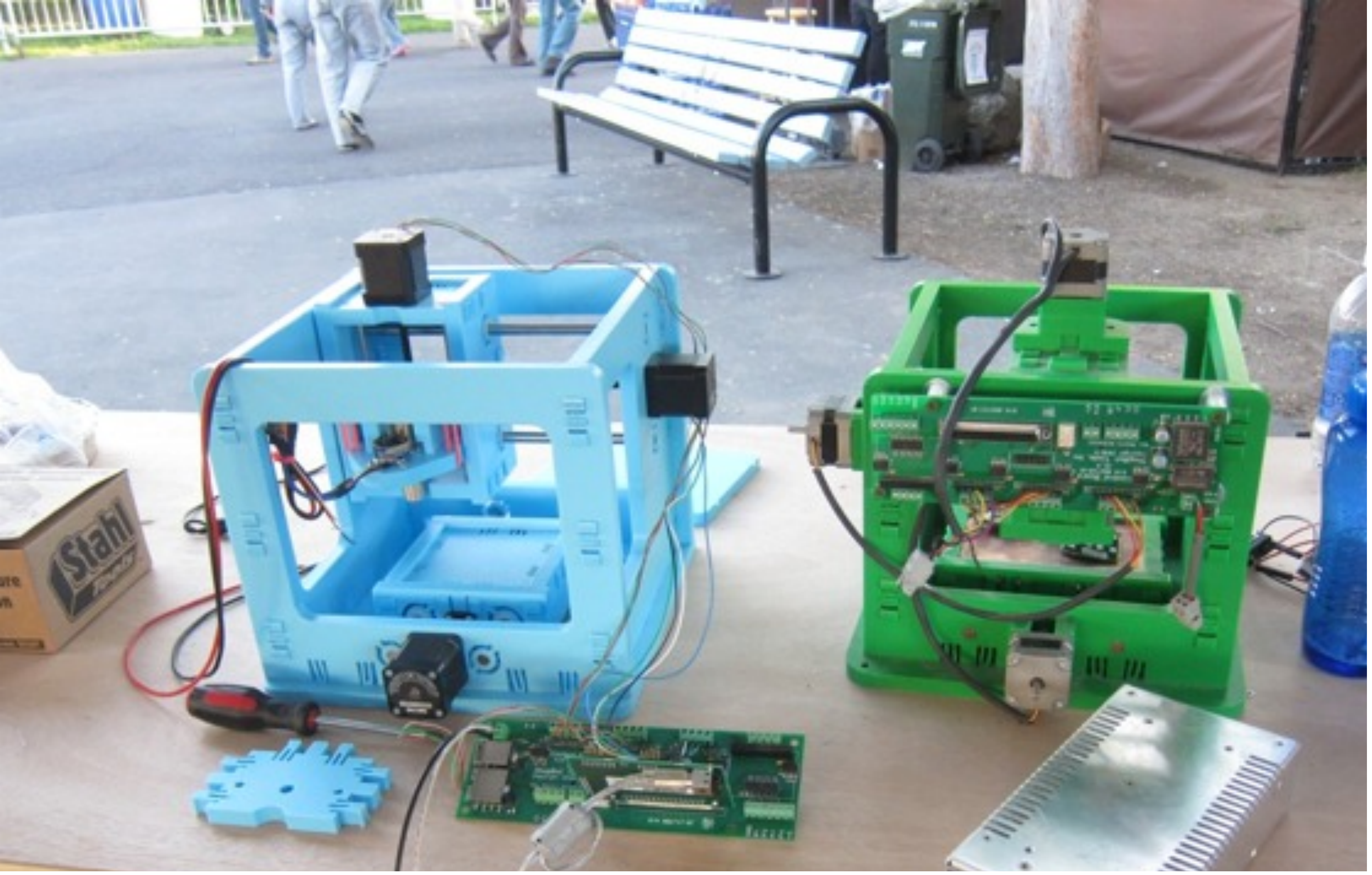


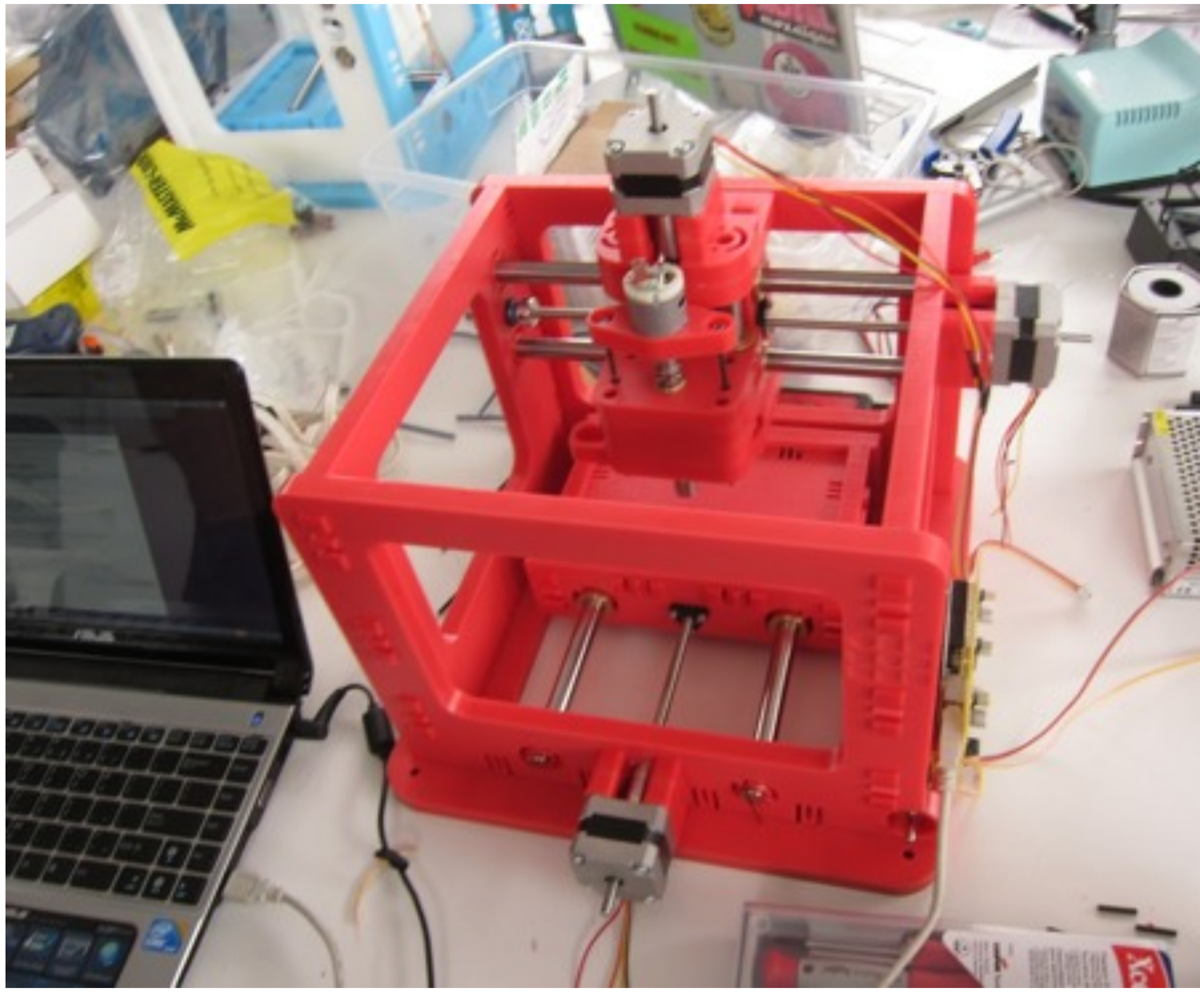
A design without lead screws, reducing cost.

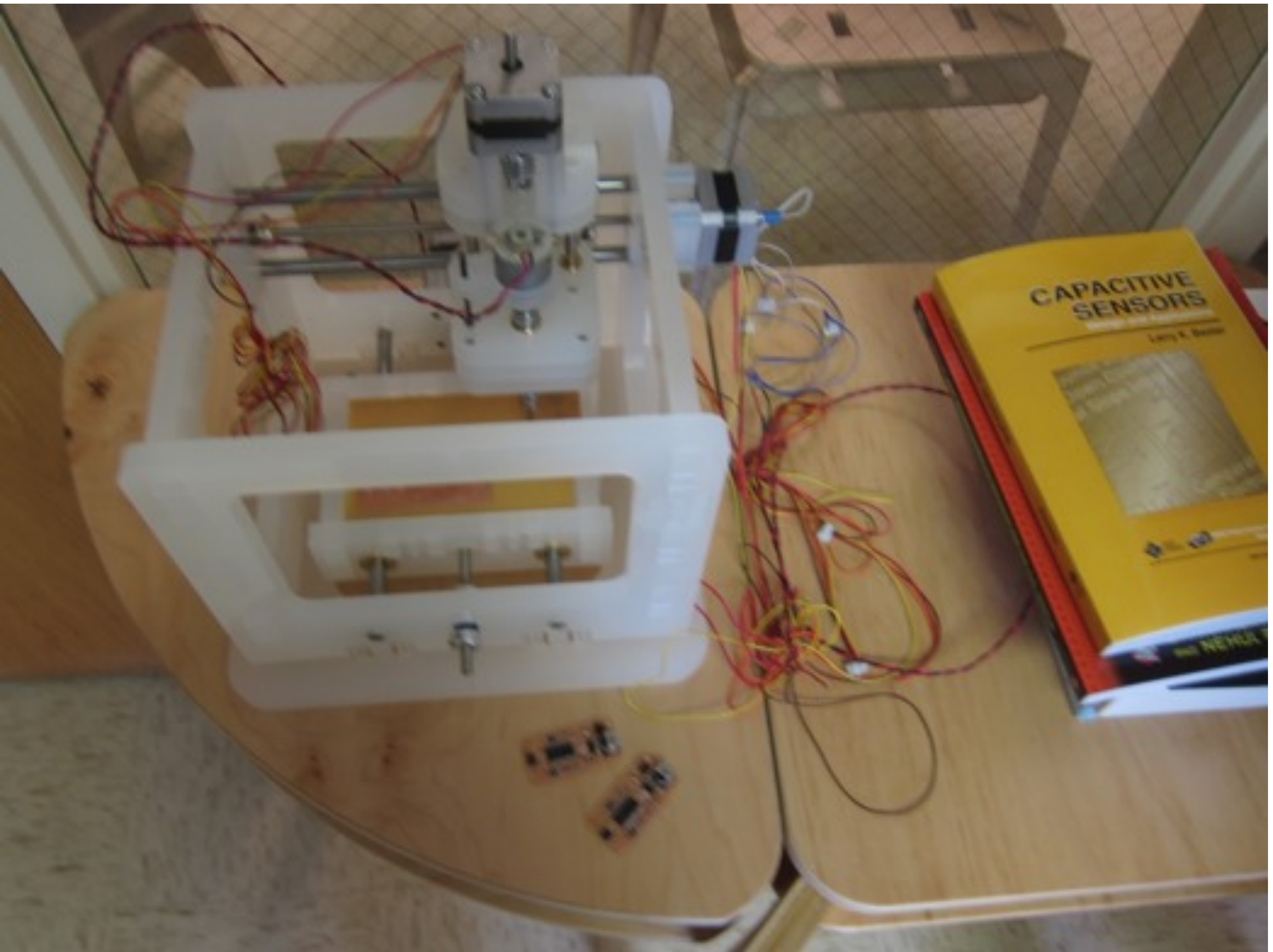
Fab-In-A-Box

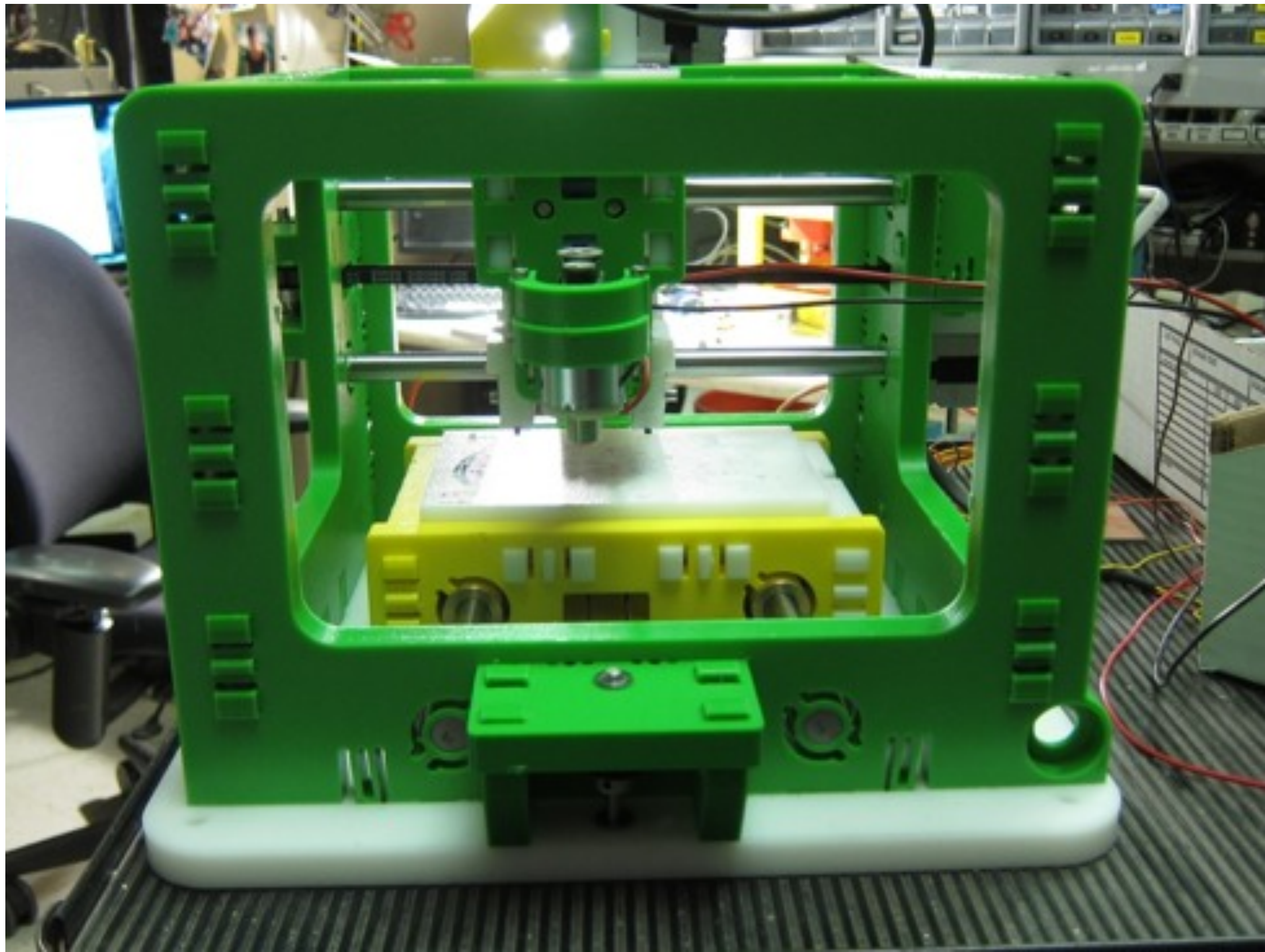
MtM Snap-Lock




Stahl

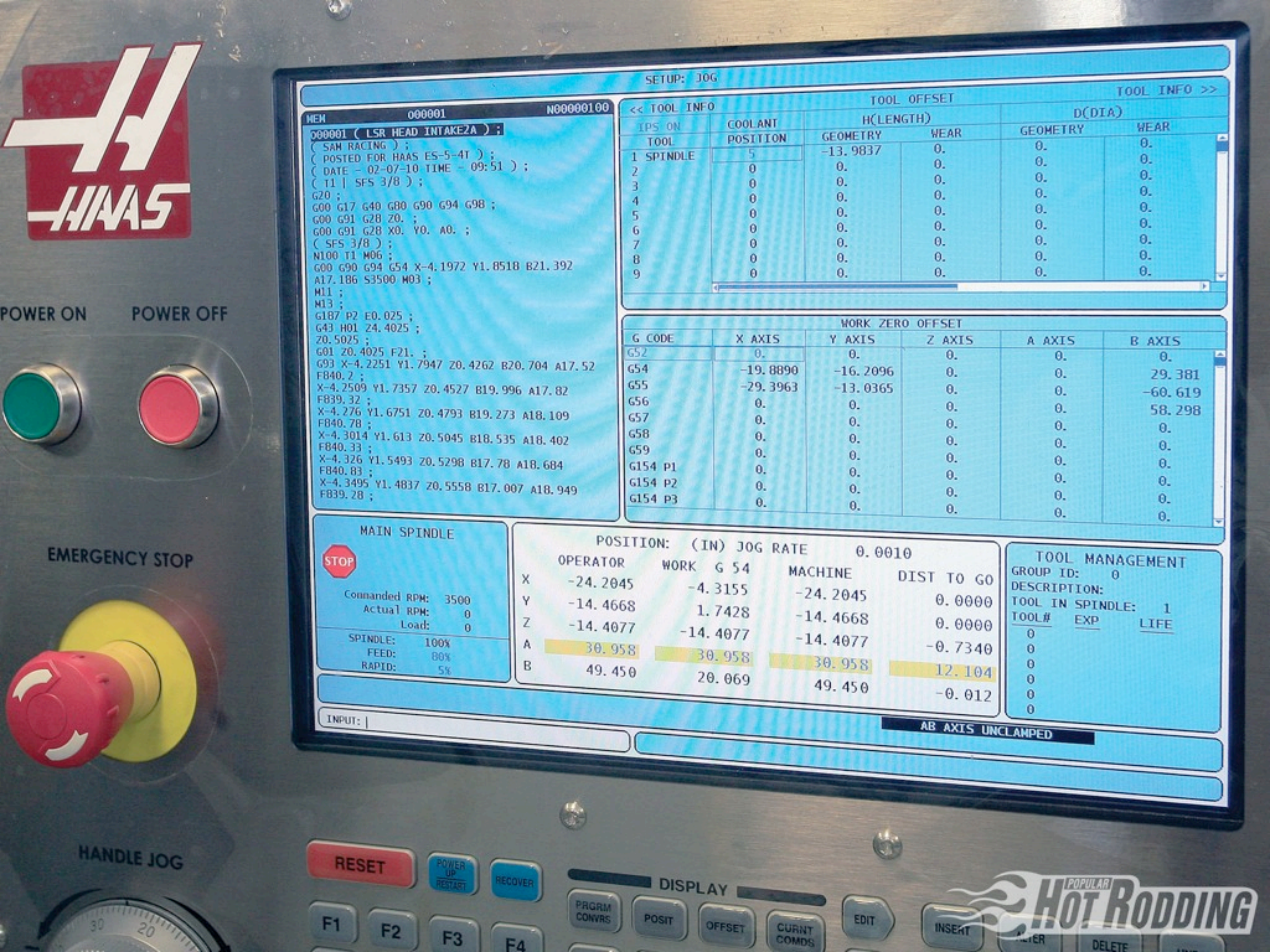



CAPACITIVE SENSORS
Larry K. Baxter



If CNC is so great, why is this how I talk to it?

```
PROGRAM (LIST PROG)                    O00101 N00000
  O00000
  O00001 (STAINLESS STEEL FLANGE)
  O00002 (BORE A PART)
  O00004 (1-1/2" PAWL G13 PROGRAM)
  O00098 (SDR .005 SHAFT CROSS HOLE)
  O00099 (SDR 1.375 SHAFT CROSS HOLE)
  O00100 (SDR VERTICAL COUNTERSUNK HOLE)
 *O00101 (1.75" PAWL G13 PROGRAM)
  O00102 (POWER GRIP ARM CASTING)
  O00103 (1.375 PAWL .200 BLADE.TXT)
  O00104 (1-1/2" PAWL G13 PROGRAM)
  O00111 (GRIP MOUNT SIDES.NC)
  O00112 (ADJUSTMENT PLATE.NC)
  O00113 (BOTTOM POWER GRIP MOUNT.NC)
  O00114 (TOP POWER GRIP MOUNT.NC)
  O00115 (2BIN SWIVEL ADAPTOR SANDWICH PL
 44 PROGRAMS  57% FREE (598106 BYTES)
ALL TO SEND, RECV, ERASE  F1 TO DUP PROG
F2 DISK WR, F3 DISK RD, F4 DIR RD
```



SETUP: JOG

```
MEM            000001                    N00000100
000001 ( LSR HEAD INTAKE2A ) ;
( SAM RACING ) ;
( POSTED FOR HAAS ES-5-4T ) ;
( DATE - 02-07-10 TIME - 09:51 ) ;
( T1 | SFS 3/8 ) ;
G20 ;
G00 G17 G40 G80 G90 G94 G98 ;
G00 G91 G28 Z0. ;
G00 G91 G28 X0. Y0. A0. ;
( SFS 3/8 ) ;
N100 T1 M06 ;
G00 G90 G94 G54 X-4.1972 Y1.8518 B21.392
A17.186 S3500 M03 ;
M11 ;
M13 ;
G187 P2 E0.025 ;
G43 H01 24.4025 ;
Z0.5025 ;
G01 Z0.4025 F21. ;
G93 X-4.2251 Y1.7947 Z0.4262 B20.704 A17.52
F840.2 ;
X-4.2509 Y1.7357 Z0.4527 B19.996 A17.82
F839.32 ;
X-4.276 Y1.6751 Z0.4793 B19.273 A18.109
F840.78 ;
X-4.3014 Y1.613 Z0.5045 B18.535 A18.402
F840.33 ;
X-4.326 Y1.5493 Z0.5298 B17.78 A18.684
F840.83 ;
X-4.3495 Y1.4837 Z0.5558 B17.007 A18.949
F839.28 ;
```

<< TOOL INFO   TOOL OFFSET   TOOL INFO >>

IPS ON TOOL	COOLANT POSITION	H(LENGTH) GEOMETRY	H(LENGTH) WEAR	D(DIA) GEOMETRY	D(DIA) WEAR
1 SPINDLE	5	-13.9837	0.	0.	0.
2	0	0.	0.	0.	0.
3	0	0.	0.	0.	0.
4	0	0.	0.	0.	0.
5	0	0.	0.	0.	0.
6	0	0.	0.	0.	0.
7	0	0.	0.	0.	0.
8	0	0.	0.	0.	0.
9	0	0.	0.	0.	0.

WORK ZERO OFFSET

G CODE	X AXIS	Y AXIS	Z AXIS	A AXIS	B AXIS
G52	0.	0.	0.	0.	0.
G54	-19.8890	-16.2096	0.	0.	29.381
G55	-29.3963	-13.0365	0.	0.	-60.619
G56	0.	0.	0.	0.	58.298
G57	0.	0.	0.	0.	0.
G58	0.	0.	0.	0.	0.
G59	0.	0.	0.	0.	0.
G154 P1	0.	0.	0.	0.	0.
G154 P2	0.	0.	0.	0.	0.
G154 P3	0.	0.	0.	0.	0.
		0.	0.	0.	0.

```
MAIN SPINDLE
STOP
Commanded RPM:  3500
   Actual RPM:     0
         Load:     0
   SPINDLE:  100%
      FEED:   80%
     RAPID:    5%
```

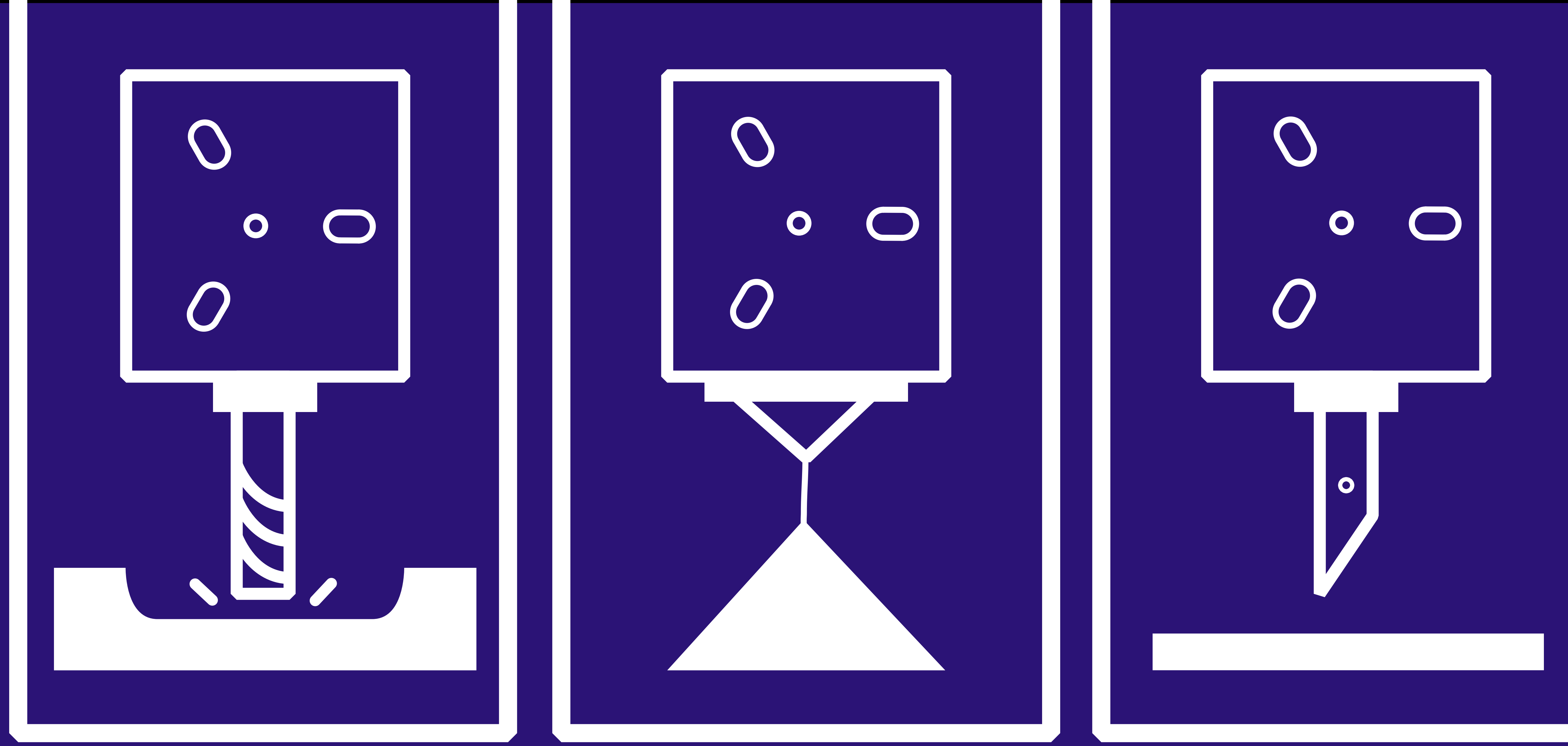
```
     POSITION:  (IN) JOG RATE    0.0010
     OPERATOR     WORK  G 54    MACHINE    DIST TO GO
X    -24.2045      -4.3155     -24.2045      0.0000
Y    -14.4668       1.7428     -14.4668      0.0000
Z    -14.4077     -14.4077     -14.4077     -0.7340
A     30.958       30.958       30.958      12.104
B     49.450       20.069       49.450      -0.012
```

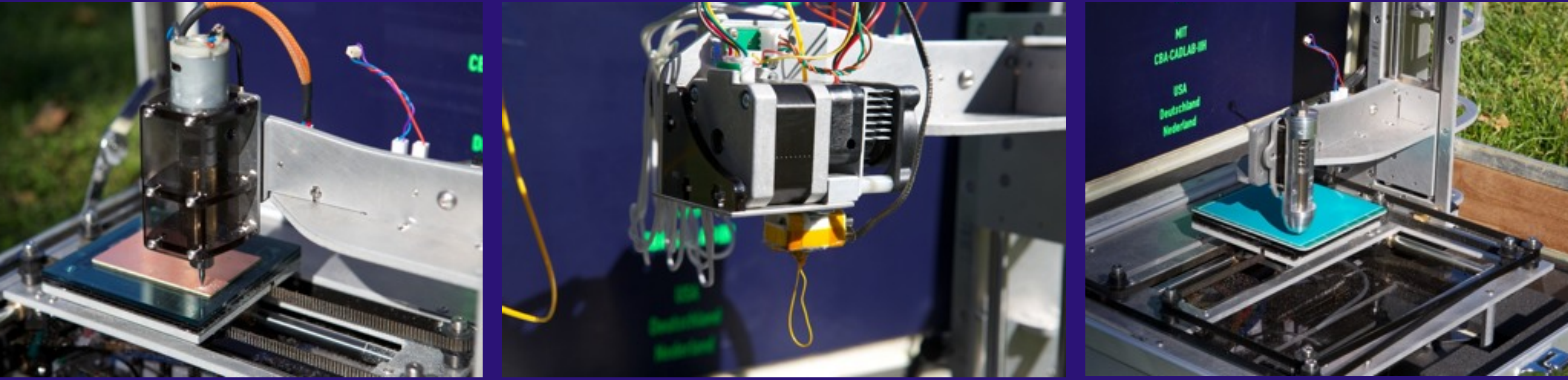
```
TOOL MANAGEMENT
GROUP ID:    0
DESCRIPTION:
TOOL IN SPINDLE:   1
TOOL#   EXP      LIFE
  0
  0
  0
  0
  0
  0
```

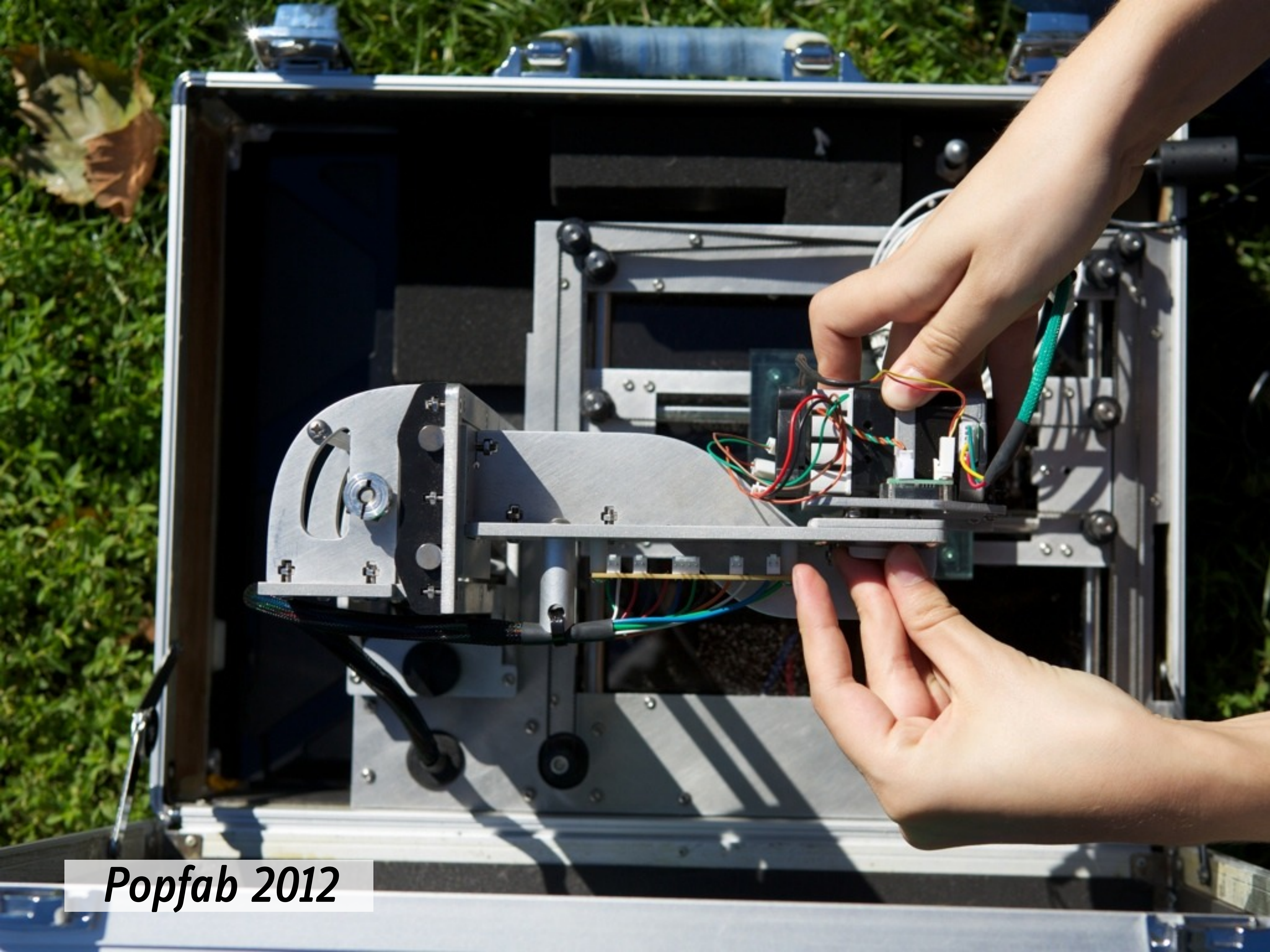
INPUT: |

AB AXIS UNCLAMPED


POPFAB
V1.0
USA
Deutschland
Nederland




MIT
CBA-CADLAB-IIH
USA
Deutschland
Nederland



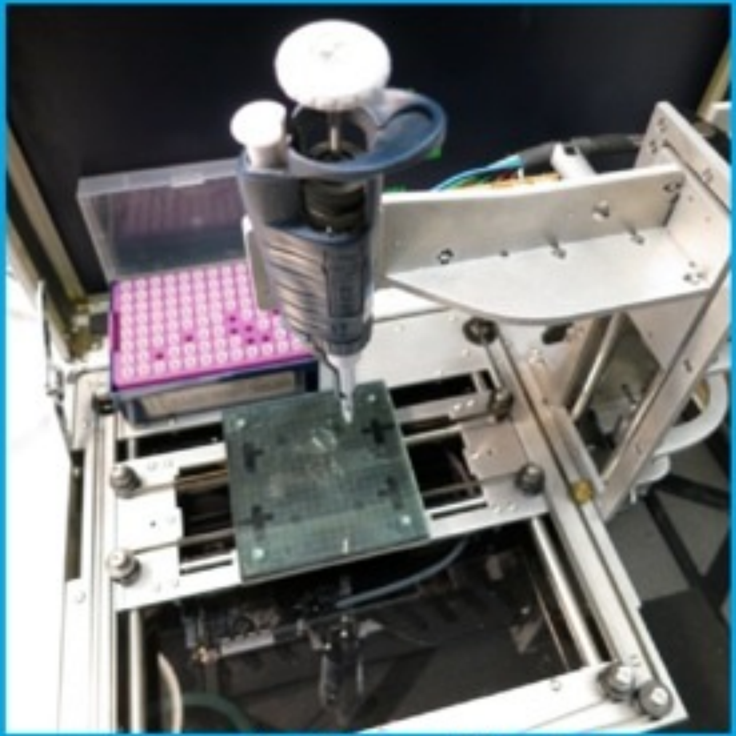
Popfab 2012

Rapid prototyping for rapid biology

how you can make automated lab equipment in an afternoon

For ~$100000s you can buy state of the art bio equipment like liquid handling robots:

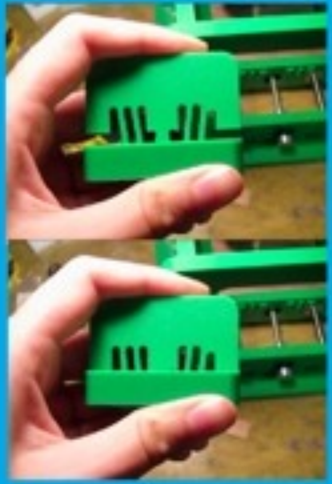
They are:
- ***cumbersome to program,***
- ***hard to extend with new capabilities,***
- ***difficult to integrate into bigger automated experiments,***
- ***impossible to retrofit to accomodate larger footprints,***
- ***and really overpriced.***



liquid handling briefcase

For ~$100s you can build faster, better, customised, modular machines using:

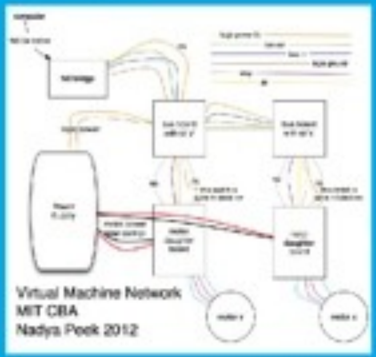
1. Self-aligning structures

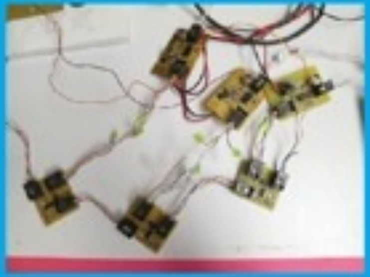


2. Custom rigid motion stages

3. Application specific toolheads

4. Modular networked machine control





5. Sensor control with software interfaces

6. Easy integration from machine to machine

Nadya Peek, peek@mit.edu, MIT Center for Bits and Atoms, February 2013

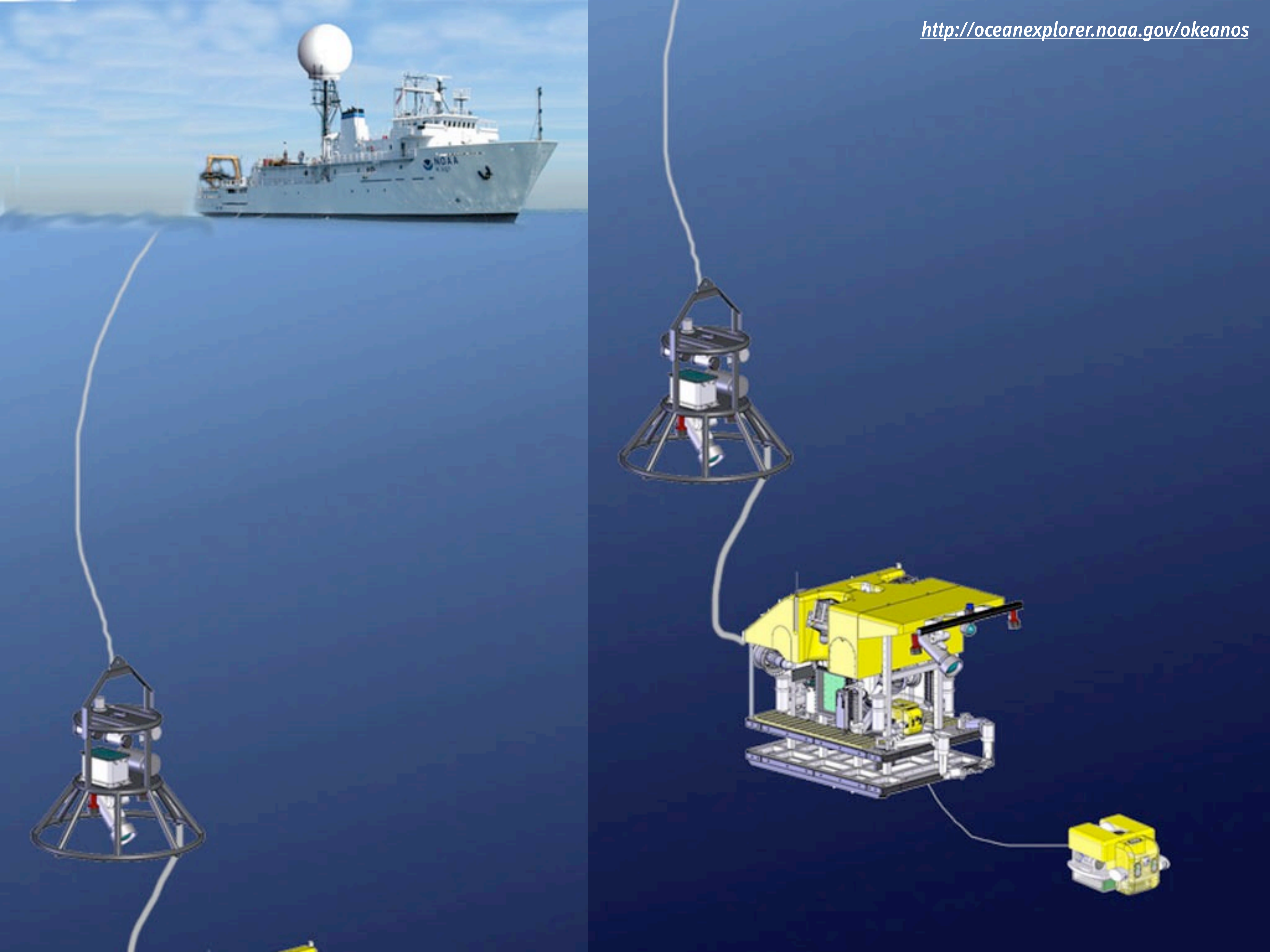
Virtual Machine Control

Each real machine part is directly controlled by a virtual machine counterpart

No state in the machine

Integrated system for control

New behaviours for machine interaction



http://oceanexplorer.noaa.gov/okeanos

Virtual Machine Control Benefits

Directly from CAD programs to machine control

Using all of a machine’s capabilities

Rapid prototyping of new, custom tools

The Internet of Things

The principles that gave rise to the Internet are now leading to a new kind of network of everyday devices, an "Internet-0"

By Neil Gershenfeld, Raffi Krikorian and Danny Cohen

In Barcelona about a century ago, Antoni Gaudí pioneered a fluid building style that seamlessly integrated visual and structural design. The expressive curves of his buildings were not just ornamental facades but also integral parts of the load-bearing structure. Unfortunately, a similar unification has yet to happen for the electronic infrastructure in a building. Switches, sockets and thermostats are grafted on as afterthoughts to the architecture, with functions fixed by buried wiring. Appliances and computers arrive as after-the-fact intrusions. Almost nothing talks to anything else, as evidenced by the number of devices in a typical house or office with differing opinions as to the time of day.

These inconveniences have surprisingly broad implications for construction economics, energy efficiency, architectural expression and, ultimately, quality of life. In the U.S., building buildings is a $1-trillion industry. Of that, billions are spent annually on drawing wiring diagrams, then following, fixing and revising them. Over the years, countless "smart home" projects have sought to find new applications for intelligent building infrastructure—neglecting the enormous existing demand for facilities that can be programmed by their occupants rather than requiring contractors to fix their functionality in advance.

Any effort to meet that demand, though, will be doomed if a lightbulb requires a skilled network engineer to install it and the services of a corporate IT department to manage it. The challenge of improving connectivity requires neither gigabit speeds nor gigabyte storage but rather the opposite: dramatic reductions in the cost and complexity of network installation and configuration.

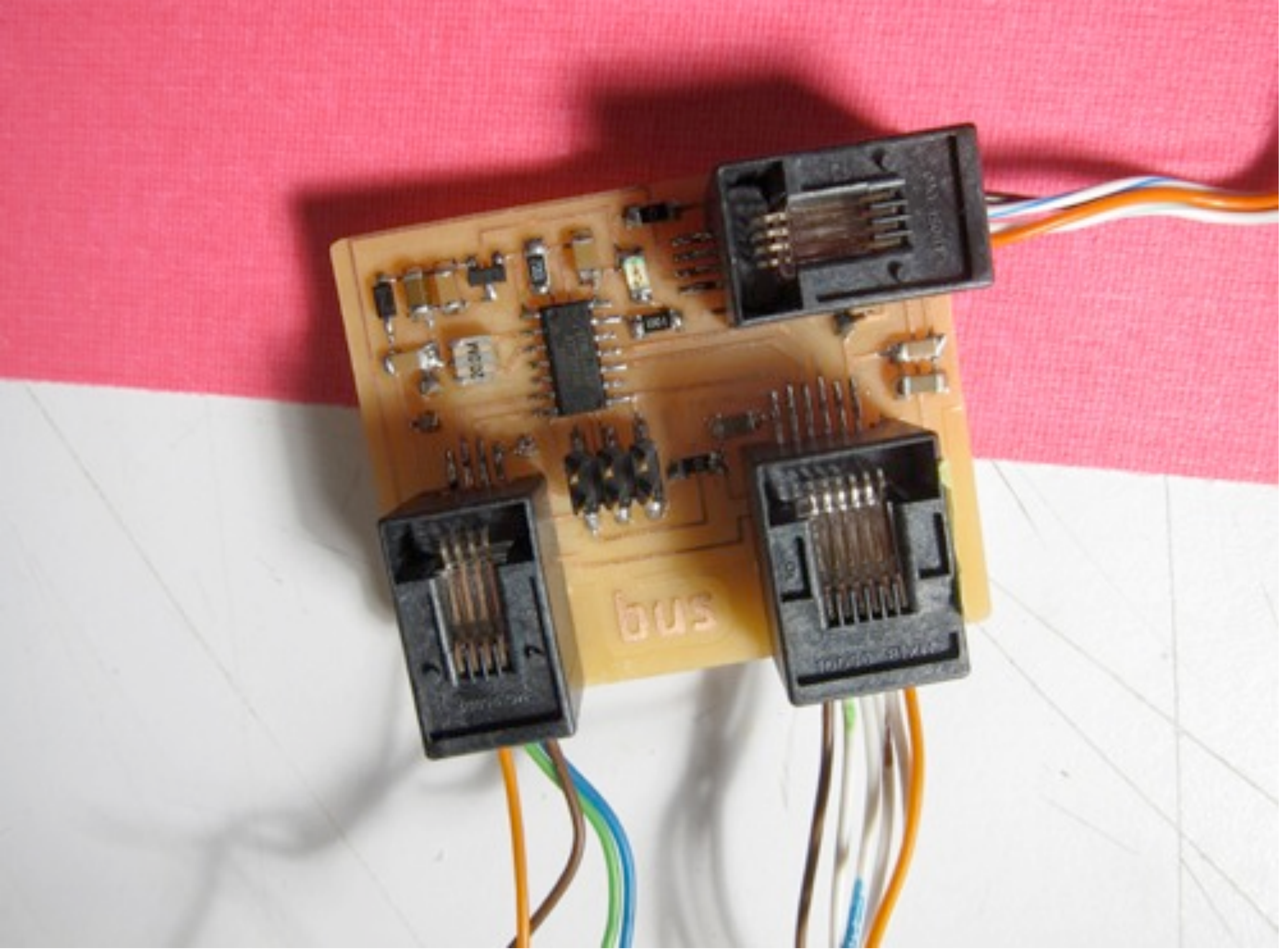
Over the years, a bewildering variety of standards have been developed to interconnect household devices, including X10, LonWorks, CEBus, BACnet, ZigBee, Bluetooth, IrDA and HomePlug. The situation is analogous to that in the 1960s when the Arpanet, the Internet's predecessor, was developed. There were multiple types of computers and networks then, requiring special-purpose hardware to bridge these islands of incompatibility.

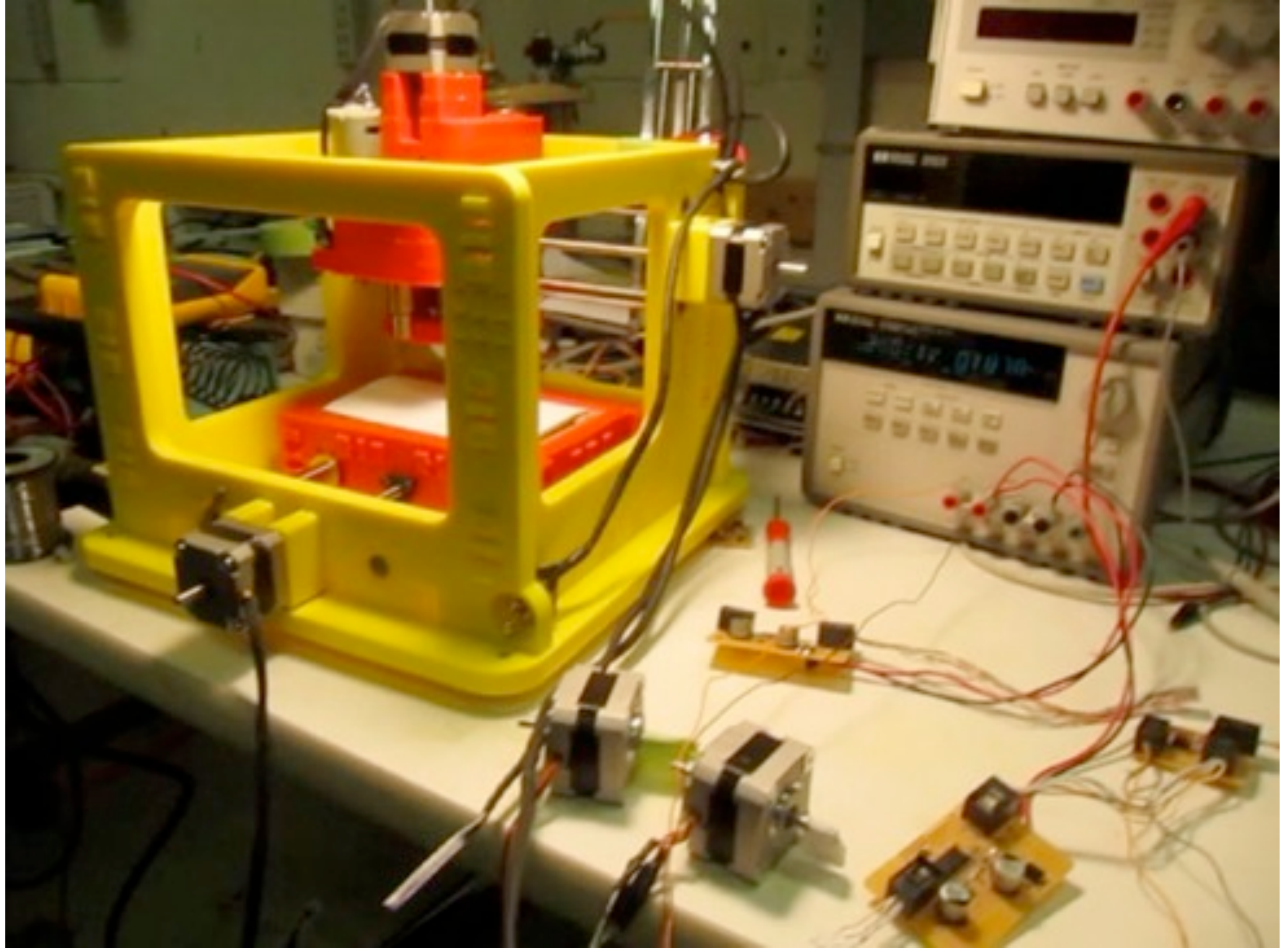
The solution to building a global network out of heterogeneous local networks, called internetworking, was found in two big ideas. The first was packet switching: data are chopped up into packets that can be routed independently as needed and then recombined. This technique marked a break from the traditional approach, used in telephone networks, of dedicating a static circuit to each connection. The second idea was the "end-to-end" principle: the behavior of the network should be determined by what is connected to it rather than by its internal construction, a concept embodied in the Internet Protocol (IP). Gradually the Internet expanded to handle applications ranging from remote computer access to e-commerce to interactive video. Each of these services introduced new types of data for packets to carry, but engineers did not need to change the network's hardware or software to implement them.

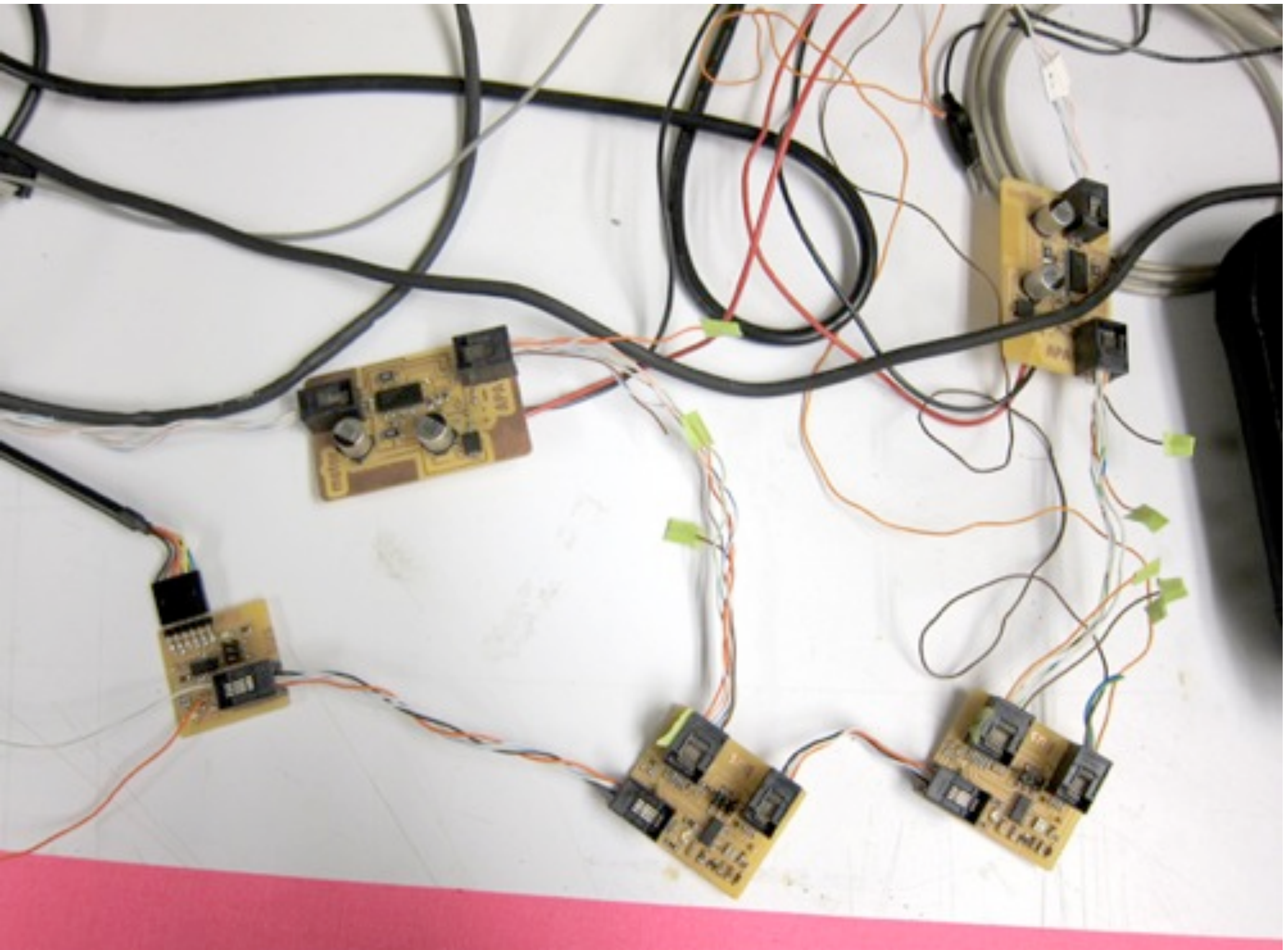
These principles have carried the Internet through three decades of growth spanning seven orders of magnitude in both performance and size—from the Arpanet's 64 sites to today's 200 million registered hosts. They represent timeless insights into good system design, and, crucially, they contain no specific performance requirements. With great effort and discipline, technology-dependent parameters were kept out of the specifications so that hardware could evolve without requiring a revision of the Internet's basic architecture.

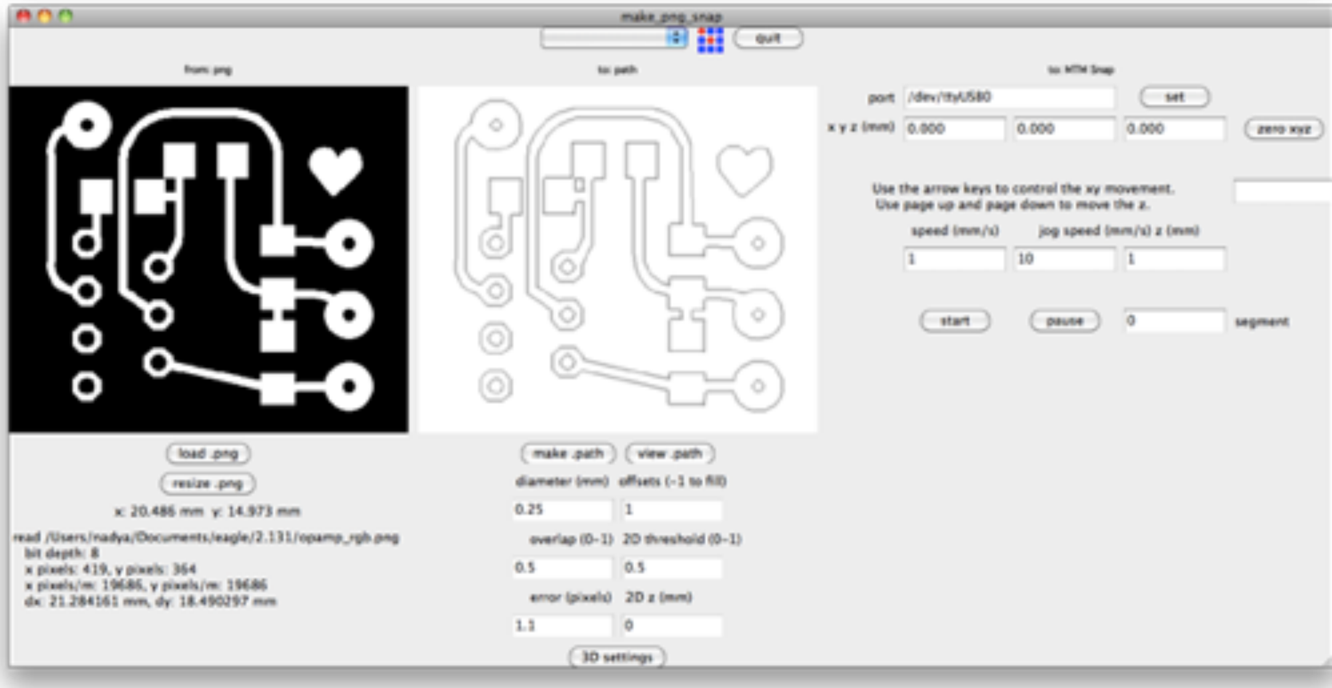
These same ideas can now solve the problem of connecting

EVEN SOMETHING AS SIMPLE as a lightbulb could be connected directly to the Internet, if suitably equipped with cheap circuitry that sends signals along the electrical wiring.









port: /dev/ttyUSB0

x y z (mm): 0.000 0.000 0.000

Use the arrow keys to control the xy movement.
Use page up and page down to move the z.

speed (mm/s): 1

jog speed (mm/s): 10

z (mm): 1

segment: 0

x: 20.486 mm y: 14.973 mm

```
read /Users/nadya/Documents/eagle/2.131/opamp_rgb.png
  bit depth: 8
  x pixels: 419, y pixels: 364
  x pixels/m: 19686, y pixels/m: 19686
  dx: 21.284161 mm, dy: 18.490297 mm
```

diameter (mm): 0.25

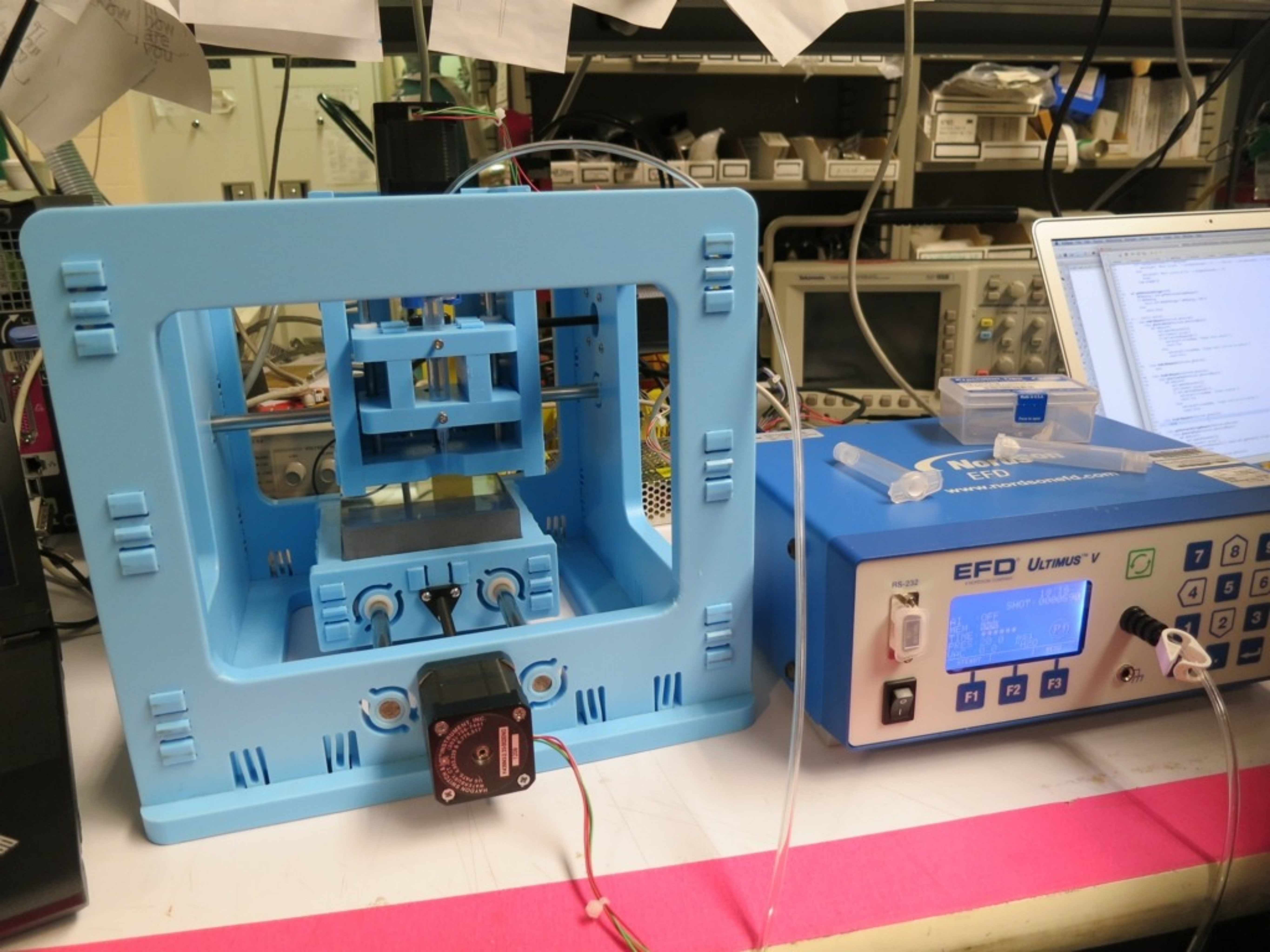
offsets (-1 to fill): 1

overlap (0-1): 0.5

2D threshold (0-1): 0.5

error (pixels): 1.1

2D z (mm): 0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Virtual Machine Control Future

Standard real time machine node communication (busses, asynchronous networks)

Open libraries of kinematics and control (ability to import motor types, stages, alternate sensors/actuators, closed loop control)

Calibration and heuristics for standard results across machine families

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