The Future of Electronics

Dr Carol Marsh OBE

Agenda

- Introduction to Electronics
- 2050
- Challenges facing Electronics

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- Introduction to Electronics
- 2050
- Challenges facing Electronics

Introduction to Electronics

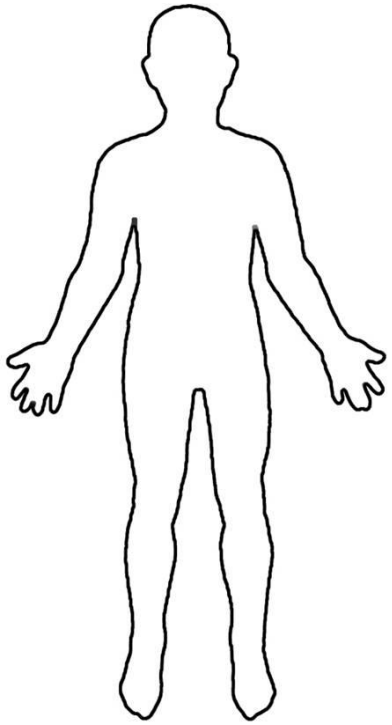
- We use electronics everyday of our lives

- Electronics keep us safe, in contact with the world and entertain us

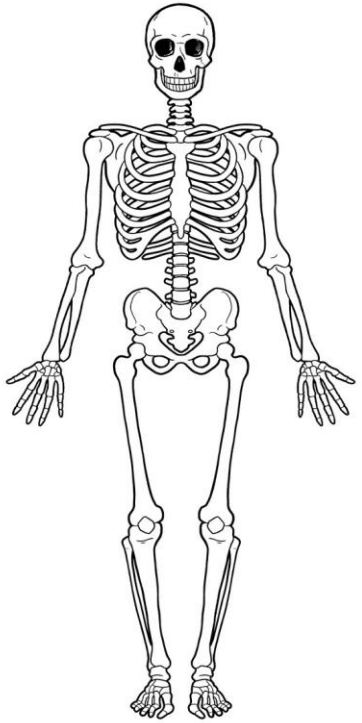
Introduction to Electronics

- But what is electronics?

System



Mechanics



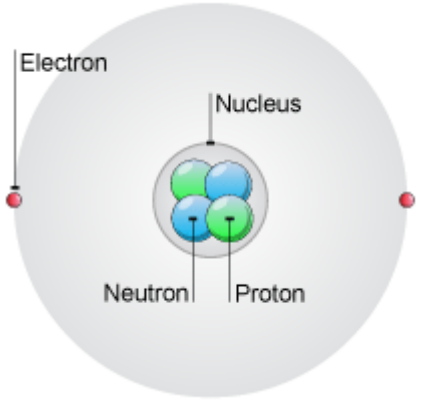
Electrics

Electronics

Software

Introduction to Electronics

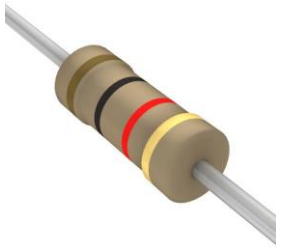
- But what is electronics?
  - The dictionary describes Electronics as:
    The branch of physics and technology concerned with the design of circuits using transistors and microchips, and with the behaviour and movement of electrons in a semiconductor, conductor, vacuum, or gas.
  - An electron is a subatomic particle which lives inside an atom and has a negative charge
  - Electronics controls the movement of these electrons using active components with the help of passive components

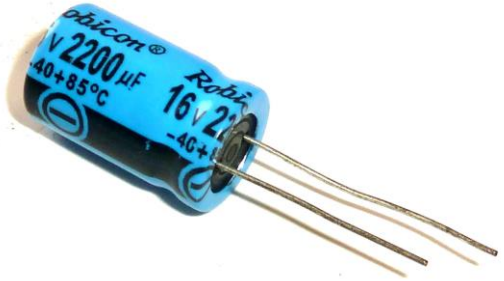


http://www.bbc.co.uk/schools/gcsebitesize/science/add_ocr_pre_2011/periodic_table/atomicstructurerev1.shtml

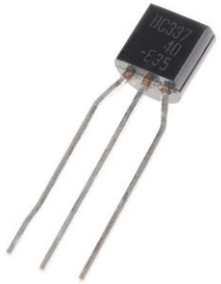
Introduction to Electronics

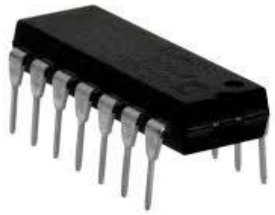
- Passive Components
  - Don’t need power to work and can’t control power but can consume it
  - Include Resistors, Capacitors and Inductors





- Active Components
  - Need power to work and can control power
  - An electronics circuit must have at least 1 active component
  - Include Transistors and Integrated Circuits





Introduction to Electronics

- Quiz – When Was Electronics Introduced?

1958

1947

1904

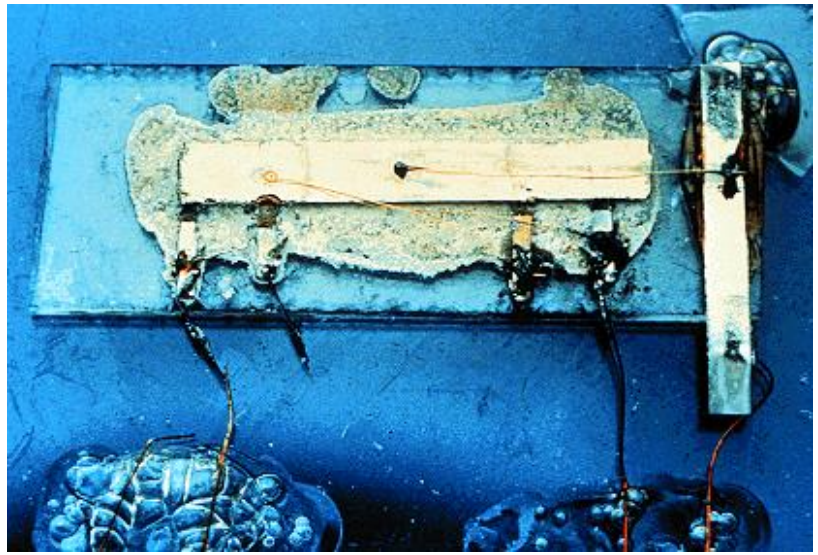
1835

Introduction to Electronics

- 1958

  Jack Kilby from Texas Instruments

  - Wired together transistors, resistors and capacitors in a single wafer
  - Invention of the first Integrated Circuit (IC)
  - Major advancement in electronics
  - Fundamental building blocks of electronics
  - An IC contains electronic circuits in a small device usually called a chip



https://www.pcmag.com/encyclopedia/term/45071/integrated-circuit

Introduction to Electronics

- Quiz – When Was Electronics Introduced?

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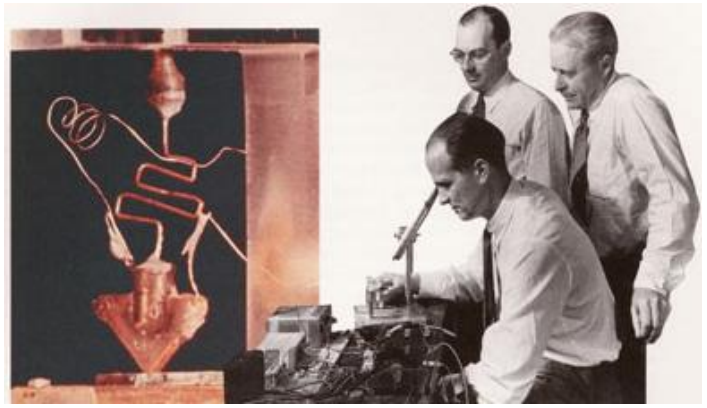
Introduction to Electronics

- 1947
  - John Bardeen, Walter Brattain and William Shockley at Bell Laboratory
  - Discovered when 2 gold point contacts were applied to germanium an output greater than the input was generated
  - Invention of the transistor - Switches and amplifiers
  - Transformed electronics
  - Replaced Vacuum Tube
  - I thought this was the birth of electronics, but I was wrong
  - However, it was when Electronics Engineering became a subject in its own right



http://www.cedmagic.com/history/transistor-1947.html

Introduction to Electronics

- Quiz – When Was Electronics Introduced?

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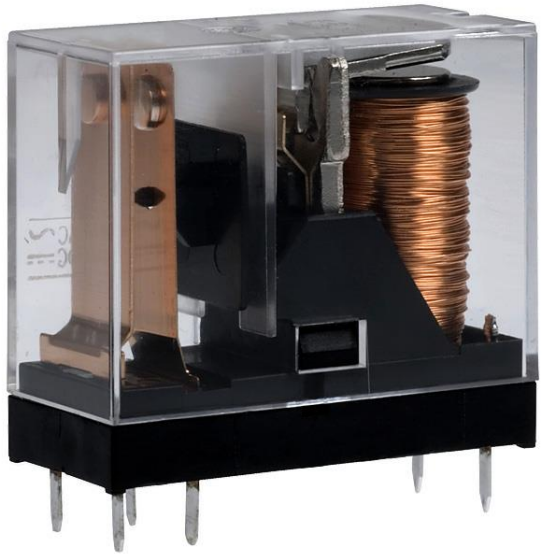
Introduction to Electronics

- 1835
  - Joseph Henry (US) or Edward Davy (UK)
  - Invented the relay for the electrical telegraph
  - This is considered more of an electrical invention rather than electronic



http://www.netprolive.com/electronics.php

Introduction to Electronics

- Quiz – When Was Electronics Introduced?

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Introduction to Electronics

- 1904
  - Sir John Ambrose Fleming
  - Invented the Vacuum Tube
  - This is considered to be the birth of Electronics

- 1906
  - Lee De Forest, an American Inventor
  - Invented the Triode
    - Vacuum Tube with 3 electrodes which amplified a weak signal
  - Major breakthrough in electronics which introduced amplification

https://www.slideshare.net/PratikshaPriyamBaruah/vacuum-tube-70436738

History Lesson

- Early 60s – When I was born
  - Black and White TVs – 3 Channels
  - Landline dial phones with party lines
  - Records and record players
  - Computers for businesses only, which occupied large room
  - No internet
  - No cashline machines, credit or debit cards – bank passbooks and cheques

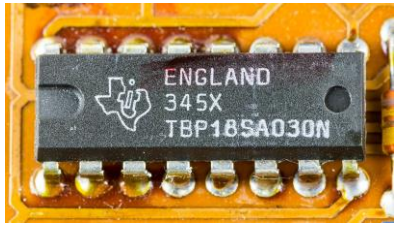
History Lesson

- Early 80s – Started Engineering
  - Colour TVs – 4 Channels
  - Mobile Phones just invented
  - Cassette tapes overtook Record sales due to the Sony Walkman portable player
    - In 2009 it was voted the top music invention of the last 50 years
  - Affordable computers for schools (Apple II) and first home computers (ZX80)
  - Internet just invented, but not the World Wide Web
  - Cashline machines, credit cards – but still bank passbooks and cheques


TWEETYOURFIRSTCOMPUTER
5/10
NIKKAI
1K GAMES
ZX81
1981
the centre for computing history
Sinclair ZX81
10 PRINT "HELLO"
20 GOTO 10
RUN
Sinclair brought computing to the masses and the ZX81 is a very important machine in computing history.
Also in this year
Royal wedding of Prince Charles and Lady Diana Spencer in Britain.

Important Inventions

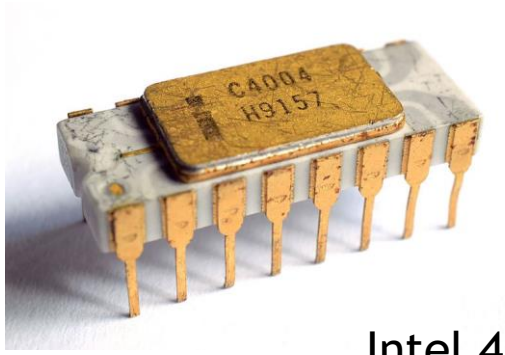
- 1970 – Programmable Read Only Memory (PROM)
  - First programmable memory
  - 256 Bytes



PROM

- 1971 – Microprocessor Intel 4004
  - First microprocessor built on a single chip
  - Processor, Arithmetic and Logic Unit, Control Unit, Memory on 1 device

1 Core, 2.3K Transistors, 10µm Process, 740kHz, 4-bit data, 4KB memory

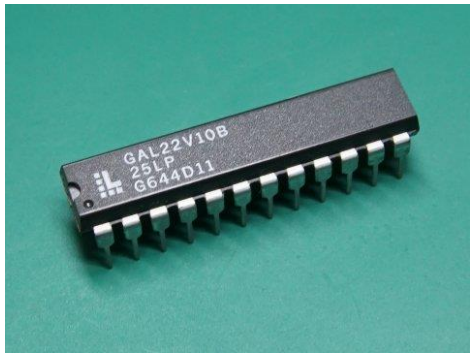


Intel 4004

https://commons.wikimedia.org/wiki/File:Intel_C4004.jpg

Important Inventions

- 1975 – Programmable Logic Devices
  - Texas Instruments
  - Simple functions: Address decoding

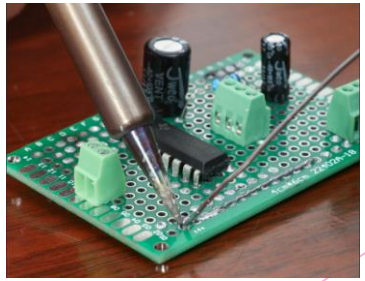


GAL 22V10

- 1985 – Field Programmable Gate Arrays (FPGA)
  - Ross Freeman, Xilinx
  - Initial FPGAs had 4,000 transistors
  - My field of expertise

XC2064

- Printed Circuit Board (PCB)
- Double Sided, Through Holes Components



https://forums.xilinx.com/t5/Xcell-Daily-Blog/Xilinx-XC2064-world-s-first-commercial-FPGA-inducted-into-IEEE-s/ba-p/775806

Now

- TVS – LED, OLED, QLED, 100s of channels
- Phones are computers in your hand
  (iPhone 2B Transistors, 20nm Process)
- Stream music and videos
- Multiple home computers and game machines
- Internet
- Credit and debit cards

Advancements

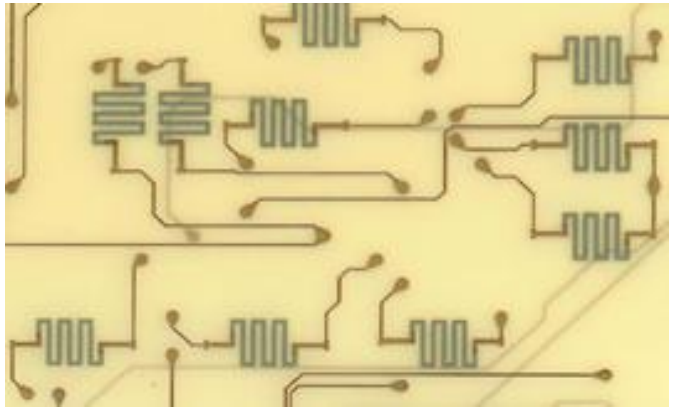
- Processors - Intel Core i9-12900K
  16 Multi-cores, 7.2B Transistors, 10nm Process, 5.2GHz, 64-bit words, 30MB memory
  (1971 1 Core, 2.3K Transistors, 10µm Process, 740kHz, 4-bit words, 4KB memory)
  In 50 years: 16 more cores, 3 million times more transistors, 7 thousand times faster with 7.5 thousand times more memory

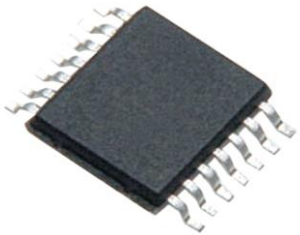
- Memory devices – 64G Bytes
  1970 256 Bytes
  In 50 years: 250 thousand times larger

- FPGAs – Xilinx Ultrascale
  30B Transistors, 14nm Process
  1985 4,000 transistors
  In 37 years: 7.5 million times larger

Advancements

- PCB – 24 Multi-layers
  Surface Mounted and Ball Grid Array Components
- Inbuilt passive components
- System’s which took up whole rooms now fit in the palm of a hand





Agenda

- Introduction to Electronics
- 2050
- Challenges facing Electronics

2050 - Medical

- Cybathlon
  - This year's Cybathlon was the largest ever
    - It's aim is to challenge teams from all over the world to develop assistive technologies suitable for everyday use with and for people with disabilities
    - The first event was in 2016, with just 6 sports
    - It's become the event for biomedical engineers to showcase their innovations
    - This year there was 18 sports
    - The number of contestants overtook the Paralympics for the first time

2050 - Medical

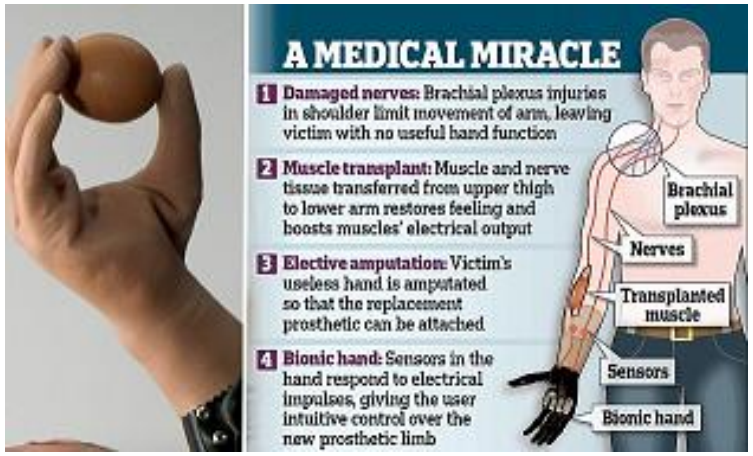
- Major Advancements in Assistive Technologies
  - Paralysed limbs
    - Electronic muscle stimulation
    - Event: Hurdles
  - Paraplegics
    - Exosuits
    - Event: 400 meters

https://www.technologyreview.com/s/546276/this-40000-robotic-exoskeleton-lets-the-paralyzed-walk/

2050 - Medical

- Major Advancements in Assistive Technologies
  - Amputated arms
    - Bionic arms
    - Event: Table Tennis
  - Blindness
    - Ocular implants

    Event: Archery
  - Aim: Affordable solutions for all physical disabilities
    - We are almost there



http://www.dailymail.co.uk/sciencetech/article-2967622/The-bionic-hand-s-operated-MIND-world-three-men-lower-limbs-amputated-replaced-robotic-prosthetics-controlled-brain.html

2050 - Medical

- Medical Advances
  - COVID in the 20s changed the way vaccines are developed
    - More collaboration world wide
    - Rules brought in so no one organisations profits
    - DNA based
    - Unfortunately there have been several more pandemics
    - But we now understand the transmission of viruses between animals and people, but not how to stop it
  - DNA is now used to diagnose illnesses
  - Smart drugs have been developed
    - Memory enhancers to help combat Alzheimer

2050 - Medical

- Medical Advances
  - Operations performed using robotics
  - 3D printed tissues and organs are standard and have greatly reduced heart attacks
  - Parkinson and epilepsy controlled by Bionic Nervous Systems
  - Continuous health monitoring for all
    - Alerted quickly to health issues
  - Life expectancy for women has risen to 93 years
    - Was 83 in the 20s

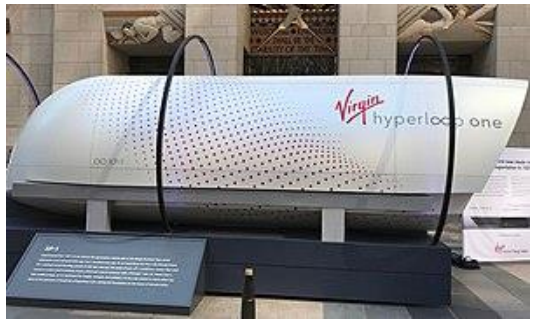
2050 - Travel

- Travel
  - World wide travel is easy
    - Scotland to Australia in 2 hours via the Spaceport at Prestwick
  - Universal translators means language is no longer a barrier
  - Reduced Packing
    - Clothes – self cleaning, change colour and auto fit
  - Colony's on Mars

https://www.scotsman.com/future-scotland/tech/scotland-in-strong-position-to-host-first-uk-spaceport-1-4662079

2050 - Travel

- Travel
  - Hyperloop connects all major cities
    - Became a reality in 2020 after the 1st passengers travelled safely
  - Trains are powered by electricity and hydrogen
  - Autonomous buses are used in the cities
  - Planes are powered by biofuel
  - Car ownership is rare
    - Vehicles are powered by hydrogen and biofuels
    - Electrical vehicles a distant memory due to infrastructure costs



Virgin Hyperloop One XP-1 pod - side view - Virgin Hyperloop - Wikipedia

2050 - Energy

- Power costs are minimal
  - Houses produce their own power – Solar, Wind Turbines, Heat Pumps
  - Connected to the Smart Grids reducing the need for power plants
- Personal devices batteries have been replaced with micro generators that harness kinetic energy from physical movement
- Smart Homes keep us
  - Connected and secure
  - Control heating, lighting etc
  - Order our food
  - Provide entertainment
- Climate change slowly being reversed – but not quick enough

2050 - Technology

- Technology designed to last at least 5 years

  - TVs replaced by Augmented Reality Systems worn as glasses
  - Mobile Phones replaced by voice activated chips and augmented glasses
  - Stream music and videos
  - Computers are voice activated
  - Internet addressing updated as number of users increase
  - Cashless society

  - PCBs have been replaced with single chips
  - New programmable biological chips – used to replicate plants

2050 - General

- Work and Learning
  - Home working which started in 2019 continued
    - Use holographic technology for meetings and personal conversations
    - More worldwide companies – location is no longer a barrier
    - Retirement age increased to 75 years old
  - Schooling has changed
    - Large choice of subjects via online courses
    - Augmented Reality headsets are as common as calculators use to be
  - Robots are everywhere doing all manual tasks
  - More free time to enjoy activities and spend time as a family and friends

2050 - Summary

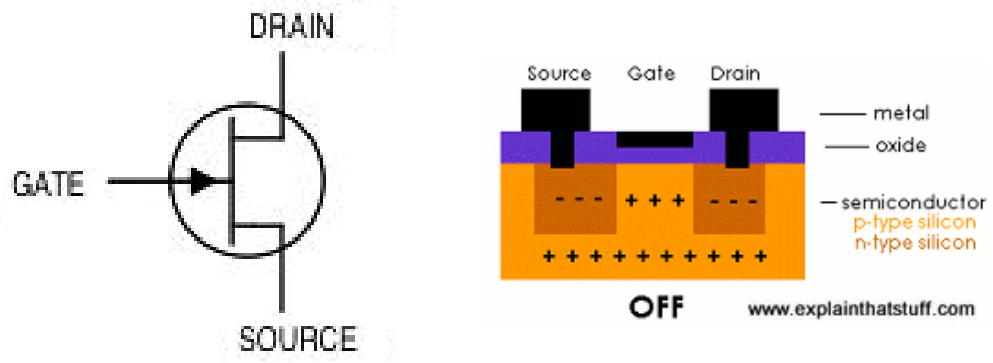
- But what do all these changes have to do with electronics?
- Everyone of these advances rely on electronics to provide the control circuitry
- Without electronics none of these advances will be possible

Agenda

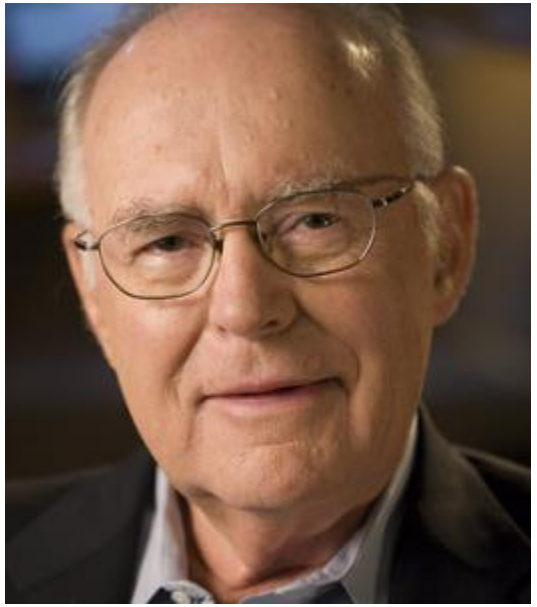
- Introduction to Electronics
- 2050
- Challenges facing Electronics

Challenges facing Electronics

- Moore's Law
  - Started in 1970
  - "The number of transistors in an IC will double every two years"
  - Some think Moore's Law is dead, but most definitely slowing down
  - Physically transistors are reaching their limit



Field Effect Transistor (FET)

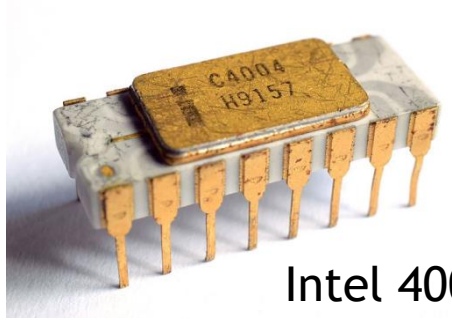


George Moore

http://www.mooreslaw.org/
https://www.build-electronic-circuits.com/how-transistors-work/
http://www.explainthatstuff.com/howtransistorswork.html

Challenges facing Electronics

- Transistor and Processes
- 1971 first CPU, Intel 4040
  - 2,300 Transistors
- Latest CPU, Intel Broadwell E5 Xeon
  - 7.2 Billion Transistors
- iPhone 13
  - 15 Billion Transistors
- Latest FPGA, Intel (Altera) Stratix 10
  - 30 Billion Transistors



Intel 4004

Intel Broadwell E5 Xeon

Intel (Altera) Stratix 10

http://www.funkykit.com/news/pc-computers/intel-launches-stratix-10-altera-fpga-combined-arm-cpu-14nm-manufacturing/

Challenges facing Electronics

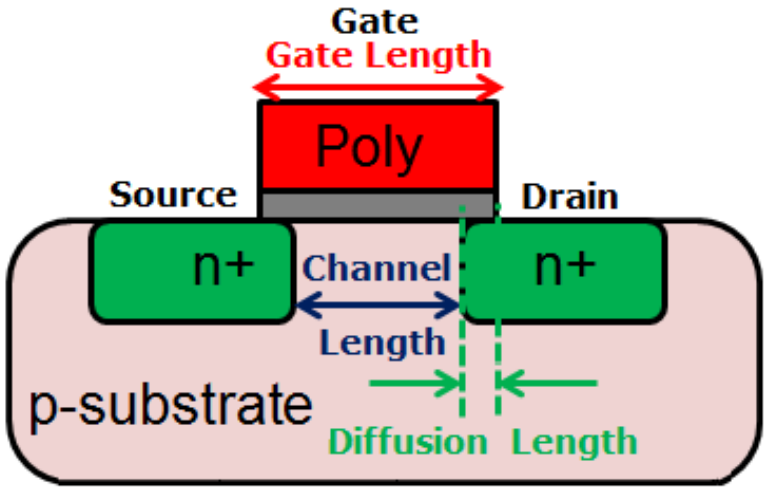
- Semiconductor Manufacturing Process
  - Process was 10µm in 1971 for Intel 4040
  - 2001 - 130nm, 2004 – 90nm, 2012 – 22nm
  - iPhone x - 20nm, iPhone 13 - 5nm
  - Just reached 1nm

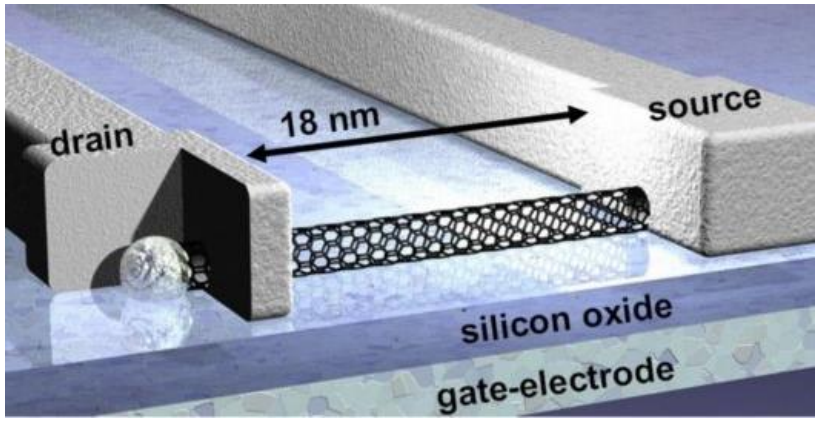
- But what does this mean?

- Why is it important?

Challenges facing Electronics

- What does it mean?
- Number represents the Channel Length in a transistor

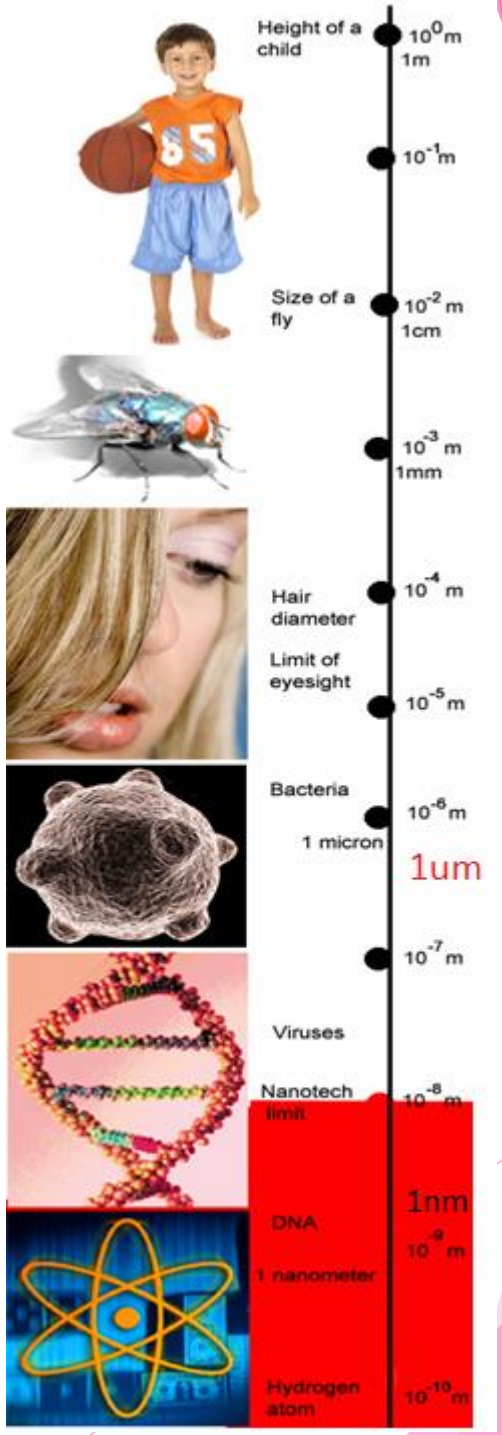




http://vlsi-soc.blogspot.co.uk/2015/12/channel-length-vs-gate-length.html
http://www.understandingnano.com/nanotube-transistor.html

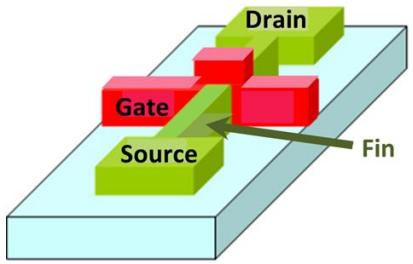
Challenges facing Electronics

- Why is it important?
- The smaller the channel length
  - The more transistors in a chip (more logic)
  - The faster transistors can switch (greater clock speeds)
  - Less power required (lower voltages)
- But getting lower will be a problem
- Starting to reach physical limits (Atom = 0.1nm)

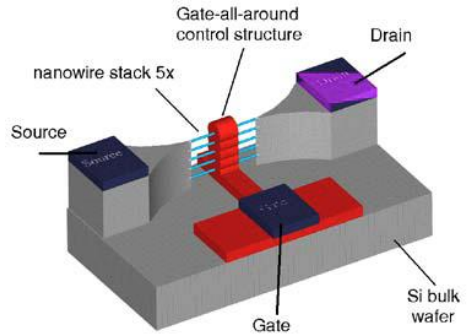


Challenges facing Electronics

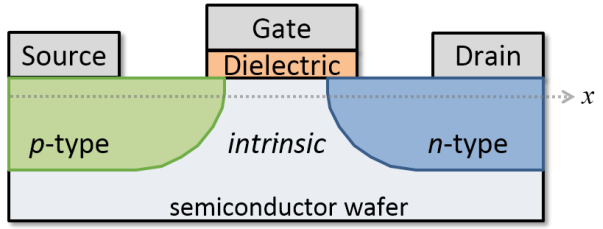
- Improving Transistors
  - FinFET (3D Transistor) – Double Gated transistor
    Called FinFETs because the source and drain region forms fins on the silicon surface
    Switches one third faster than FETs at a lower voltage
  - The development of FinFETs meant 22nm could be achieved
  - To get below 14nm new transistor structures were required
  - Gate All Around (GAA) FETs – FinFET on its side surrounded by the gate
  - Tunnel FET (TFET) - Source and drain terminals are doped with opposite types



FinFET



GAA FET



TFET

https://semiengineering.com/going-to-gate-all-around-fets/

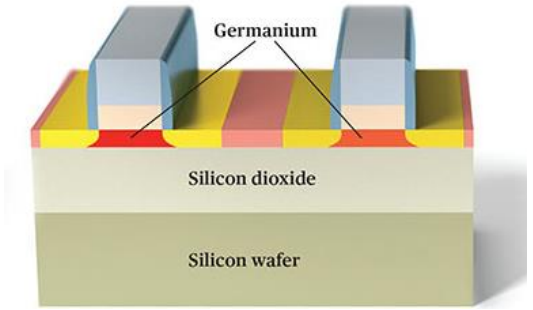
Challenges facing Electronics

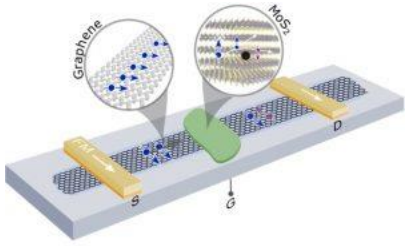
- Vacuum Tubes
  - Transistors replaced Vacuum Tubes in the 1960s
  - Electrons travel faster in a vacuum than through a transistor
  - Enthusiast about high-fidelity sound reproduction don't like digital sound so a niche market has opened up for vacuum tube audio equipment
  - NASA has creating a nano-sized vacuum tube that's
    - Faster and hardier than the transistor
    - Able to survive the harsh radiation of outer space.
    - It operates at frequencies up to 0.46 terahertz
      - 10 times faster than the best silicon transistors
  - Drawbacks
    - Need 10V to switch (transistor needs 1V)
    - Expensive to manufacturer

http://www.sciencemag.org/news/2012/05/return-vacuum-tube

Challenges facing Electronics

- Alternative Materials
  - Reintroduction of Germanium or Silicon-Germanium
    - Germanium was used for first transistors but was dropped
    - Used in ICs so not difficult to add to transistors
  - Indium Arsenide and Gallium Arsenide
    - Electrons in Indium Arsenide move 30 times more than in silicon
    - Difficult to add to transistors
  - Graphene
    - Could be a thousand times faster and use a hundredth of the power
    - André Dankert and Saroj Dash of Chalmers University of Technology in Gothenburg investigating spintronics (spinning electrons)
    - Difficulty is finding the “switching” point





Graphene Transistor

https://spectrum.ieee.org/semiconductors/materials/germanium-can-take-transistors-where-silicon-cant
https://www.electronicsweekly.com/news/first-graphene-transistor-2017-07/

Challenges facing Electronics

- Flexible Electronics
  - Range of materials – organic polymers, graphene, ceramic
  - Smartphone display, solar cells on rolls of plastic, smart newspapers
  - Flexible implants to help paraplegics walk
  - Weave into clothes for smart textiles

- Problem to solve
  - How to power

Flexible Graphene

https://graphene-flagship.eu/exhibitions/MWC2018/Pages/DataCom.aspx

Challenges facing Electronics

- Parallel Technology
  - One solution is if we can't go faster then go parallel
  - Based on how our brains work
  - Comparison below between Brain and Fastest supercomputer
    - Chinese Tianhe-2 Supercomputer, costs $290 million, massive
    - 32,000 multicore Intel Xeon Ivy Bridge chips, and 48,000 Xeon Phi chips

	Supercomputer	Brain
IPS	5,000	38,000
Architect	Linear	Massively Parallel
Language	Rigid	Fuzzy
Backup	Easy	Not possible

https://www.computerworld.com/article/2497197/high-performance-computing/china-surpassing-u-s--with-54-9-petaflop-supercomputer.html
https://www.quora.com/If-the-human-brain-were-a-computer-it-could-perform-38-thousand-trillion-operations-per-second-The-world%E2%80%99s-most-powerful-supercomputer-BlueGene-can-manage-only-002-of-that-But-we-cannot-perform-like-a-supercomputer-Why

Challenges facing Electronics

- Parallel Technology
  - Supercomputer
    - Factor of 7 slower (could be achieved in 6 years if follow Moore's Law)
    - Size (think of computers in the 60s compared to laptops)
    - Artificial Intelligence (AI) could solve the fuzzy logic problem
  - Could match brain's capacity within a generation
    - But not the functionality
  - Massive achievement, bring us nearer to understanding our own brains

Challenges facing Electronics - Stats

- Technology
  - The UK is leading the world in:
  - Plastic Electronics
  - Graphene

The **UK** has the **6th** largest **Electronics** industry in the world

Over **90%** of **smart phones** contain **Electronics designed in the UK**

Top technology trends all depend on Electronics:
Internet of Things, autonomous vehicles, augmented reality, wearables, renewables

The Electronics sector contributes **6% to the UK GDP**

1.5% of population

https://www.ukesf.org/wp-content/uploads/2016/01/UKESF-Infographic-A4.pdf

GDP-Gross domestic product

Challenges facing Electronics

- Electronics Engineers
  - Elephant in the room is the lack of engineers
  - EngineeringUK 2022 report
  - Highlight:
    Since 2010, the number of females in electronics has risen from 2.8% to 15.2% - 2,453 more
  - Lowlight:
    Since 2010, the number of males in electronics has reduced by 15,335
  - Overall loss of 12,883 engineers
  - In a time when we need the number of engineers to grow
  - We need to get children interested in engineering
  - UK Electronics Skills Foundation (UKESF) is specifically targeting electronics

Engineering UK report - EngineeringUK | Inspiring tomorrow's engineers.

Summary

- Electronics have become an integral part of our lives
- I've described my idea of the future
  - Electronics is fundamental, but we need a step change in technology
- Biggest problem is going to be the lack of engineers
  - Without them none of these advancements will be possible
- How do we enthuse children?
  - Maybe by letting them know what the future could look like
  - Or better still, get them to define their future
- There are initiatives to get children interested in engineering
  - But, they are not working fast enough
  - We need to do something different and quickly
- The future could be amazing:
  But only if we can improved the technology and have enough engineers

Questions