

Physics, computing, programming

<http://ds9a.nl/> - bert.hubert@netherlabs.nl

<http://tinyurl.com/phycomp> (+notes)



That's me, circa 1996

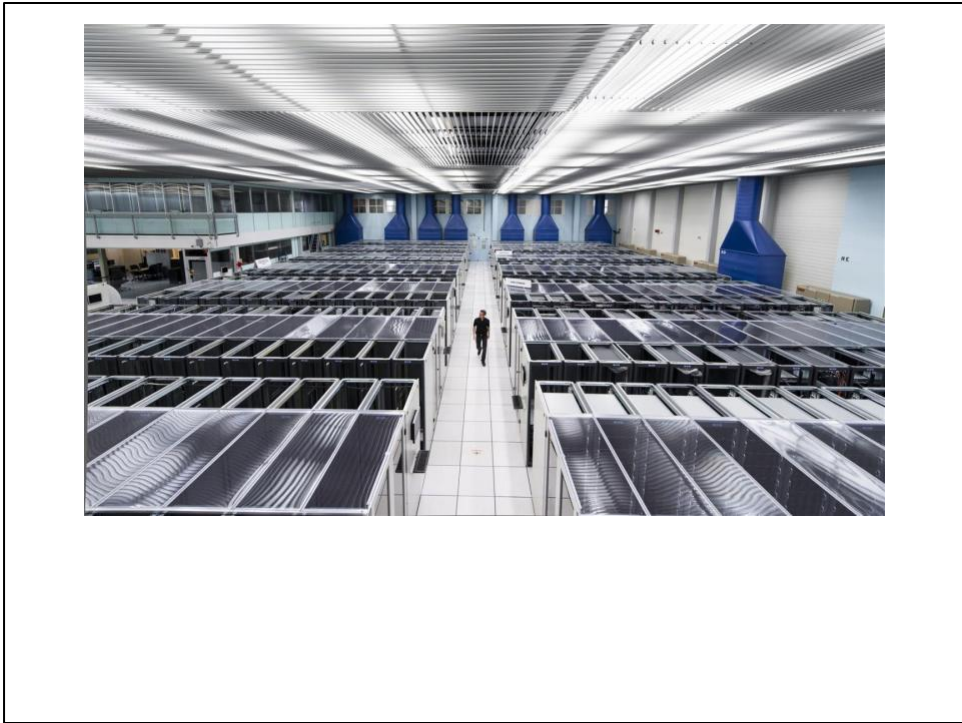
23 months ago today



Announcement of the discovery of the higgs boson. They skipped the second part of the announcement by Fabiola Gianotti. In Comic Sans.

Some LHC computing stats

- $\sim 0.5 \cdot 10^9$ collisions/s, one every 2 nanoseconds
- 15,000 terabyte of raw data/day
 - 300MB/s after first filter
- 140 data centers in 33 countries
- >200,000 CPU cores in “tier 0” data centers in Meyrin (Switzerland) and Budapest (Hungary)

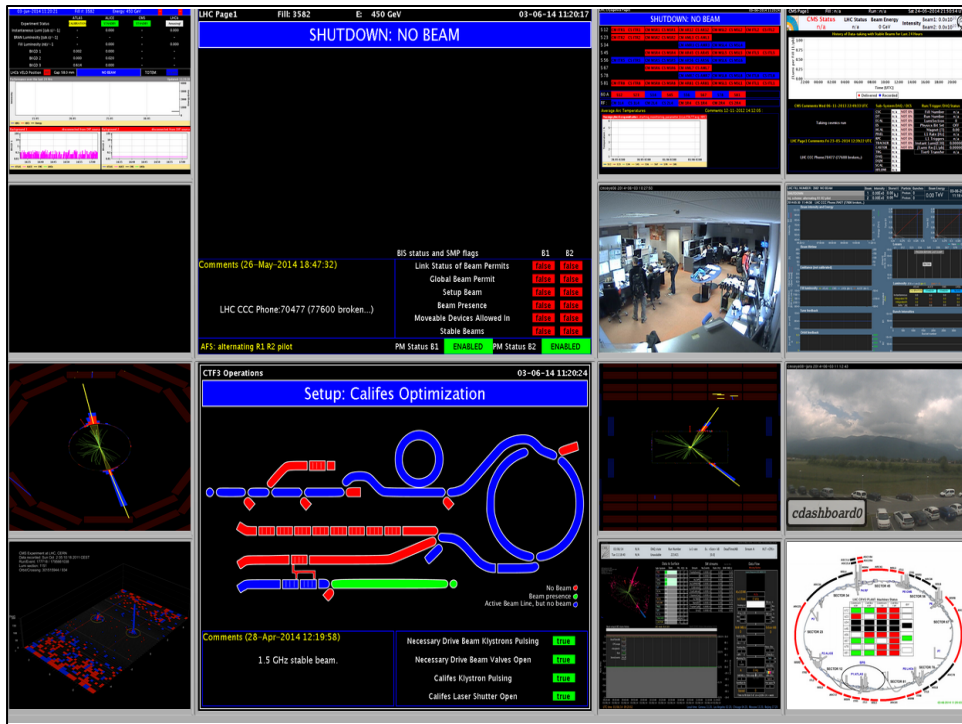


Around 4MW of computing power here. Nothing compared to rest of LHC ;-)

No Computers



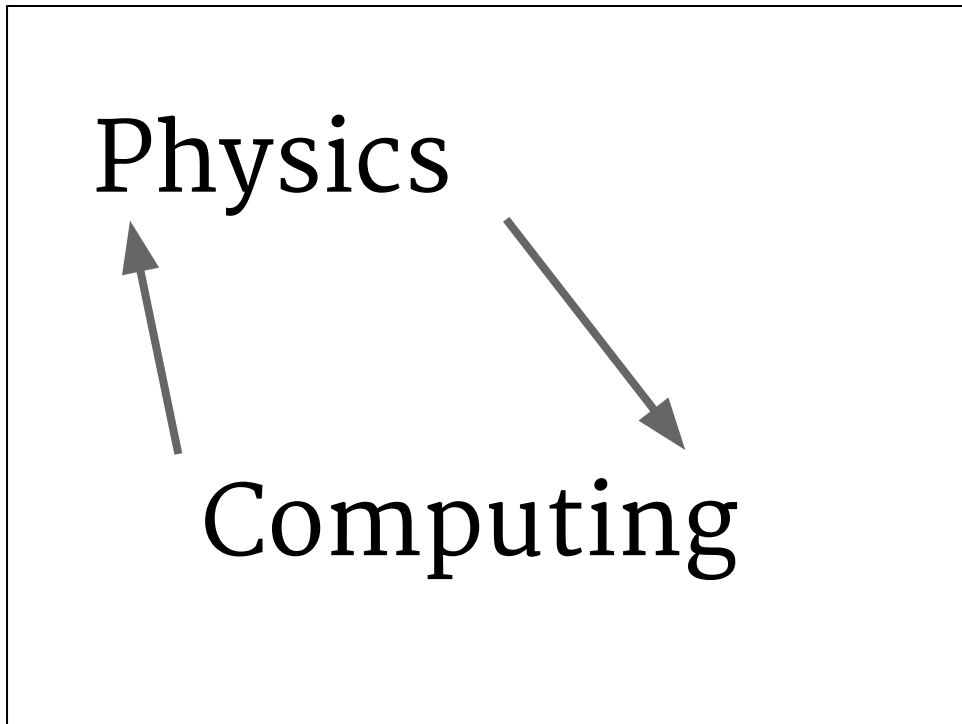
No Higgs!



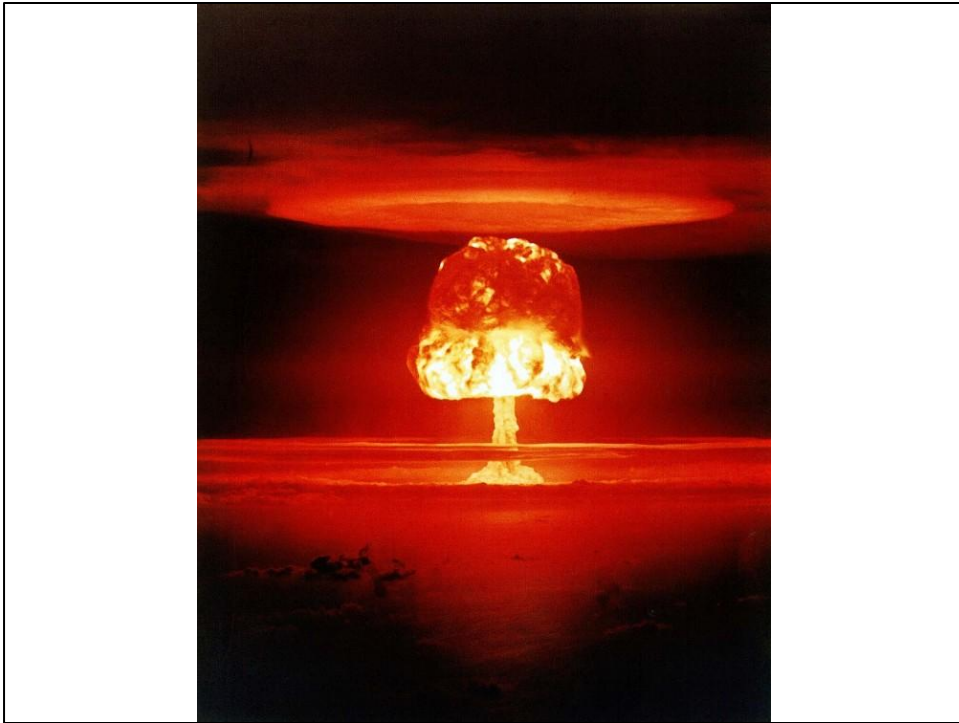
This is all webbased, but remarkably basic 'teletext' like. This is no accident. Pre-web, CERN used some kind of videotex, and it stuck. They now emulate it in HTML.



First ever webserver. CERN donated web technology to the world for free. In return they got the Higgs boson. They also got hacked.



Close interchange - a "recent" gift was GMR, http://en.wikipedia.org/wiki/Giant_magnetoresistance 1987, in stores in 1995!
<http://www.wdc.com/wdproducts/library/other/2579-850121.pdf>



<http://scienceblogs.com/startswithabang/files/2009/05/Hbomb-600x753.jpg>
<https://www.youtube.com/watch?v=0ogSC6JKkrY> MANDATORY - <http://calteches.library.caltech.edu/34/3/FeynmanLosAlamos.htm>

John von Neumann

“He made major contributions to a number of fields,^[1] including mathematics (foundations of mathematics, functional analysis, ergodic theory, geometry, topology, and numerical analysis), physics (quantum mechanics, hydrodynamics, and fluid dynamics), economics (game theory), computing (Von Neumann architecture, linear programming, self-replicating machines, stochastic computing), and statistics”

Plus.. the hydrogen bomb.



http://en.wikipedia.org/wiki/John_von_Neumann

First Draft of a Report on the EDVAC

by John von Neumann,

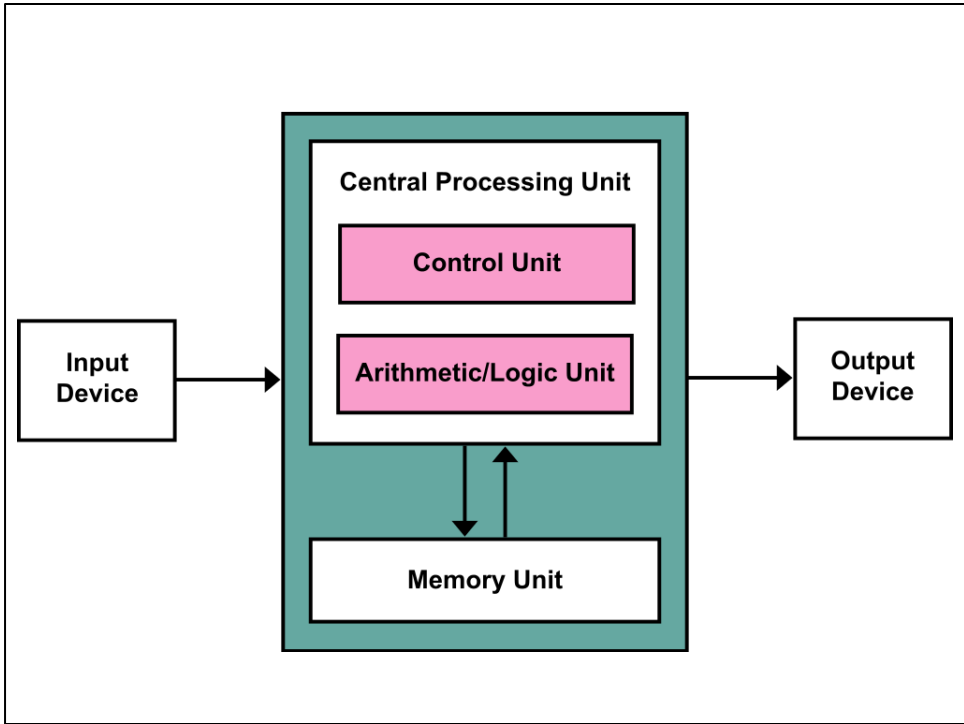
Contract No. W-670-ORD-4926,

Between the United States Army Ordnance Department
and the University of Pennsylvania Moore School of Electrical
Engineering

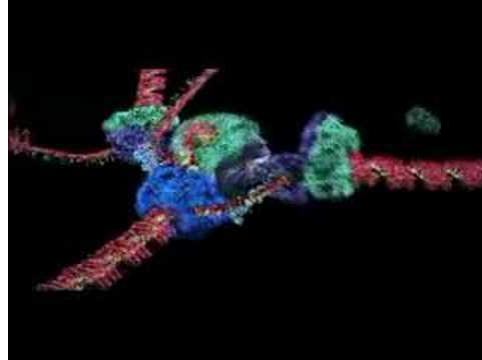
University of Pennsylvania

June 30, 1945

[https://sites.google.com/site/michaeldgodfrey/vonneumann/vnedvac.pdf?
attredirects=0&d=1](https://sites.google.com/site/michaeldgodfrey/vonneumann/vnedvac.pdf?attredirects=0&d=1)



This is so universal this table looks superfluous



One of the very few examples of a 'non-Von Neumann' architecture
This shows how DNA gets replicated, and it is astoundingly impressive and stupid at the same time.
http://en.wikipedia.org/wiki/Okazaki_fragments

**Further connections
between physics and
computing**

Have nature do the math

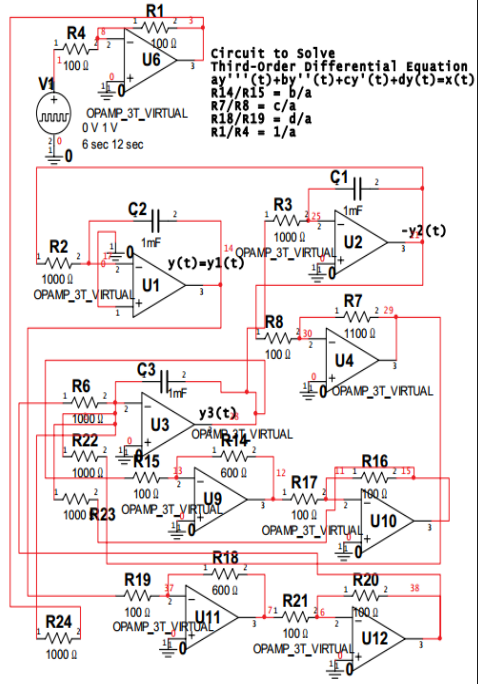
- Simplest form: addition. Want to know $2+2$? Take two 2 kilo weights, and weigh them!
- More seriously, circuits of opamps, capacitors and coils have (frequency) responses described by differential equations
- **To solve differential equation: make a circuit that behaves like it & measure!**

<https://www.science.uva.nl/museum/AnalogComputers.php>

Other example: the slide rule

Thus we have the set of three first order differential equations

$$\begin{cases} \frac{d}{dt} y_1(t) = y_2(t) \\ \frac{d}{dt} y_2(t) = y_3(t) \\ \frac{d}{dt} y_3(t) = -\frac{d}{a} y_1(t) - \frac{c}{a} y_2(t) - \frac{b}{a} y_3(t) + \frac{1}{a} x(t) \end{cases} \quad (2)$$



http://download.springer.com/static/pdf/578/chp%253A10.1007%252F978-1-4020-8737-0_44.pdf?auth66=1402039277_eafd253d5f323289f4440e64a1d291f6&ext=.pdf



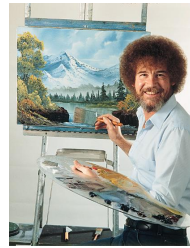
<http://upload.wikimedia.org/wikipedia/commons/thumb/7/7e/AKAT-1.JPG/427px-AKAT-1.JPG>

<http://www.tabletmag.com/scroll/129988/did-poland-invent-the-pc>

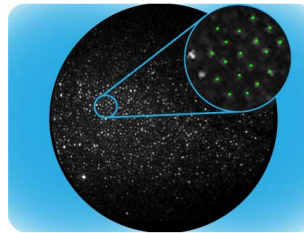
Wojciech Hubert Żurek



Bob Ross



Cosmological experiments in superfluid helium? **“Here I discuss the analogy between cosmological strings and vortex lines in the superfluid, and suggest a cryogenic experiment which tests key elements of the cosmological scenario for string formation”**



http://upload.wikimedia.org/wikipedia/commons/f/fd/Wojciech_H._Zurek.gif
<http://www.nature.com/nature/journal/v317/n6037/abs/317505a0.html>

**Some fundamental &
natural limits on
computing**

Limits

- “Electron per bit” ratios now in order of 100,000 (SDRAM) or 40(!) (Flash) (DNA: 32 atoms)
 - “free particle detectors”
- Cosmic rays originally blamed for memory errors
- Alpha particles from RAM packaging turned out to be way more important - manufacturers need to keep (very) clean
- Thermal neutrons captured by boron

- Some nice physics by Landauer on minimum energy expenditure per bit change: $kT \ln 2$

<http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=06515709>

<http://uw.physics.wisc.edu/~himpel/memory.html>

http://en.wikipedia.org/wiki/Landauer%27s_principle

The damn speed of light

$F = 3\text{GHz}$

Distance-per-cycle:

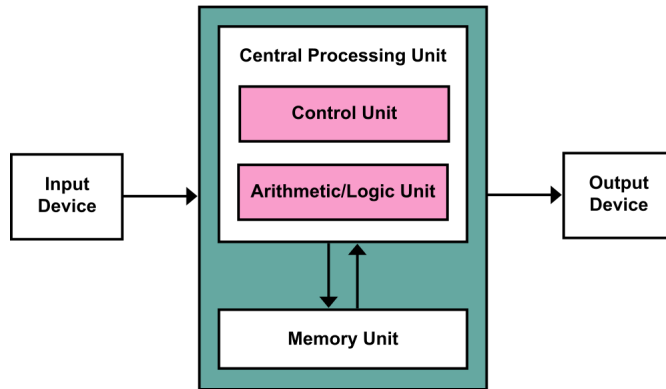
$c/F = 10\text{cm}$

Round trip: 5 cm

Actual size of computer:
>>5 cm

Typical CPU: 1.6*1.6cm ->
2.3cm max round trip

Power density: 500kW/m²
(500 times more than
sunlight)



http://ark.intel.com/products/37150/Intel-Core-i7-950-Processor-8M-Cache-3_06-GHz-4_80-GTs-Intel-QPI

http://en.wikipedia.org/wiki/Clock_skew

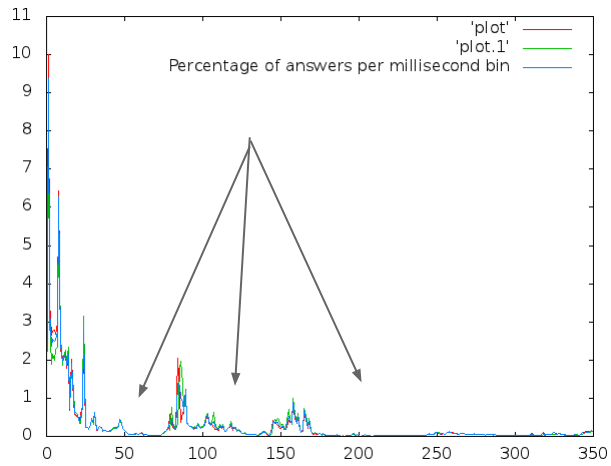
Computing, these days, is about nothing other than latency

- Get data, think about it, return data
 - Repeat
- Fundamental reasons why this takes time:
 - c
 - Index of refraction
 - Thermal noise / averaging
 - Rotating media

Impact of latency

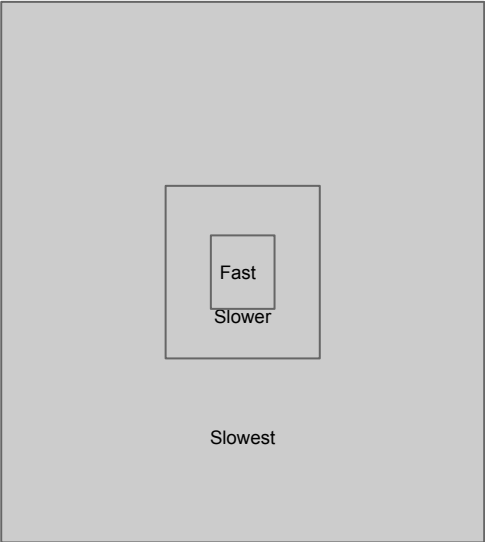
- Let's assume a billion retrievals:
 - From on-CPU L1 memory: 8cm / 0.5s
 - **System RAM: 30m / 100s**
 - SSD read: 45km / 1.7 days
 - Round trip within same building: 150km / 6 days
 - Rotating media: 16.5 weeks
 - Amsterdam <-> San Francisco: 5 years
- See - nothing else matters!

“Four million pings only”

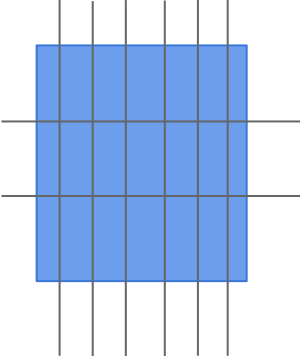


<http://bert-hubert.blogspot.nl/2012/01/four-million-pings-only-aka-1.html>

How to benefit



Your data



Some “real world” impact: index of refraction

“Ryan described what he witnessed inside the exchanges: The frantic competition for nanoseconds, clients’ trying to get their machines **closer to the servers within the exchanges**, the tens of millions being spent by high-frequency traders for tiny increments of speed”

“The first **microwave connections** between London and Frankfurt have been launched, cutting the time to send a trade by about 40 percent compared with optic fiber cables.”

“A laser **beam** technology developed for the U.S. military for communication between fighter jets is to be used over the route between Britain and **Germany** in coming months.”

Please, please, don't go work doing complicated things for banks & high frequency traders!

<http://www.reuters.com/article/2013/05/01/us-highfrequency-microwave-idUSBRE9400L920130501>



http://www.nytimes.com/2014/04/06/magazine/flash-boys-michael-lewis.html?_r=0

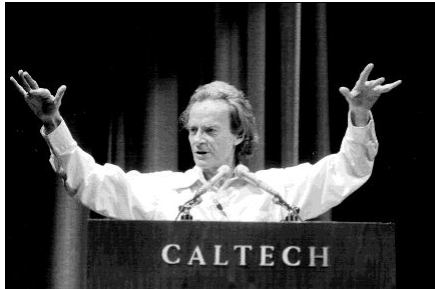
“A Heisenbug is a computer programming jargon term for a software bug that seems to disappear or alter its behavior when one attempts to study it.”

-- for reals

<http://en.wikipedia.org/wiki/Heisenbug>

The analog quantum computer

without the hype



Behold!

“Simulating physics with computers”

- 1981 presentation by Feynman at “1st conference on physics and computation”, MIT
 - “Invented the quantum computer”
- Quantum computer not even the subject of the presentation!
 - “afterthought”
- 1982 paper well worth reading

Google “simulating physics with computers” to find several links

Can we simulate nature with a computer?

- Not exactly - 2^N complexity of simulation
 - Simulation quickly more complex than reality
- Quite surprisingly, for classical universe:
yes - if you accept a probabilistic simulation of probabilistic universe, otherwise too hard
- Can we simulate quantum nature probabilistically using a classical computer?
Absolutely not (because there are no hidden variables)

But can we simulate quantum nature with a “quantum computer”?

- Here, in two pages, Feynman concludes that at least some quantum systems can be ‘intersimulated’ by a quantum computer, and hints that this might be universal
- But wait! **This quantum computer can calculate something our “Newton-computer” can’t!**

WE'RE BACK!!!



$$H(t) |\psi(t)\rangle = i\hbar \frac{d}{dt} |\psi(t)\rangle$$

.. at your service!

<http://upload.wikimedia.org/wikipedia/commons/thumb/7/7e/AKAT-1.JPG/427px-AKAT-1.JPG>

But now what

- Despite much hype, so far this is what there is to it - we can look at quantum behaviour, and **hope that it matches math we want to do**
- Story “does everything in parallel” just not true
- Two well known algorithms:
 - Shor - prime number decomposition
 - Grover - faster dictionary lookups

<http://math.nist.gov/quantum/zoo/>

http://en.wikipedia.org/wiki/Quantum_algorithm

The one ACTUAL remaining problem

Nobody cares about your crypto
<http://pqcrypto.org/>

(friends of mine)

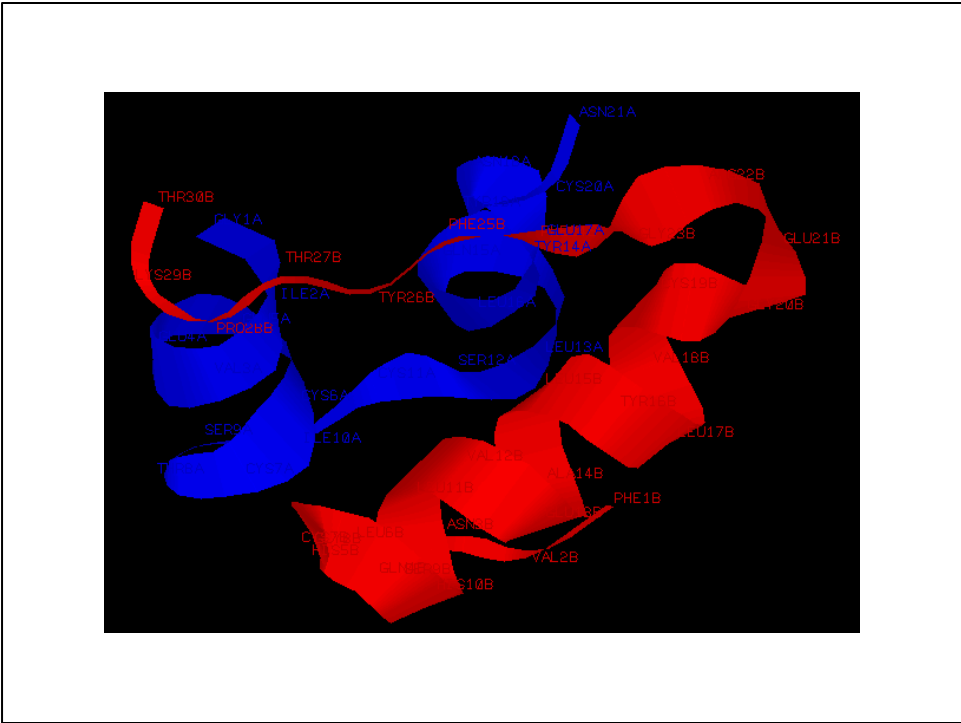
DNA of Insulin

ATGGCCCTGTGGATGCGCCTCCTGCCCTGCTGGCGCTGCTGGCCCTCTGGGGACCTGAC
CCAGCCGCAGCCTTTGTGAACCAACACCTGTGCGGCTCACACCTGGTGAAGCTCTCTAC
CTAGTGTGCGGGGAACGAGGCTTCTTCTACACACCAAGACCCGCCGGGAGGCAGAGGTG
GGGCAGGTGGAGCTGGGCGGGGGCCCTGGTGCAGGCAGCCTGCAGCCCTGGCCCTGGAG
GGGTCCCTGCAGAAGCGTGGCATTGTGGAACAATGCTGTACCAGCATCTGCTCCCTCTAC
CAGCTGGAGAACTACTGCAACT**TAG**



MALWMRLPLLLALLALWGPDPAAAFVNQHLCGSHLVEALYLVCGERGFFYTPKTRREAED
LQVQVELGGGPGAGSLQPLALEGSLQKR | GIVEQCCTSICSLYQLENYCN

(51 amino acids, ~500 atoms)

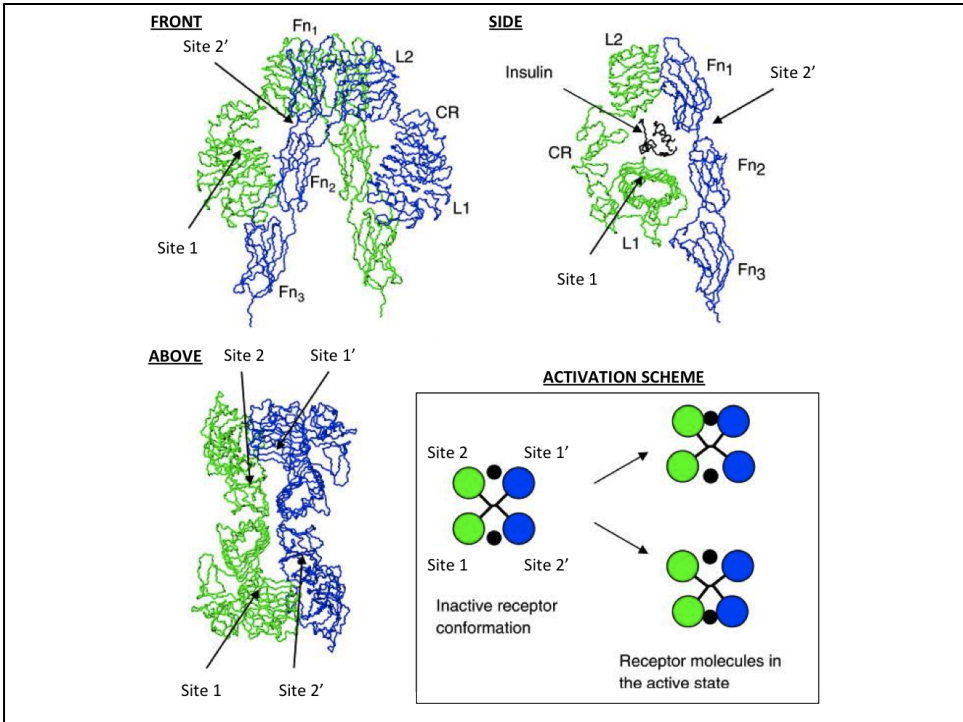


<http://www.biotopics.co.uk/as/insulinribbons.gif>

DNA -> Aminoacids of Insulin Receptor

```
MATGGRRGAAAAPLLVAVAAALLGAAGHLYPGEVCPGMDIRNNLTRLHELENCVIEGHLQILLMFKTRPEDFRDLSFFKLIMITDYLLLFVRYGLESKOLFENLTVIRGSRFFNYAL
VIFEMVHLKELGLYNLMNITRGSVRIEKNNELCYLATIDMSRIILDSVEDNYIVLNKDDNEECGDI CPGTAGKTNCFPATVINGQFVERCWTSHRQKRVCTICKSHGCTABGLCHSECL
GNC SQDDPTKCVACRNFYLDGRCVETCPPYYHFQDMRCVNFSCQDLHKKNSRRQGHQYVIHNNKCIPECPSGYTMNSSLCTPCLGCPKVCCHLLESEKTI DSVTSAQELRGC
TVINGSLIINIRGGNNLAAELEANLGLIEEISGVLKIRRSYALVLSLFFRKLRLIRGETLEIGNYSFYALDNQNLRLQMLNWSKHNLITQGKLFHYNPKLCLSEIHKMEEVSGTKGRQE
RNDIALKTNGDQASCENELLKFSYIRTSFDKILLRWEFYWPPDFRDLGLFMYKEAFYQNVTEFDGGDAGCSNSWTVDIDPPLRSNDPKSQNHFGWLMRGLKFWTQYAFVKTIVTFS
DEERTYGAKSDIIYVQTDATNPSVFLDPI SVSNSSQIILKWKPPSDPNGNITHYLVFERQAESELEFDYCLKGLKLPSTWSPFPESEDSQKHNSQSEYEDSAGECCSCPKTDSQL
KELEESSFRKTF EDYLNENVVFVPRKTSSTGQAEDEPRSPRKRSLGQVGNVTVAVPTVAAFPNTSSTVPTSPEEHRPFKVVNKESLVI SGLRHFTCYRIELQACNQDTPREERCVAADV
SARTMPEAKADDIVGVTHEIFENNVVHLMWQEPKEPNGLIVLYEVSRYRGDEELHLCVSRKHFALERGCRRLGSLPGNYSVRI RATS LAGNSWTEPYFYVTDYLDVPSNIAKIIIG
PLIFVFLFSVIGSILYFLRKRQPDGPLGLYASSNPEYLSASDVPCSVYVDEMEVSRKITLLRELQGGFQGMVYEGNARDIKGEAETRVAVKTVNESASLRERIEFLNEASVMKG
FTCHHVRLLGUVSKGQPTLVVMEIHAHGDKSLVLSRLEPEAENNGRPPPTLQEMIQMAEIIADGMAV LNAKKFVHRDLAARNCMVAHDFTVKIGDGMTRDIYETDYYRKGKGLLPV
RMMAPESLKDGVFTTSSDMSFGVWLWEITSLAEQPHYQLSNEQVLKFMVDGGYLDQDPNCFERVTDLMRMWCQFNFMKRPFTLEIVNLLKDDLHPSFFEVSFHSEENKAPSESELEME
FEDMENVPLDRSSHCRQEEAGGRDGGSSILGFKRSVEEHI PYTHMNGGKNGRILLTPRSNFS
```

The bit in red is where the insulin actually intersects



<http://upload.wikimedia.org/wikipedia/commons/f/f6/IR-binding-site-scheme.png>

And we can't do it..!

Last two picture slides represent thousands of person years of research!

The first level dream:

```
insShape = aminoAcidToShape(DNAToAminoAcid(insulinseq));  
recptShape = aminoAcidToShape(DNAToAminoAcid(recptseq));  
match = shapeMatch(insShape, recptShape);
```

The real dream:

```
... humanGenome.findMatches(insShape);
```

The real real dream:

```
... humanGenome.findAllMatches();
```

http://en.wikipedia.org/wiki/Protein_folding#Computational_methods_for_studying_protein_folding

The dataset, the problem

- We have genomes from thousands of species, and we can recognize proteins, promoters, suppressors within them
 - <ftp://ftp.ncbi.nlm.nih.gov/>
- But what talks to what? Which virus hooks on where?
- Can only find out in the lab in laborious and somewhat scary ways ('final bleed anti-rabbit')
- **Impact of automation would be revolutionary**

<http://www.sciencemag.org/content/338/6110/1042.short> "the protein folding problem"

“They had very nice problems”

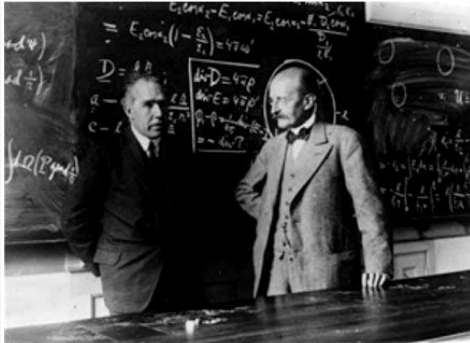
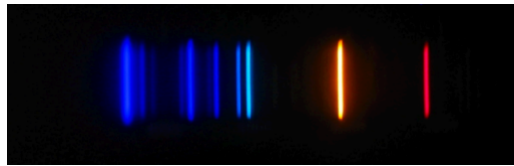


Figura 1. Niels Bohr e Max Planck em 1930 no Instituto Niels Bohr. Foto gentilmente cedida pelo Arquivo Bohr, Copenhagen

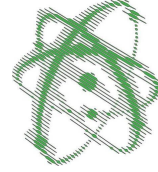
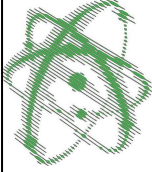


Here's yours

MALWMRLPLLLALLALWGPDPAAAFVNQHLGCGSHLVEALYLVCGERGFFYTPKTRREAED
LQVGQVELGGGPGAGSLQPLALEGSLQKR | GIVEQCCTSICSLYQLENYCN

?

MATGRRRGAAPLLVAVALLGAAGHLYPGEVCPGMDIRNNLRLHELENCVIEGHLQILMFKTRPEDFRDLSFFKLIMITDYLLFRVYGLSKDLFNLTVIRGSRFFNYAL
VIFEMVHLKELGLYNLMNITRGSVRIEKNNELCYLATIDWSRILDSVEDNYIVLNKDDNEECGDICPGTAGKTNCPATVINGQFVERCWTSHCQKVCPTICKSHGTAEGLCCHSECL
GNCSPDDPTKCVACRNFDLGRCVETCPFFYHFQDWRVCNFSFCQDLHHKCNRRQCHQVVIHNNKCIPECPSGYTMNSNLLCTPCLGFCPKVCHLLEGETIDSVTSAQELRGC
TVINGSLIINIRGONNLAELAMGLIEEISGVLKIRRSYALVLSLFFPKRLRIRGETLEIGNYSFYALDNQMLQMDWSKHNLTITQGLFFHYNPKLCLSEIHMEEVSGTKGRQE
RNDIALKTNQDQASCENELLFYSYIRTSFKILLRWEFYWPPDFRDLGFMFLYKEAPYQNVTEFDGQACGNSNWTVDIDPFLRSNDPKSQNHGMLMRGLKRWQYAIFFVKTIVTFS
DERRTYGAKSDIIVVQTDATNPSVPLDISVSNSSQIILKWKPPSDPNNGITHYLVFERQAEDSEFELDYCLKGLKLPSTWSPFPEEDSQKHNGSEYEDSAGECCCPKTDQIL
KELEESSFRKTF **EDYLHNVVV**FVPRKTSSTGAEADPPSRKRRLSGDVGNVTVAVTVAAFNSTSTSVPTSPPEHRPFKEVVKESLVISGLRHFTGYRIELQACQDTPPEERCSVAAYV
SARTMPEAKADDIVGVTHEIFENNVVHLMWQEPKFNGLIVLVEVSRYRYGDEELHLCVSRKHFALEGRCLRGLSPGNYSVRIRATSLAGNSWTEFTYFYVDYLDVPSNIAKIIG
PLIFVFLSVVIGSILFLRKRQPDGPLGYASSNPEYLSASDVFPSCSVTVDEWEVSREKITLLRELGGGSPGMVYEGNARDIKGEAETRVAVKTVNESASLRERIEFLNEASVMKG
FTCHRHVRLLVGVSQKQPTLVVMEHMAHGDLSYLRSLRPEAENNGRPPPTLQEMIQMAE IADGMAYLNAKKFVHRDLAARNCMVAHDFVKIGDFGMDTRDIYETDYRKGKGLLPV
RWMAPESLADGVFTTSSDNWSFGVVLWEITSLAEQPYQGLSNEQVLKFMDDGGLDQDNCPEPVTDLMRMCWQFNPKMRPTFLEIVNLLKDDLHPSFEVSVFHSSENKAFSESELENE
FEDMENVPLDRSSHCQREAGRDGSSLGFKRSYEEHIPYTHMNGKKNRILTLFRSNPS



Ψ

“If you had discrete quantum systems, what other discrete quantum systems are exact imitators of it, and is there a class against which everything can be matched? I believe it's rather simple to answer that question and to find the class, but I just haven't done it”

- Richard Feynman, 1981

<http://tinyurl.com/phycomp>