**A few Billions of people and
a 1000 B devices interconnected
RSA, London, 2009-june-25**

**Dr Ir Egbert-Jan Sol,
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TNO | Kennis voor zaken

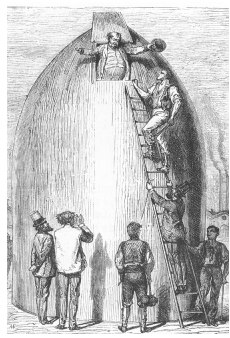Egbert-Jan.Sol@TNO.nl

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Jules Verne

More then 100 years ago,
he saw just a glimpse.

A space rocket did not
became a large bullet

What will 2100 look like?

The stone age was not ended
because of lack of stones,

so our silicon age will not end
because of lack of sand

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From mainframe to smart push-pins
3-times an order of 1000

Scale log mm³:
1890 US census (human & electro-mech)

12 1940 relay based cryptography	1000 m3 (= 10 x 10 x 10 m)	
11 1955 vacuum-tube	100 m3 (= 5 x 5 x 5 m = 125 m3)	
10 1959 mainframe discrete transitor Appollo	10 m3 (=2.5 x 2.5 x 2.5 m = 15,6 m3)	
9 1970 minicomputer integrated circuit	1 m3 = 1000 dm3 = 10^6 cm3 = 10^**9** mm3	
8 1979 microcomputer = human body	100 dm3 =(50 x 50 x 50 cm3)	
7 1984 AT 36 liter, 1988 Pentium 22 liter	10 dm3 =10 liter (15 lt = 25 x 25 x 25 cm3)	
6 1992 notebook 2 lt	1 dm3 = 1000 cm3 = 10 x 10 x 10 cm3	
5 2000 PDA = appx 5 cm3	100 cm3 = 5(12,5) x 5 x 5(2) cm3	
4 2008 SiP = appx 2,5 cm3 cubic inch	10 cm3 = 2,5 x 2,5 x 2,5 cm3	
	1 mm x 12,5 cm x 12,5 cm	
3 2017 cubic centimeter	1 cm3 = 1000 mm3 = 10 x 10 x 10 mm3	
2 2025 intelligent push-pin (punaiske)	100 mm3	

- Dimensions: pin length 10 mm by 1 mm
  top 10 mm diameter by 1 to 2 mm thickness
  volume: pi x 5 square x 1 + 10 = 100 mm3

The stone age was not ended by lack of stone –
The silicon age was not ended by lack of sand

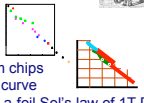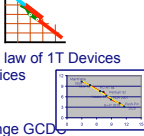|		
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3 2017 smart stone	1 cm3 = 1000 mm3 = 10 x 10 x 10 mm3	
2 2025 intell. push-pin (punaiske)	100 mm3 = 5 x 5 x 5 mm3	
1 2033 smart pebble	10 mm3 = 2,5 x 2,5 x 2,5 mm3	
	Kurzweil: 1 liter intelligent matter (= bucket of 1M intell. Sand grains)	
0 **2040** intelligent sand	1 mm3 = 10^9 µm3 = 1000 x 1000 x 1000 µm3	
-1 2048	10^8 µm3 = 500 x 500 x 500 µm3	
-2 2055	10^7 µm3 = 250 x 250 x 250 µm3	
-3 2060 intelligent clay	0,1 mm3 = 10^6 µm3 = 100 x 100 x 100 µm3	
-6 2080	0,01 mm3 = 10^3 µm3 = 10 x 10 x 10 µm3	
-9 2100 cell	1 µm3 = = 1 x 1 x 1 µm3	

Not manipulation silicium kristal, or even organic polymer chain, but programmable (DNA) polymer chains
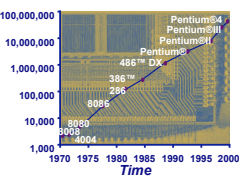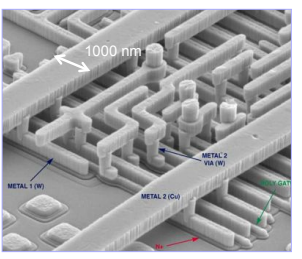

The future of connectivity

- I am not a professor who has to publish.
  I am not a consultant earning money by talking.
  I'm the Chief Technology Officer (directeur kennis)
    at TNO Science & Industry,
      a 1000 people public R&D organisation

- We can't predict the future, however ….
    we can learn from history
      and extrapolate learning curves

- Technology – 3 learning curves
  - 1st Moore's law on chips towards 10 nm chips
  - 2nd "a Dollar a Day" bandwidth learning curve
  - 3rd The intelligence push-pin, system-in-a-foil Sol's law of 1T Devices
    - Single 3D chip in a system-in-foil and 1T devices

- Application: The connected car
  - The 2011 Grand Cooperative Driving Challenge GCDC
    at the Helmond-Eindhoven A270 Highway in the Netherland

Moore's law for Integrated Circuit build up

of transistors on a chip

today determined not in
the USA, but by ASML
in the Netherlands

100,000,000
10,000,000
1,000,000
100,000
10,000
1,000

Pentium®4
Pentium®III
Pentium®II
Pentium®
486™ DX
386™
286
8086
8080
8008
4004

1970 1975 1980 1985 1990 1995 2000
Time

1000 nm

METAL 2 VIA (W)
METAL 1 (W)
METAL 2 (Cu)

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Slide 1: From Micro-Electronics to Nano-Electronics

Nano   Micro

1000 =1µm

Resolution (nm)

submicro

100 nm

nano

- ◆ 436 nm
- ■ 365 nm
- ▲ 248 nm
- ○ 193 nm
- ■ 130 nm
- ▲ 90 nm
- ● 65 nm
- ▲ 45 nm
- ● 32 nm
- ● 22,16,10 nm
  Immersion
  EUV

1985 1990 1995 2000 2005

Year

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Slide 2: The Computerless Computer Company (HBR 1991)
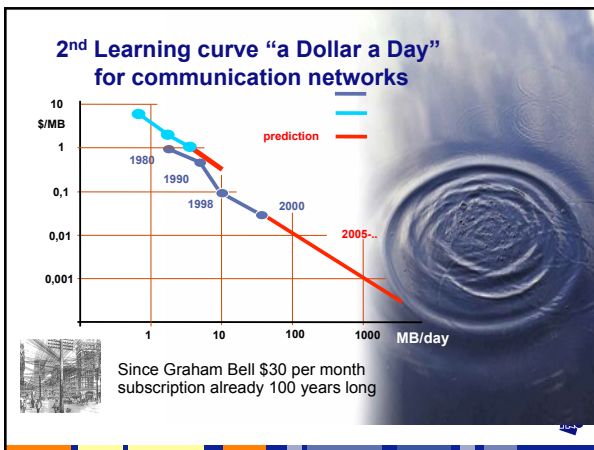
Moore's law: performance/price ratio improvement for micro-electronics implies a factor 2 in 18 months

That's 1000 x in 15 years

Costs/MIPS

Legend
Mainframes
PC's

SOFTWARE IS SCARCE

HARDWARE IS COSTS

HARDWARE IS CHEAP

Microsoft

Microsoft

BIOS

IBM, Compaq, Taiwan, ...

1975-1985: Hardware Decade

1985-1995: Software Decade

Replacing:
typewriter by a text editor
calculator by a spreadsheet

Slide 3: 2nd Learning curve "a Dollar a Day" for communication networks

$/MB

10
1
0,1
0,01
0,001

prediction

1980
1990
1998
2000
2005-..

1   10   100   1000   **MB/day**

Since Graham Bell $30 per month subscription already 100 years long
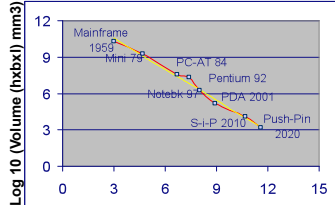
Slide 4: Fixed (Wireline) Telephony: Graham Bell - 1876 the breakthrough was Twisted Pair - 1881 then it took only 10 years - 1891

**Patent nr 244426,
A.G. Bell, 10-july-1881**

**New York,
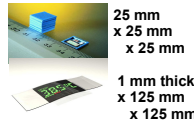10 year later, 1891,
Broadway/John Street**

Slide 5: Moore's Law: factor 1000 in 10-15 years

# of transistors on a chip

100,000,000
10,000,000
1,000,000
100,000
10,000
1,000

Pentium®4
Pentium®III
Pentium®II
Pentium®
486™ DX
386™
286
8086
8080
8008
4004

1970 1975 1980 1985 1990 1995 2000
Time

**Performance/Price doubling in 18 months
= 1000 x in 15 years**

Costs/MIPS

Legend
Mainframes
PC's

MIPS

€/MB/day

Mobil

Fixed

MB/day

Comm. (KPN)

Softw.

Processing is free.

?

Hardw. (IBM)

70-80

Softw. (Micro-Soft)

Hardw.

80-90

90-2000

Slide 6: 4th-G 500B things Internet

1st Generation Internet: Academic

The internet of things (& cars)

**2nd G: Microcomputers & WWW
and Dial-in modems**

3rd G: Broadband (fibre/UMTS)

**4th G (ambient) Internet by 2020
is ubiquitous, embedded, hidden**

1980: 250 users on 1 mainframe

1500
1000
500
0

◆ Fixed
■ Mobile

1993 1997 2001 2005 2010   **year**

Nr of fixed & mobile lines in 1000

2000: 1 mobile + 1 PC per user

**2020: 250 Embedded, wireless
devices per user
@ 2B humans is 500B**

**500B is just beyond imagination
yearly today's 2B mobile phones**

Slide 1

3th Learning curve for smart (punaiske) devices
(from mainframe to ambient push-pin computer)

Log 10 (Cum. Amount of devices) 6=1M, 9=1B

Note: SiP = System in a Package

(c) TNO Industrial Technologies, Egbert-Jan Sol, ejsol@dse.nl, 2004

9 = 1B 10x10x10 cm
(1 litre) devices by 2000

10 = 10B 5x5x5 cm
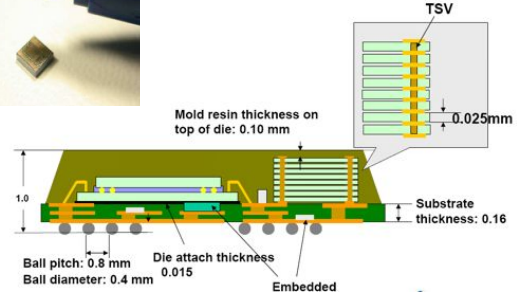PDA/phones by today

11 = 100B 1 cubic" (2,5 cm)
devices by ? 2010

25 mm
x 25 mm
x 25 mm

1 mm thick
x 125 mm
x 125 mm

12 = 1000 B 1x1x1 cm
devices by ? 2020

Slide 2

Typical System in Package in 2010

TSV

Mold resin thickness on top of die: 0.10 mm

0.025mm

1.0

Substrate thickness: 0.16

Ball pitch: 0.8 mm
Ball diameter: 0.4 mm

Die attach thickness 0.015

Embedded

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Slide 3

3D chip wafer stacking
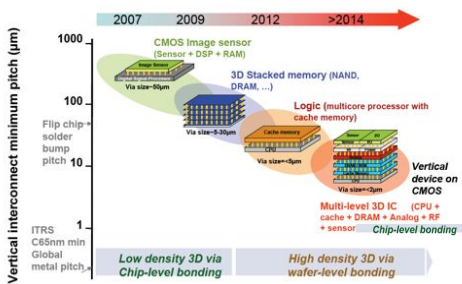
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Slide 4
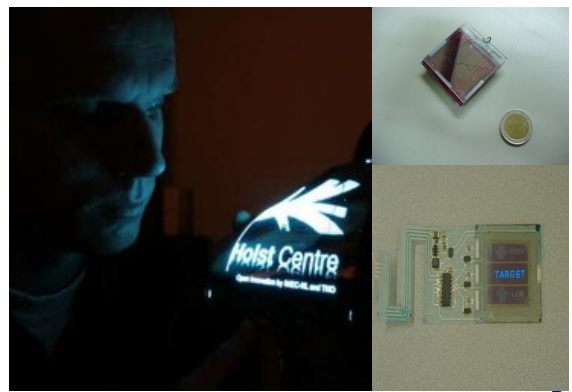
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Slide 5

TNO Metal Jetters
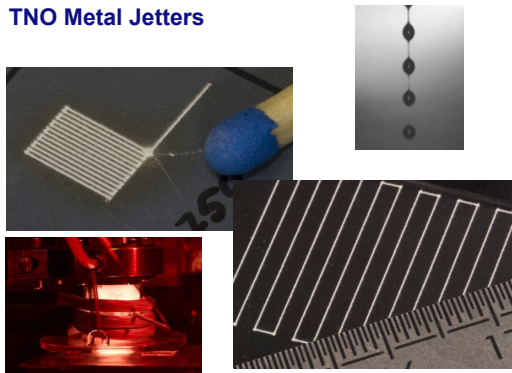
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Slide 6

TNO Polymer Jetters

3 mm high
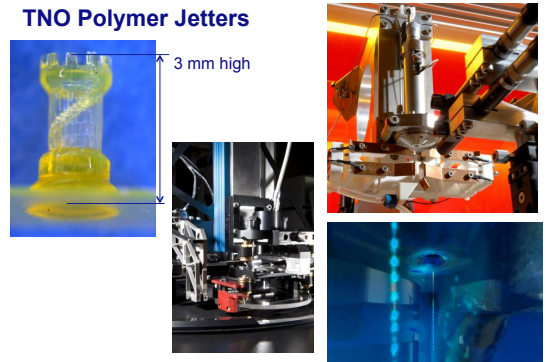
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Slide 1

Example: system-in-foil applications in sports

Timing of catch
Dirk Lippits

Boat accel (m/s²3)	Catch time (s)	Power eff (%max)
2.4	0.76	81
Targets	0.76	83

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Slide 2

The Paradigm shift:
What does this mean for you?

Service-Creation
Start-ups
(The next Bill Gates)

€/ MB/day

Mobi
Fixed

Costs/MIPS

Legend
Mainframes
PC's

MB/day

Comm. (KPN)

Softw.

Proces-sing is free.

Softw. (Micro-Soft)

Hardw.

Hardw. (IBM)

Appli. & Service

Death of distance

Open Source

Give Away Hardware

Levi's & Caterpillar
of the 21st gold rush

70-80   80-90   90-2000   2000-2020

Slide 3

The paradigm shift in automotive
The Connected Car

• From mechanical moving machine to

• A computer on four wheels with a mechanical frame for comfort and protection in case the electronics, or worse the software fails

• From a system where all information (visual, radio, etc) goes one-way towards the car and its driver to

• A system that achieves maximal (two-way) contact with its environment by means of sensors and communication, in order to become an

automatic moving machine – a real auto automobile

Slide 4

TNO vehicle generations for the 21st century

Gen. 5: Fully automatic driving

Gen. 4: Cooperative driving

Gen. 3: Single lane auto pilot

Gen. 2: Support and correct

Gen. 1: Inform and influence

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Slide 5

TNO vehicle generations for the 21st century

Note: nG=1G+..nG,   e.g. 3G=1G+2G+3G

Gen. 5: Fully automatic driving

Gen. 4: Cooperative driving
(COOD, light swarms)

Gen. 3: Single (smart) lane
C-ACC, platooning

Time: 7 years/G
Say 2G (+1G) by 2012
3G: 2020, 5G implemented
by 2035, full 2040

Gen. 2: Support and correct
bijv ACC, CCC

Gen. 1: Inform and influence

Slide 6

Traffic Jam Reduction

Speed upstream - 10% CA

Simulation A12 4 to 3 lane section at Woerden: 30% less jam with 10% ACC

"Slimstrook (dutch) (Smart Lane)

10 years ago it was possible

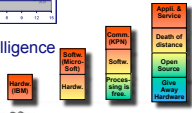The challenge is the introduction

So we a GCDC, june 2011

Slide 1

2010 demo – 2011 GCDC - Scenario 2: Platooning

- Objective:
  - mitigate downstream disturbances
  - Perform maneuvers
- Challenge type:
  - Feedback/hybrid control (CACC)
  - wireless communication
- System type: automatic
- Vehicle instrumentation:
  - communication system
  - sensors (radar, lidar and/or vision)
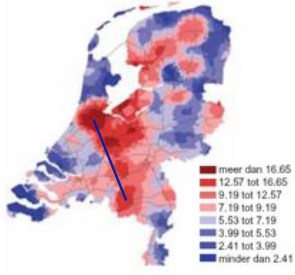 - automatic throttle & brake system

Slide 2

Conclusion

- We can't predict the future (of connectivity), but we can learn from history and extrapolate 3 learning curves
- Technology
  - From Mainframe via PC to ambient intelligence
  - From Hifi-set via iPod to intelligent foils
  - Ambient Intelligence of 1T devices
- One of a many application
  - Cooperative driving car 2020
  - Ultimately autonomous car 2040

"Frankly sir, we're tired of being on the cutting edge of technology."

Slide 3

Economic growth in Netherlands

- A2 highway
  - Amsterdam
  - Eindhoven

meer dan 16.65
12.57 tot 16.65
9.19 tot 12.57
7.19 tot 9.19
5.53 tot 7.19
3.99 tot 5.53
2.41 tot 3.99
minder dan 2.41

bron: Bureau Louter, 2003