

Bio(tech) Interlude: PCR and DNA Sequencing

3 Nobel Prizes:

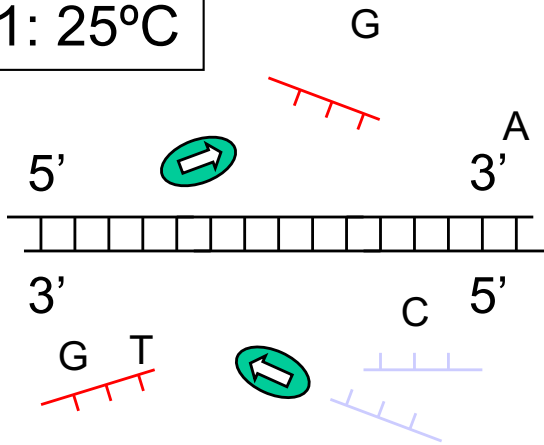
PCR: Kary Mullis, 1993

Electrophoresis: A.W.K. Tiselius, 1948

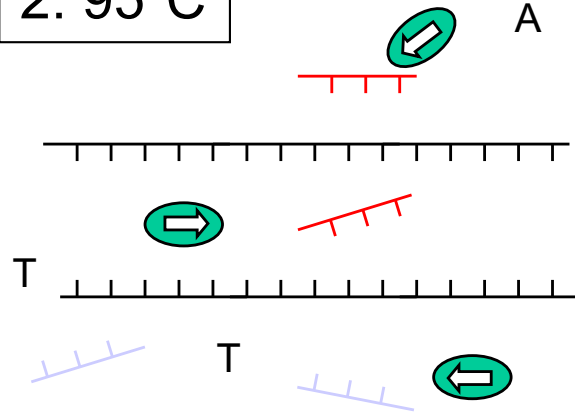
DNA Sequencing: Frederick Sanger, 1980

PCR

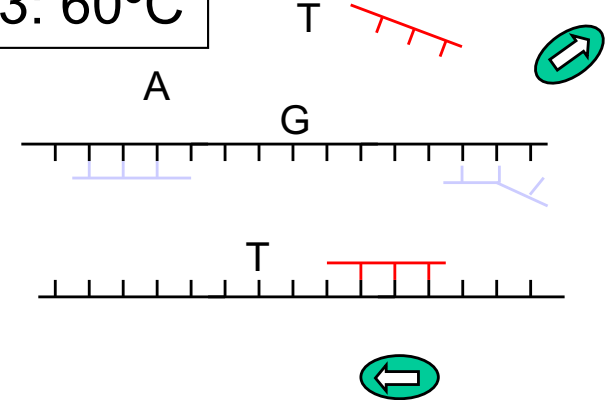
1: 25°C



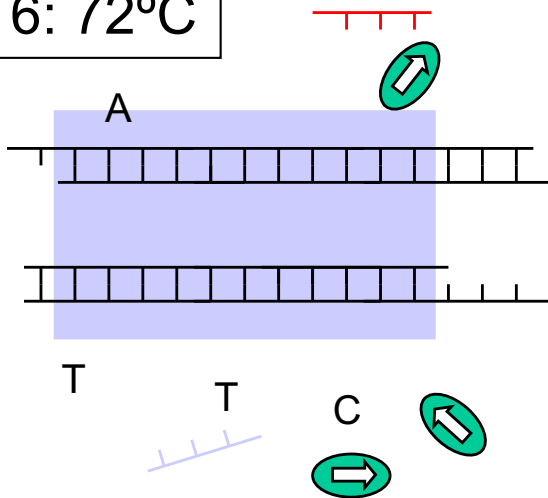
2: 95°C



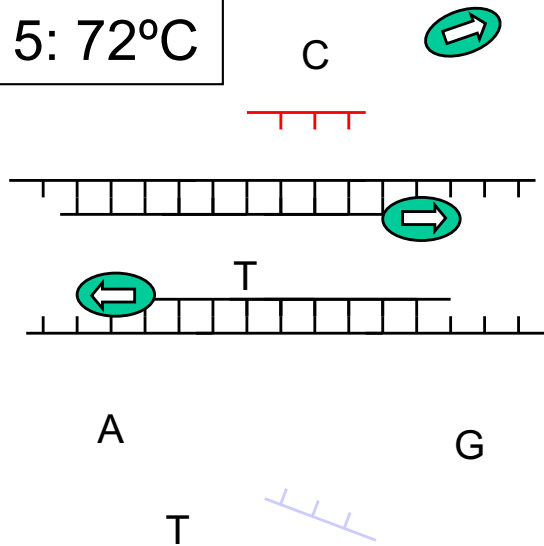
3: 60°C



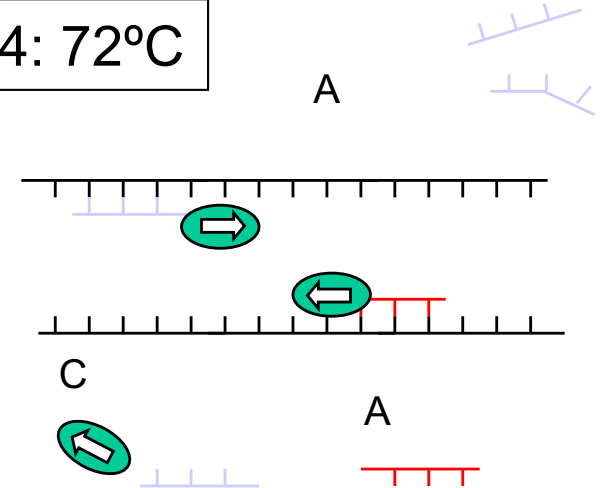
6: 72°C



5: 72°C



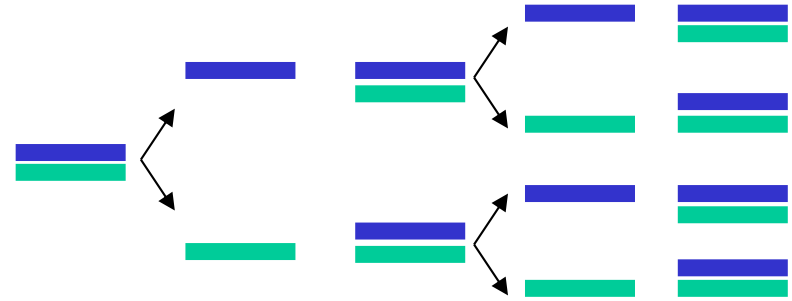
4: 72°C





Hot spring, near Great Fountain
Geyser, Yellowstone National Park

PCR



Ingredients:

- many copies of deoxy nucleotide triphosphates

- many copies of two primer sequences (~20 nt each)

- readily synthesized

- many copies of Taq polymerase (*Thermus aquaticus*),

- readily available commercially

- as little as 1 strand of template DNA

- a programmable “thermal cycler”

Amplification: million to billion fold

Range: up to 2k bp routinely; 50k with other enzymes & care

Why PCR?

PCR is important for all the reasons that filters and amplifiers are important in electronics, e.g., sample size is reduced from grams of tissue to a few cells, can pull out small signal amidst “noisy” background

Very widely used; forensics, archeology, cloning, sequencing, ...

And Covid Testing

Table 2. Sensitivity* Mean Estimates of the EUA authorized SARS-CoV-2 molecular diagnostic tests using the FDA SARS CoV-2 Reference Panel

Product LoD (NDU/mL***)	Developer	Test
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180	PerkinElmer, Inc.	
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540	ScienCell Research Laboratories	
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PLOS BIOLOGY

OPEN ACCESS PEER-REVIEWED

METHODS AND RESOURCES

A Rapid Test Offers Hope for Community Screening

In a small study in San Francisco, Abbott's BinaxNOW identified infectious people nearly as accurately as a P.C.R. test.

Detection of SARS-CoV-2 RNA by multiplex RT-qPCR

Eriko Kudo, Benjamin Israelow, Chantal B. F. Vogels, Peiwen Lu, Anne L. Wyllie, Maria Tokuyama, Arvind Venkataraman, Doug E. Brackney, Isabel M. Ott, Mary E. Petrone, Rebecca Earnest, Sarah Lapidus, M. Catherine Muenker, [...], Akiko Iwasaki

[view all]

Version 2

1000000

Published: October 7, 2020 • <https://doi.org/10.1371/journal.pbio.3000867>

600000

Boston Medical Center

ry SARS-CoV-2 Panel

say

-19 Test

<https://www.fda.gov/medical-devices/coronavirus-covid-19-and-medical-devices/sars-cov-2-reference-panel-comparative-data>

DNA Forensics

E.g. FBI “CODIS” (combined DNA indexing system) data base

As of 2018, over 13,000,000 offender profiles

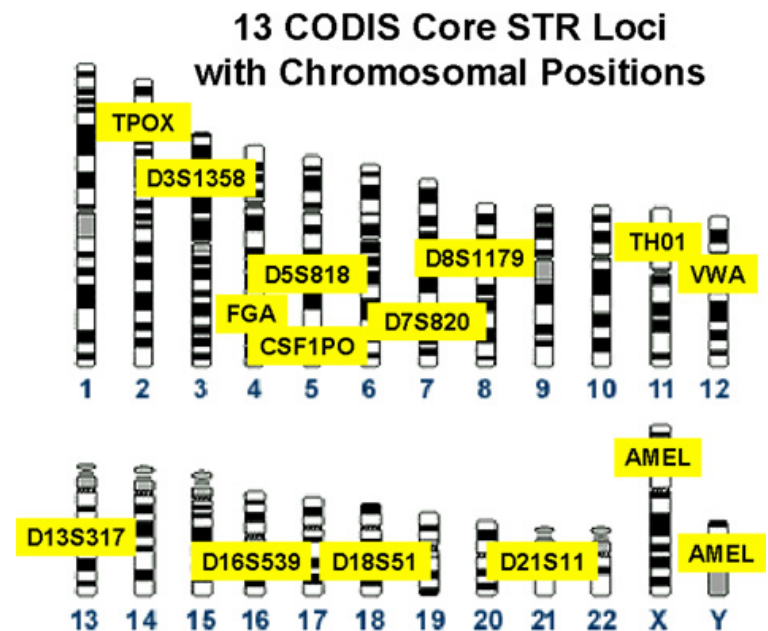
Picked 13 “short tandem repeats”, i.e., variable-length regions of human genome flanked by (essentially) invariant sequences (primer targets), several alleles common at each locus, of which you have 2

Amplify each from, e.g., small spot of dried blood

Measure product lengths (next slides)

<http://www.fbi.gov/about-us/lab/biometric-analysis/codis>

<http://www.dna.gov/solving-crimes/cold-cases/howdatabasesaid/codis/>



Gel Electrophoresis

DNA/RNA backbone is negatively charged (they're acids)

Molecules moves slowly in gels under an electric field

- agarose gels for large molecules

- polyacrylamide gels for smaller ones

Smaller molecules move faster

So, you can *separate DNAs & RNAs by size*

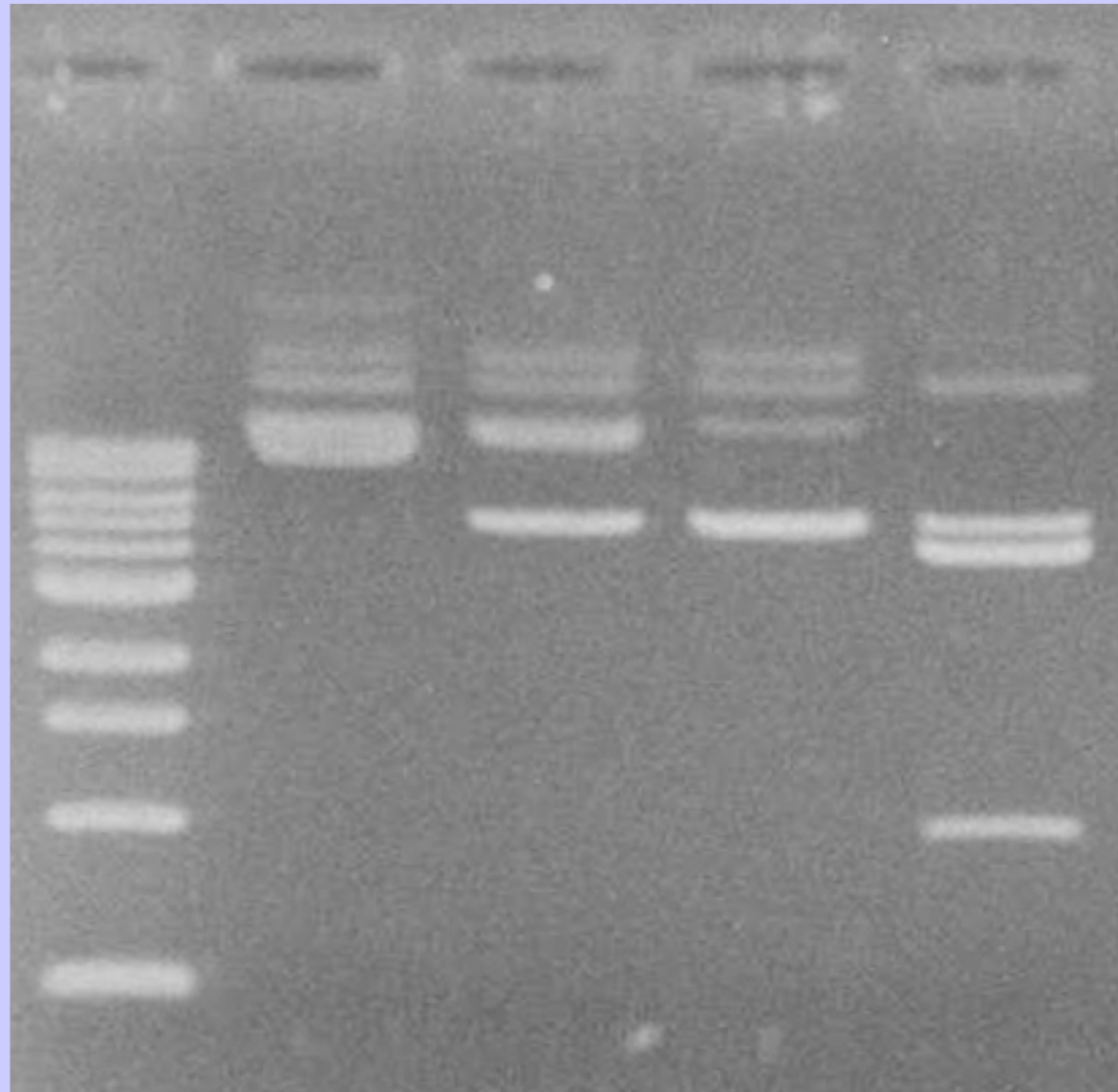
Nobel Chem prize, 1948 Arne Wilhelm Kaurin Tiselius

lane 1 lane 2 lane 3 lane 4 lane 5

10,000 bp →

3,000 bp →

500 bp →



-



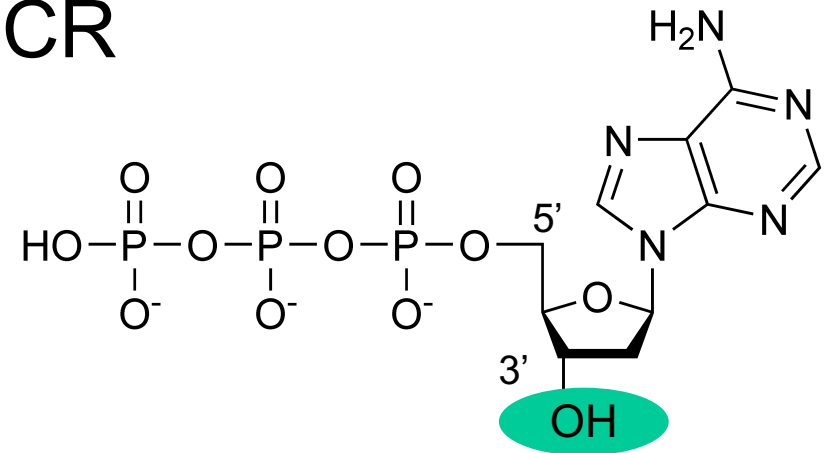
+

DNA Sequencing – Sanger Method

Like one-cycle, one-primer PCR

Suppose 0.1% of A's:

are *di*-deoxy adenosine's;
backbone can't extend
carry a green florescent dye



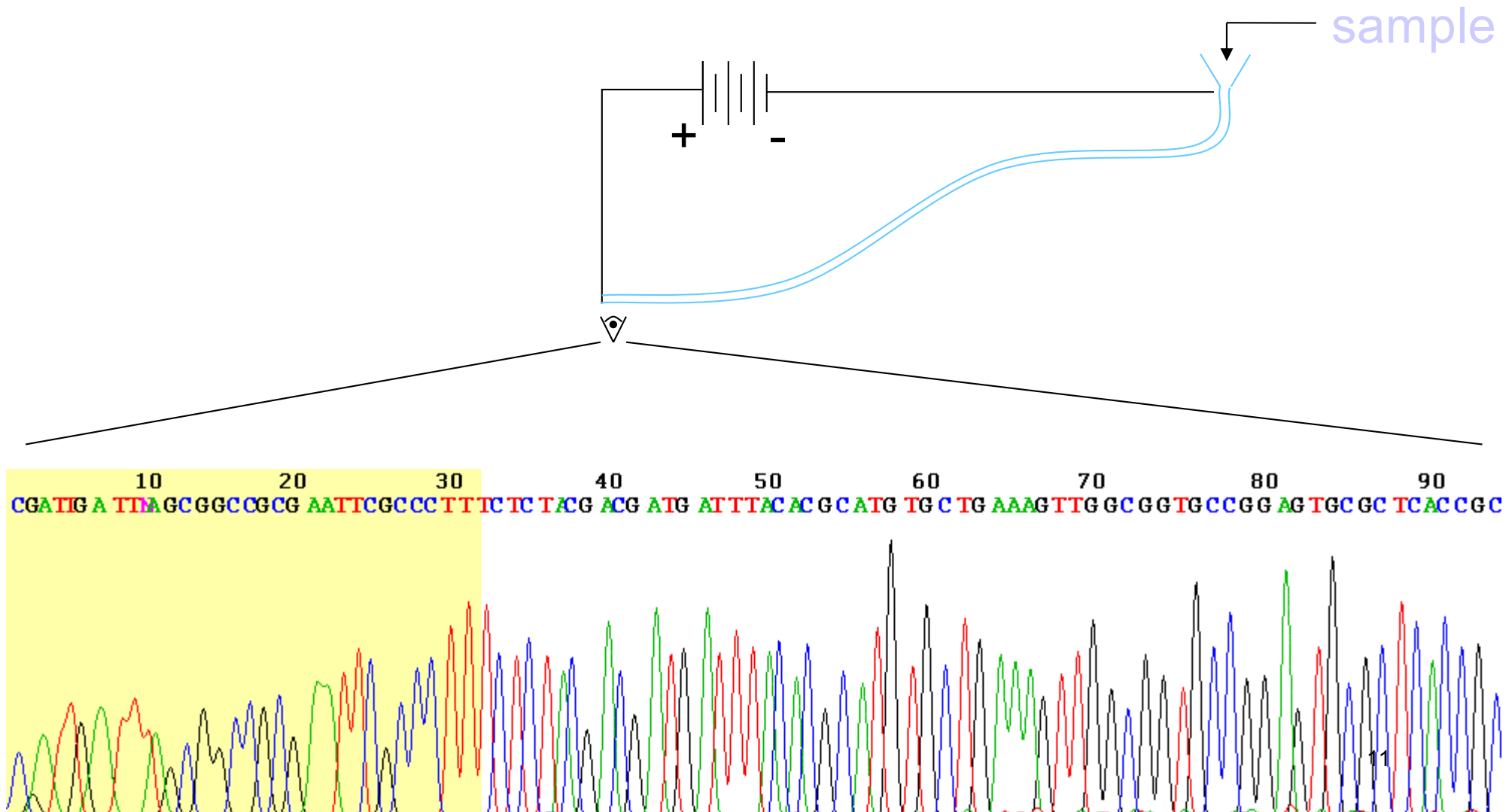
Separate by capillary gel electrophoresis

If frags of length 42, 49, 50, 55 ... glow green,
those positions are A's

Ditto C's (blue), G's (yellow), T's (red)

DNA Sequencing

Sanger with capillary electrophoresis



Sequencing A Genome

Highly automated

Typical Sanger “read” about 600 nt

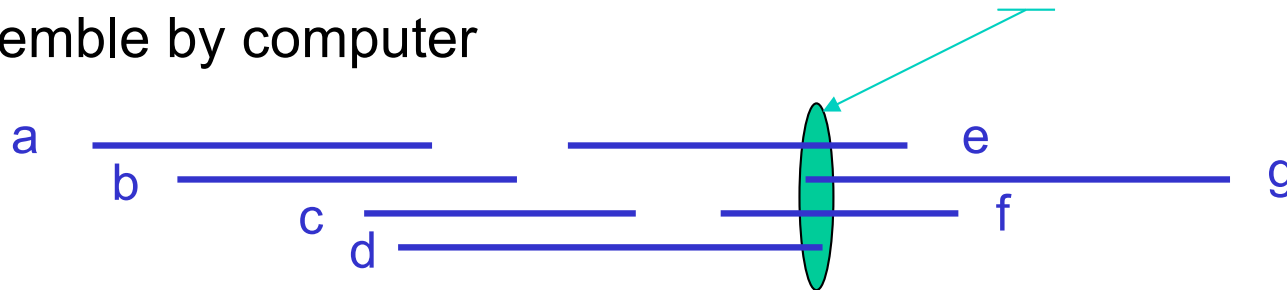
“Whole Genome Shotgun” approach:

randomly fragment (many copies of) genome

sequence many, enough to cover each base 10x or more times

reassemble by computer

E.g., human
genome project:
 $\approx 30\text{Gbases}$ and
 $\approx 3 \times 10^9 / 600 \times 10$
 $= 5 \times 10^7$ reads



Complications: repeated region, missed regions, sequencing errors, chimeric DNA fragments, ...

But overall accuracy $\sim 10^{-4}$, if careful

Illumina Sequencing

~1 billion microscopic PCR “colonies” on 1x2” slide

“Read” ~50-150bp of sequence from (1 or 2) ends of each

Ends fluorescently labeled, blocked, chemically cycled

“Reversible dye terminators”

Automated: takes a few days; ~ 100 G bases/day

Costs a few thousand dollars

Generates terabytes of data (mostly images)

I,e., ~ 30x human genome/day

(you need 25x-50x to assemble)

(equal to all of pre-2008 Genbank)

“Next Generation” Sequencing

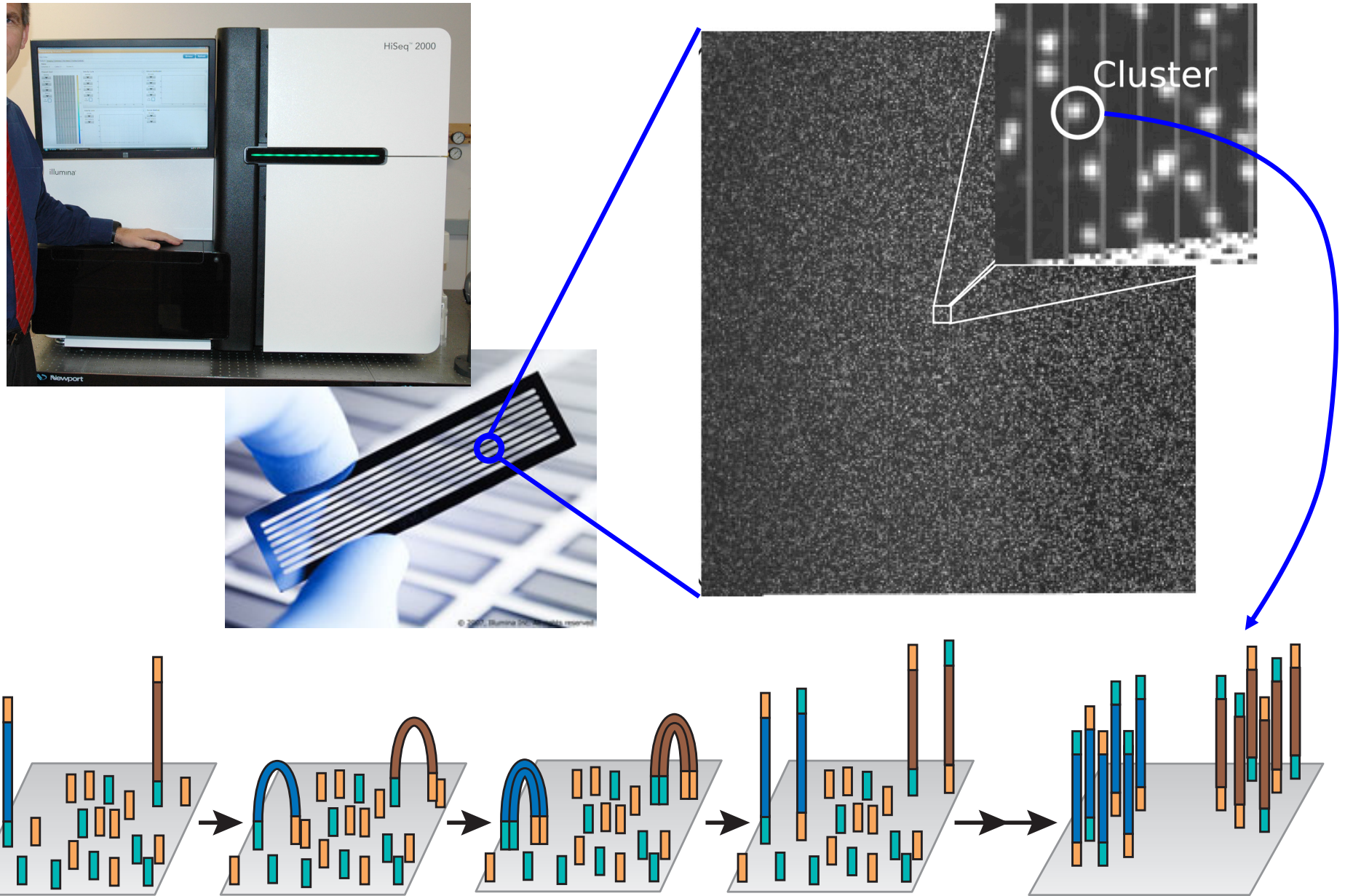
Many technical improvements to Sanger approach over many years, culminating in highly automated machines used for the HGP

Since then, many innovative new ideas/products:

- Helicos: single molecule fluorescence tethered to flow cell
- Ion Torrent: semiconductor detection of ions released by polymerase
- Roche 454: emulsion PCR; pyro sequencing
- ABI SOLiD: emulsion PCR, sequence by ligation, “color-space”
- Illumina: colony PCR; reversible dye terminator
- Oxford Nanopore
- Pacific Biosciences: single tethered polymerases in “zero mode waveguide” nano-wells, circularized DNA, “real time”
- Complete Genomics: rolling circle replication/DNA nanoballs

Off-market?

Technology is changing rapidly!



http://www.technologyreview.com/sites/default/files/legacy/pgenome_x220.jpg
<http://bioinformatics.oxfordjournals.org/content/25/17/2194/F1.large.jpg>

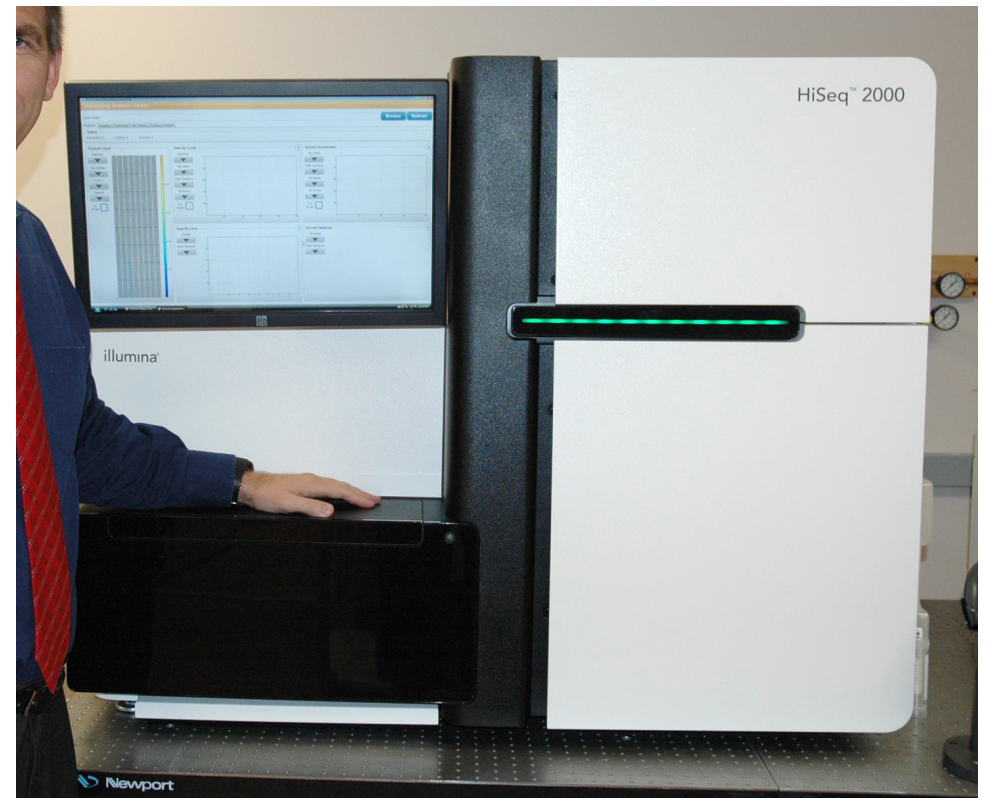
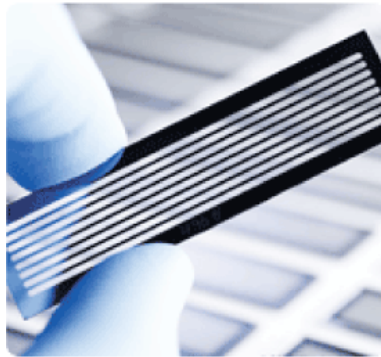
Fig from: Shendure and Ji 2008. "Next-Generation DNA Sequencing.." *Nature Biotechnol* 26 (10) (October): 1135–1145. doi:10.1038/nbt1486.

Modern DNA Sequencing

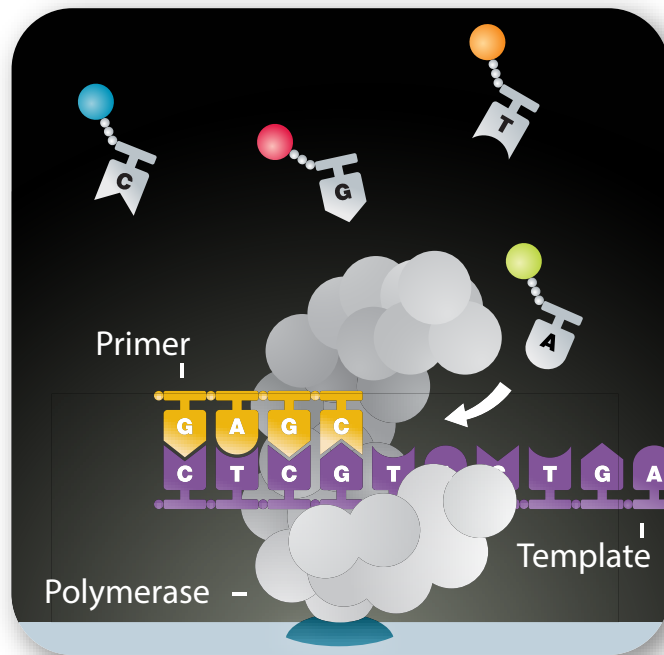
A table-top box the size of your oven (but costs a bit more ... ;-) can generate ~100 billion BP of DNA seq/day; i.e.

= 2008 genbank,

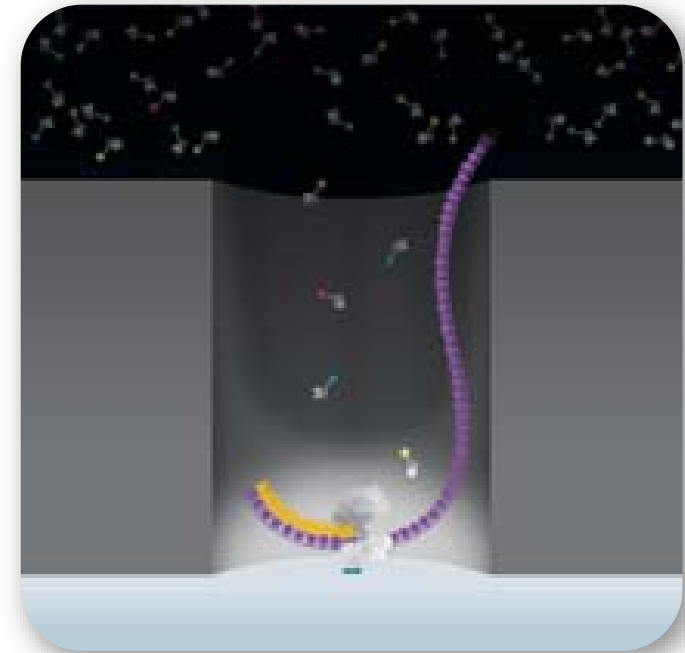
= 30x your genome



Pacific Biosciences



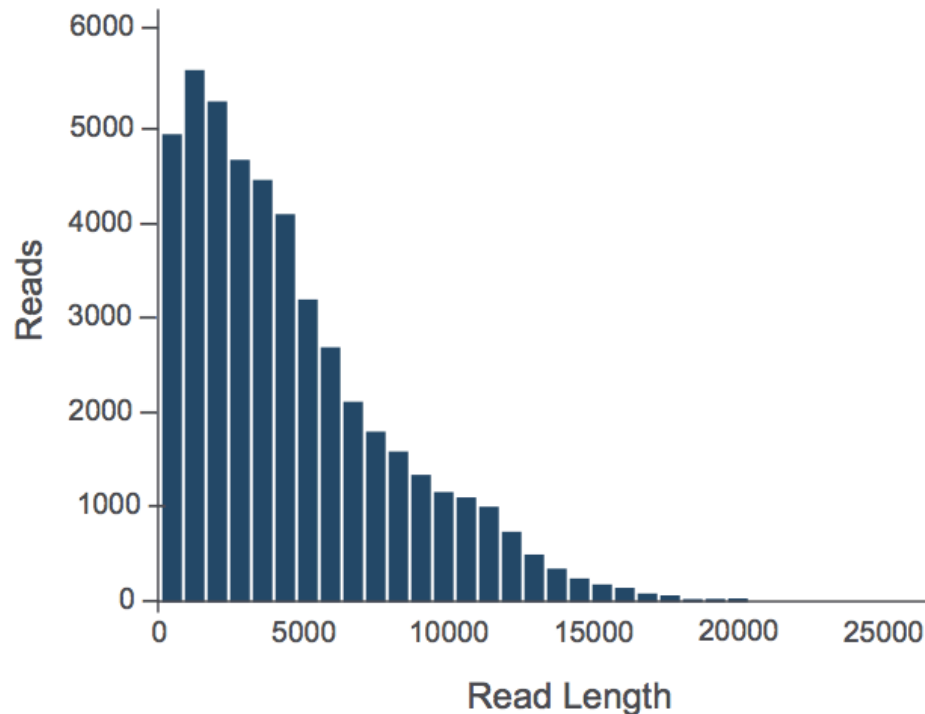
Phospholinked
nucleotides



Zero-Mode
Waveguides

Pacific Biosciences

Read Length Distribution



Advantages:

- single molecules
- long reads
- direct CH₃ detection

Disadvantages:

- throughput
- error rate; (circularize?)

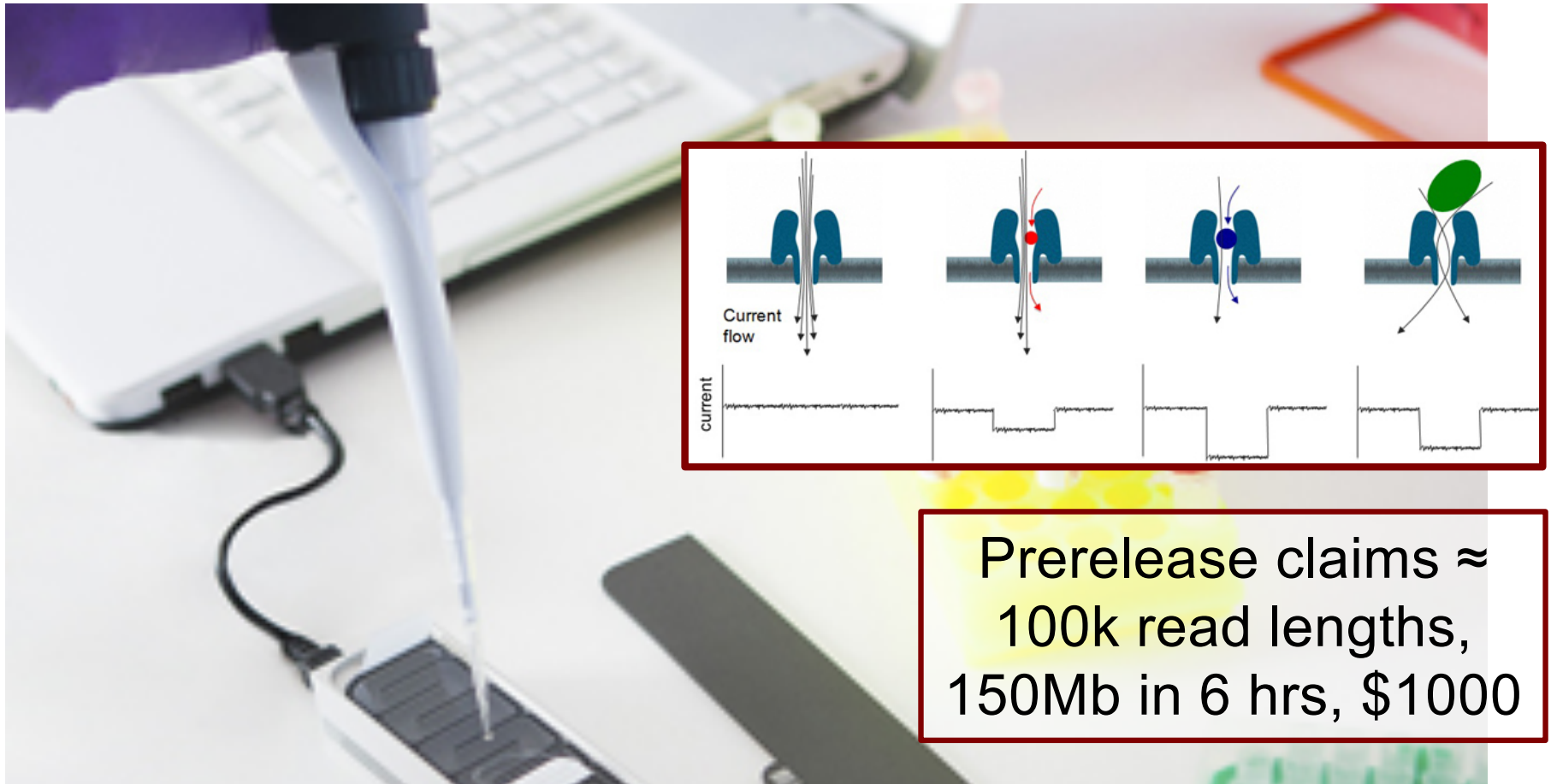
Read Length:

Average:	4,606 bp
95 th Percentile:	11,792 bp
Maximum:	23,297 bp

Throughput

per SMRT [®] Cell:	216 Mb
	47,197 reads

Oxford Nanopore



Personal Genomes

2001: ~\$2.7 billion (Human Genome Project)

2003: ~\$300 million

2007: ~\$1 million

2008: ~\$60 thousand

2009: ~\$4400

Now : <<\$1000 (?) *bioinformatics not included...*

Summary

PCR allows simple *in vitro* amplification of minute quantities of DNA (having pre-specified boundaries)

Sanger sequencing uses

- a PCR-like setup with modified chemistry to generate varying length prefixes of a DNA template with the last nucleotide of each color-coded

- gel electrophoresis to separate DNA by size, giving sequence

Sequencing random overlapping fragments allows genome sequencing (and many other applications)

“Next Gen” sequencing: many innovations

- throughput up, cost down (lots!)