Chip Innovations and Computer Revolution

Supercomputer Conference, November 16, 2006, Tampa, Florida
Invited Speech

Commentary

SC or Supercomputer Conference is held in the United States every year in November, and is one of the world's largest supercomputer related academic conferences along with ISC or International Supercomputer Conference held every year in June in Europe. Supercomputer performance ranking (TOP 500) is announced at both these academic events, so they gather great attention of researchers and engineers in the computer field.

In the communities of computer science, the interest in semiconductor innovation is very strong. This time, I was asked to talk about semiconductor technologies in general, including the introduction of "Makimoto’s Wave".

First, after mentioning paradigm shift in electronics, I touched on the subject of "computer revolution“ based on the concept of "Figure of Merit" which I previously proposed. Analyzing the actual data, I presented that “Figure of Merit of computers increases by 1000 times every 10 years". It was the first presentation on this subject at the appropriate computer conferences.

After talking about "semiconductor innovations" and "Makimoto’s Wave", I stated that the robotics will become a driver to lead the whole electronics in the future.

Let me introduce a memorable episode about this speech. In the Figure of page 10 “Brief History of Computer Revolutions”, I stated that "the world's first computer is ENIAC", but a gentleman came to me immediately after the presentation, and pointed out that "The world's first computer is not ENIAC but ABC or Atanasoff Berry Computer". I made a research on this matter after I came back home and confirmed this fact. His name is Vladimir Getov, Professor of Westminster, and we still keep in touch each other.

SC 2006
November 16, 2006

Chip Innovations and Computer Revolution

Tsugio Makimoto, Ph. D.

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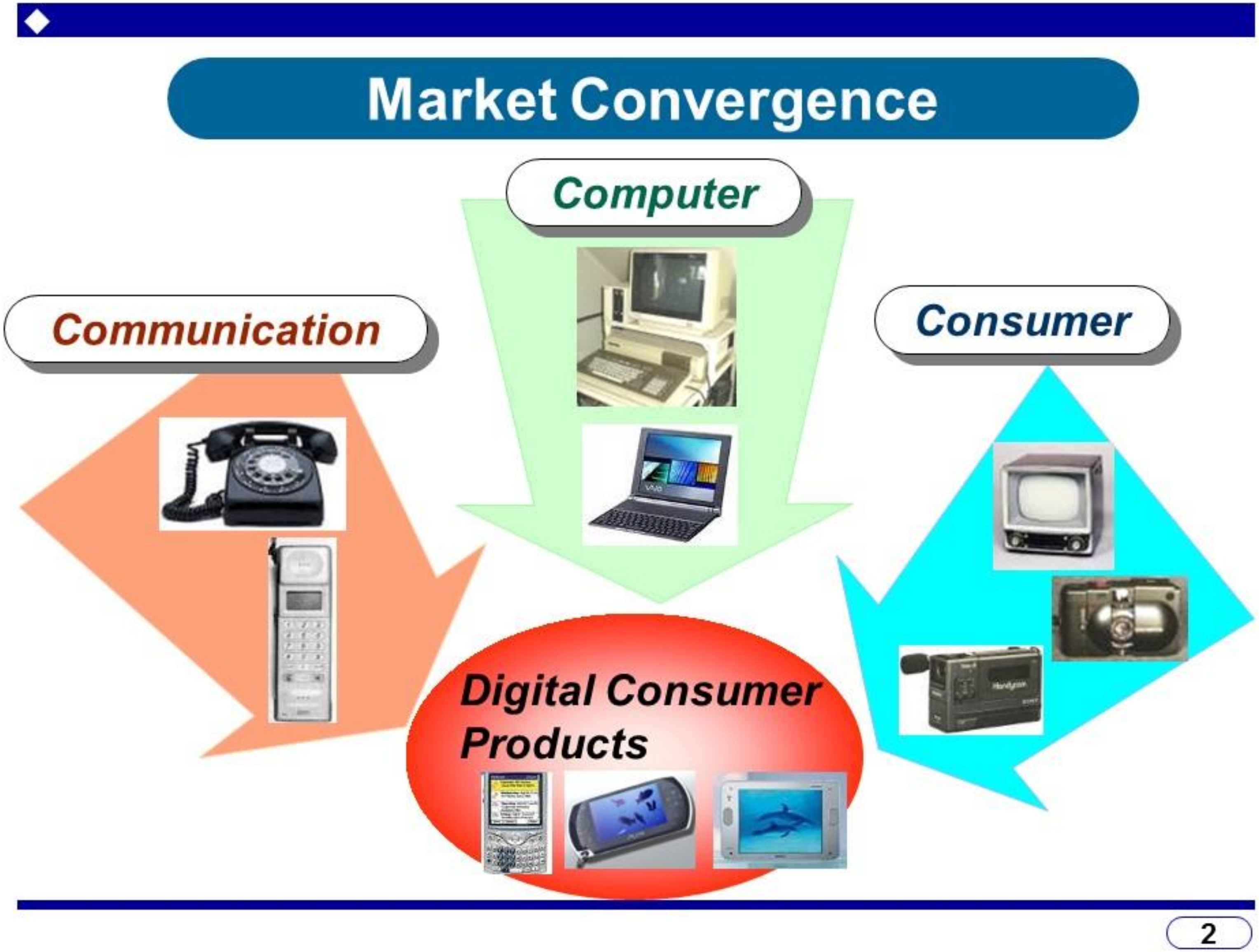
Former Corporate Advisor, Sony Corporation

Most of the subjects in SC are computer related, but my presentation was unique in a sense that it was a prospect of computer revolutions as seen through the semiconductor window.

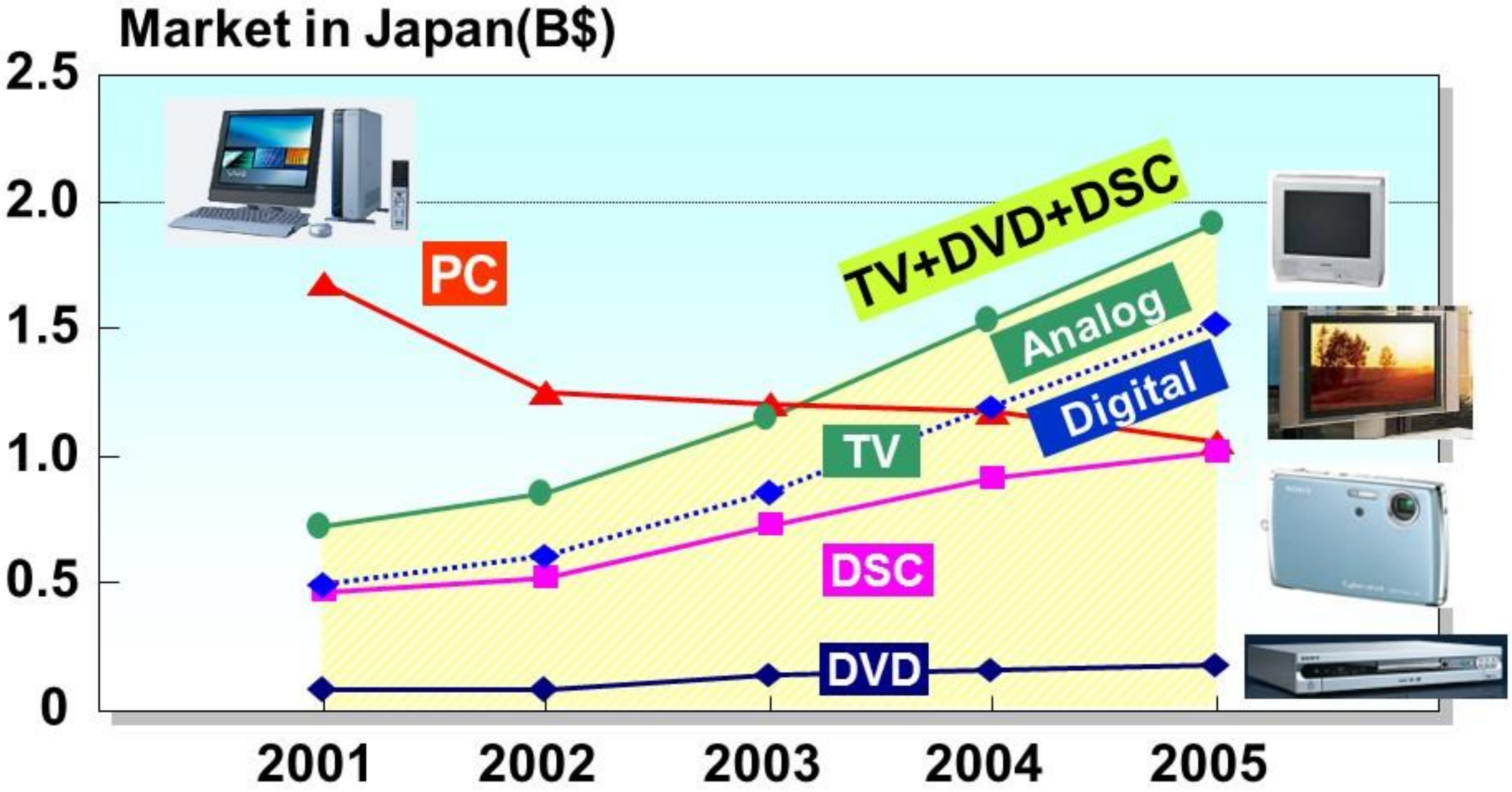
Outline

- **Changing Paradigm in Electronics**
- Computer Revolution
- Chip Innovations
- Implications of Makimoto's Wave
- Future Outlook



There have been clear boundaries between the communication, computer, and consumer markets so far. Today the boundaries are blurring, and many electronic equipment are converging to "digital consumer products". The major factor that led to such market convergence is firstly digitilization of information and secondly semiconductor innovation, especially CMOS innovation.

PC vs. Three Big CEs



Source: JEITA

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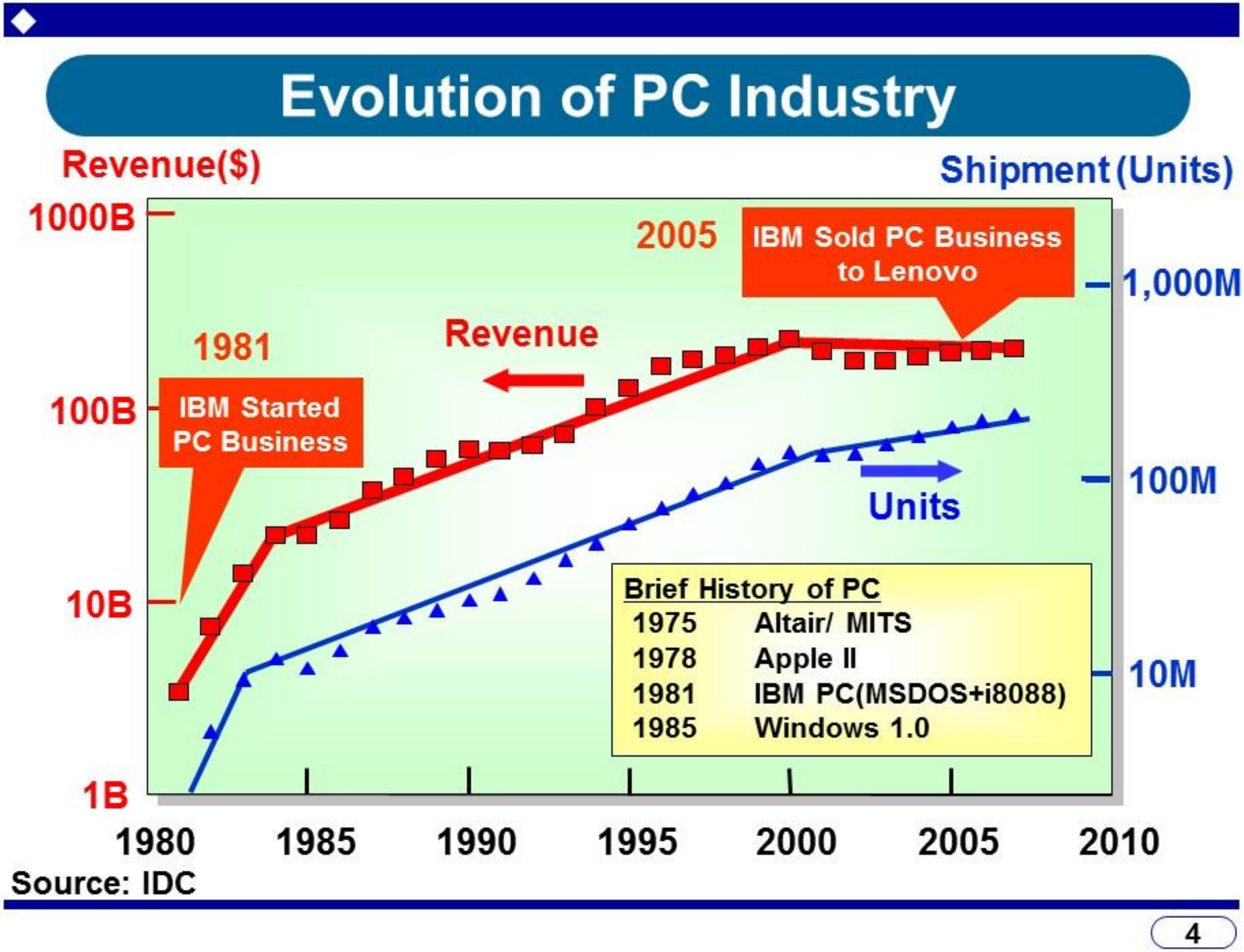
In Japan, PC has already passed its peak, and it has given way to digital consumer products as the leading role in the electronics market.
In 2004, the combined markets of TV, digital camera, and DVD together exceeded the PC market. This is a symbol of the paradigm shift.



The red line shows the size of the world PC market since 1980. Although it had grown steadily until around 2000, the trend has been almost flat after that. The blue line is the trend in the number of units, and it has been growing continuously to even today, and the price has decreased accordingly. PC already became a mature industry, and it is no longer a growth engine of electronics.

Changing Aspects of Computer Companies

- ★ Apple's iPod Opened the New Trends of Portable Music Players
- ★ Microsoft Started Game Business
- ★ Dell Started Flat Pannel TV Business
- ★ IBM Supplying Game Chips to Three Majors
- ★ IBM Sold PC Business to Lenevo


(Source: Apple's web site)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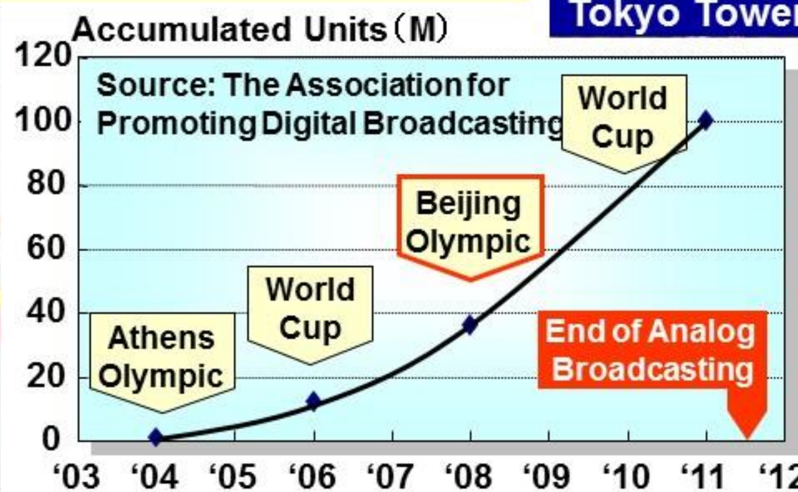
This shows examples of how computer companies are changing. Apple released iPod and opened a new genre of portable music players. Microsoft entered the game market. Dell began business of flat panel TV. IBM supplies semiconductors for game consoles and sold the PC division to Lenovo (China). All these companies have drastically changed towards the consumer field.

December 1, 2003 –Start of TDTV--

- Terrestrial Digital Broadcasting to Start in Tokyo, Osaka and Nagoya, Japan
- 100M TVs to be Digitalized by 2011
- $2,000B of Economic Effect



In Japan, terrestrial digital broadcasting will start soon, and the big economic effect is expected. Prime Minister Junichiro Koizumi attended the ceremony of broadcasting start on December 1, 2003, and raised a toast. In 2011, all analog broadcasting will be over and 100 million digital TVs are expected to spread.

Photo taken by Y.Sakai

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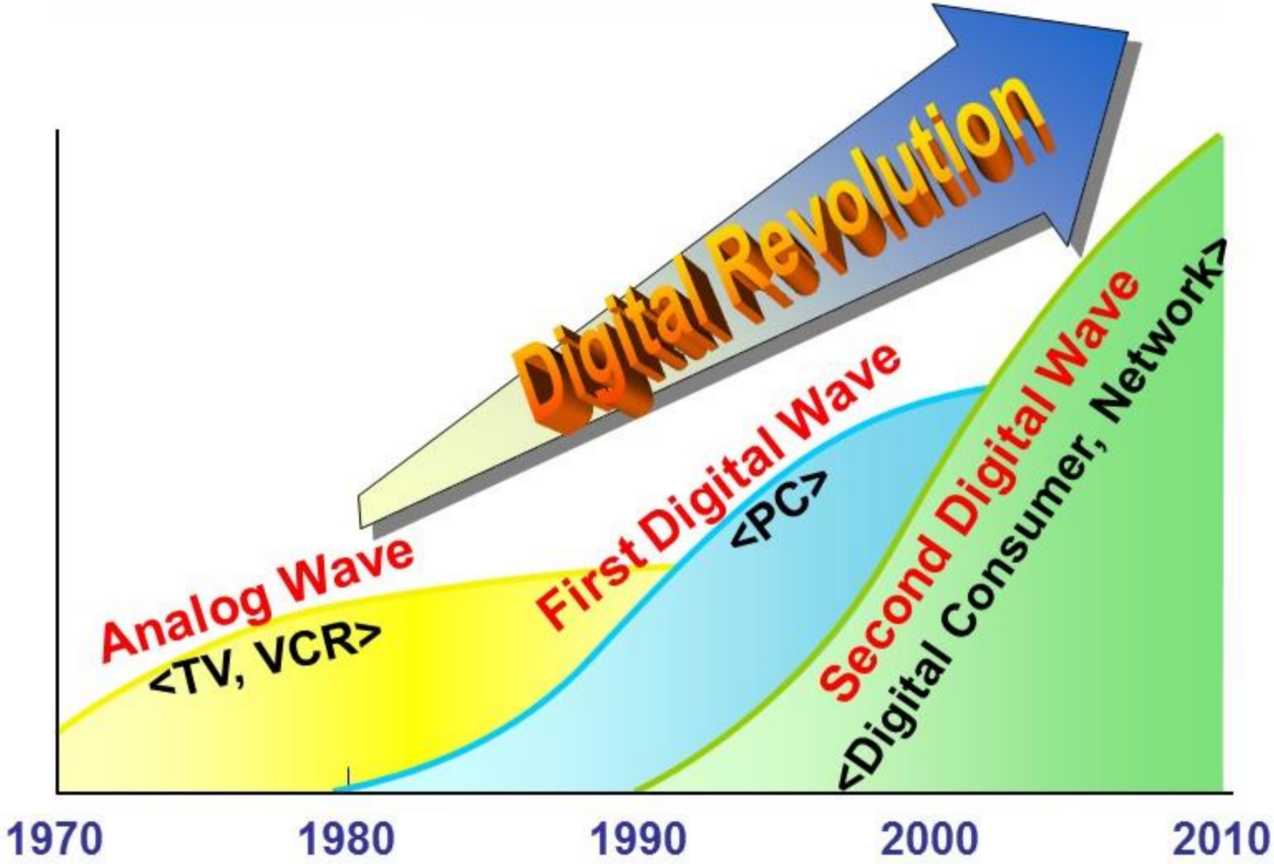
Everyone, do you know why TV changes from analog to digital? This picture was taken when a friend of mine bought a digital TV. His cat did not show any interest in analog TV before, but when it became digital the cat delightedly chased birds on the screen. In other words, even a cat can recognize the difference between analog and digital. A lot of laughter in the venue.

Three Big Waves of Electronics



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The figure expresses the paradigm shift of electronics as three waves. The first wave is an analog wave such as TV, VCR, etc. The first digital wave was driven by the PC from the 1980s, and the second digital wave, from the 1990s, was driven by digital consumer products which are connected to the network. A paradigm shift from the PC centric to digital consumer centric is now in progress.

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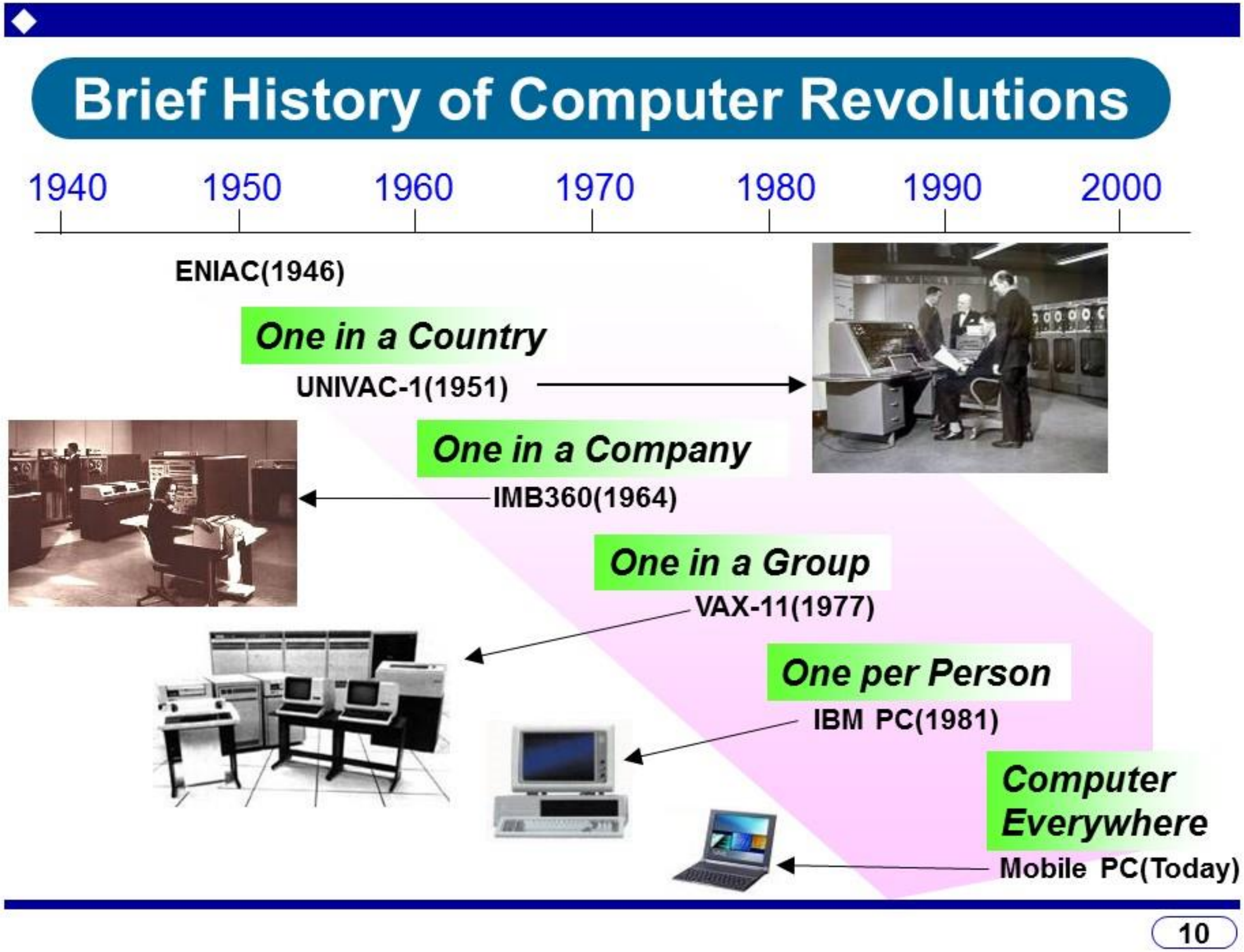

The first computer ENIAC was introduced in 1946, followed by its commercial version UNIVAC–1 in 1951.The computer was a treasure as "one machine in one country“ in this time. Changes in semiconductor devices, from transistor to IC, to MPU, and to SoC pushed the democratization of computers. Today, “computer is everywhere”.

Comparing UNIVAC-1 vs Mobile PC

	UNIVAC-1 (1951)	Mobile PC (Today)	Ratio
Performance (MIPS)	0.1	2,300	$2.3x10^{4}$
Size (cc)	$7.4x10^{8}$	$2.0x10^{4}$	$2.7x10^{-5}$
Power (W)	$1.3Ex10^{6}$	52	$4.2x10^{-5}$
Price ($)	$9x10^{5}$	1,500	$1.6x10^{-3}$

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This table compares the characteristic figures like performance, size, power, and price between mobile PC at the time and UNIVAC-1, the first commercial computer. Progress in 55 years is in 3 to 4 orders of magnitude level for all the parameters, and it is truly spectacular. The biggest factor that has made such great progress is semiconductor innovation.

Figure of Merit of Electronic Equipment

★ $$\text{Figure of Merit} = \frac{(\text{Intelligence})}{(\text{Size}) \times (\text{Cost}) \times (\text{Power})}$$

★ Indicator of the technological progress in the long range

★ Guiding principle for the future direction of development

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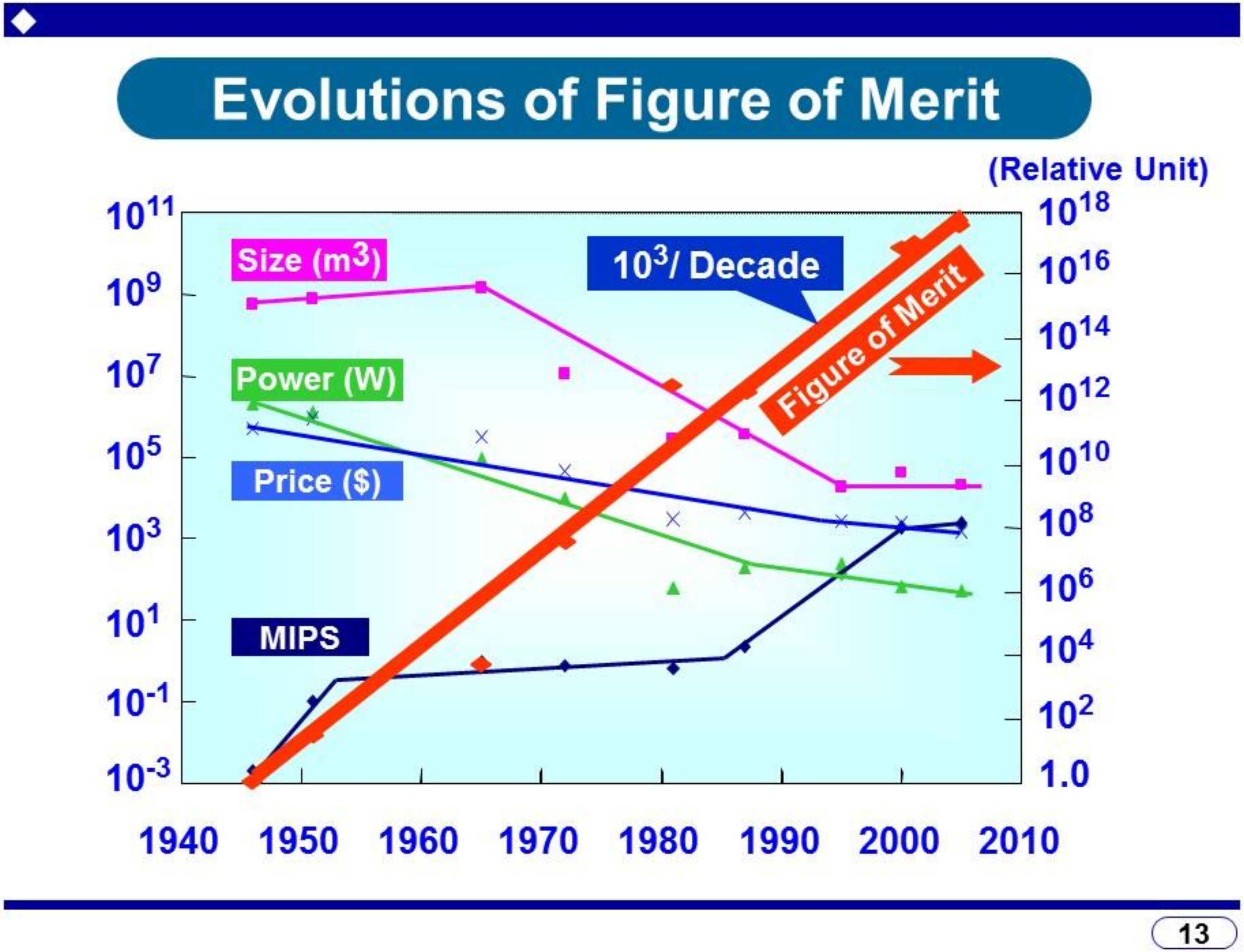
The equation above defines Figure of Merit (FoM) of electronic equipment including computers . FoM is an indicator of long-term technological progress, and it becomes a guideline for development. That is, every development is aimed at maximizing FoM. This concept was proposed in the previous speech, but this was the first proposal in a big computer conference.



The figure shows the evolutions of Figure of Merit for computers. The thin lines indicate the four parameters in the formula, and the red thick line indicates FoM. Changes in individual parameters are not necessarily smooth, but the values of FoM are distributed almost linearly. The upward slope of the straight line is "1000 times in 10 years", which corresponds with "speed of computer progress".

Some Images of Future PC

Case 1

Same performance, 1/10 times lower cost,

1/10 times smaller size,

1/10 times lower power

OLPC

One Laptop per Child for $100.
Initiated by N. Negoroponte.

Case 2

10 times Performance, Same cost,

1/10 times smaller size, 1/10 times lower power

Case 3

100 times performance, Same cost

1/10 times smaller size, Same Power

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Let's imagine images of PC in ten years with the assumption that the progress is 1000 times in 10 yeras. Case 1 is a cost oriented "100 dollar PC" direction. Case 2 is tablet PC direction with high performance, compact, and low power. Case 3 is the direction of a super high performance desktop PC. These can be achieved in ten years by semiconductor innovations.

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Major Events for Chip Innovations

- **Invention of Transistor**
  Shockley,Bardeen, Brattain (1947)
- **Invention of IC**
  Kilby (1958), Noyce (1959)
- **Moore's Law**
  Moore (1965)
- **Introduction of Microprocessor**
  Intel (1971)

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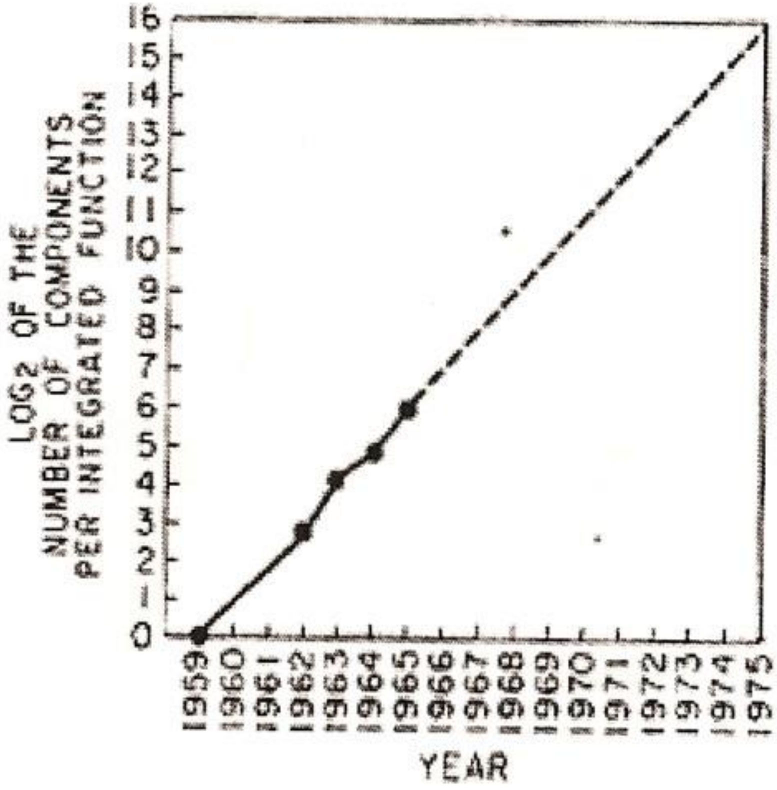
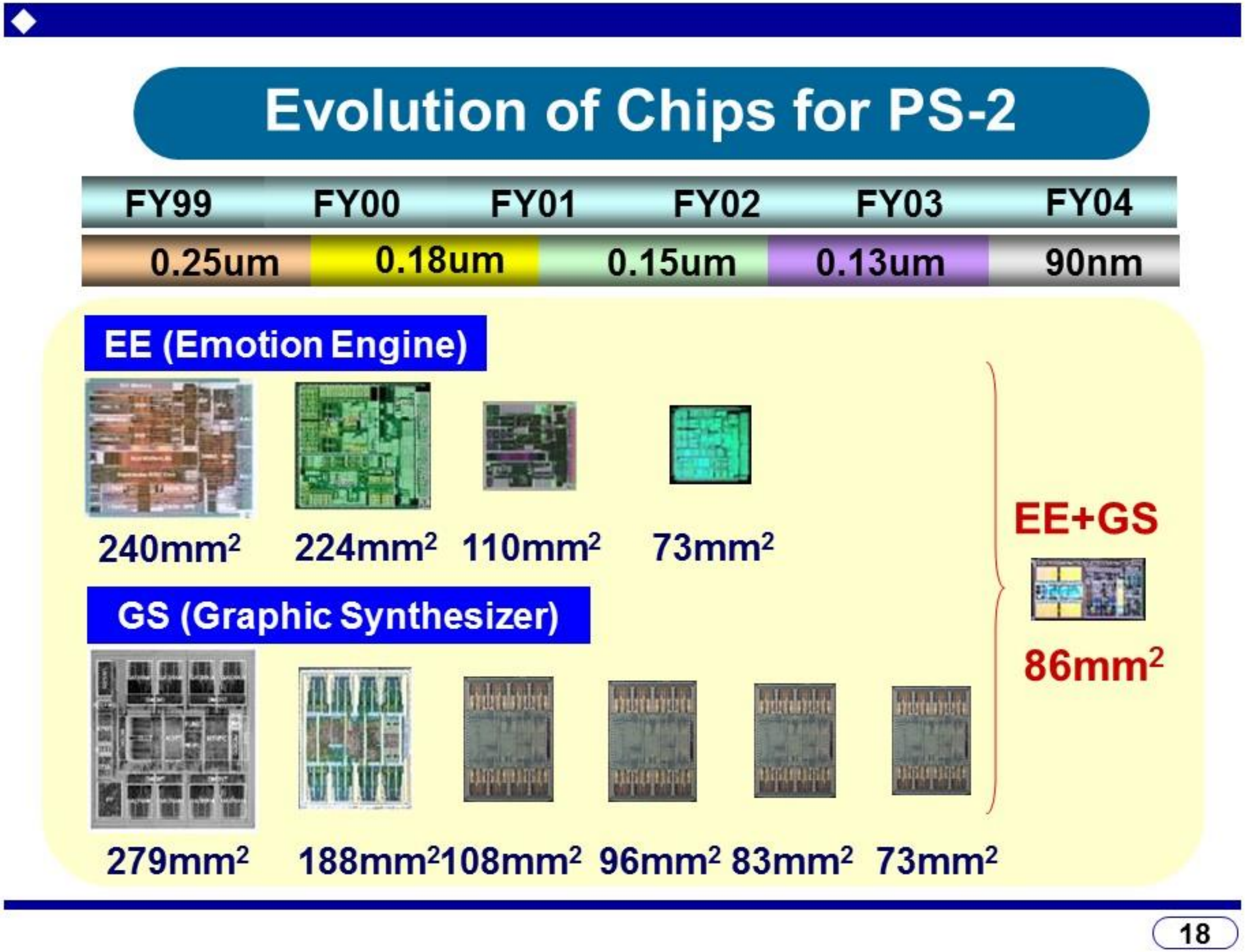
These are important events concerning semiconductor innovation. The first is transistor invention in 1947, the second is IC invention in 1958/1959, the third is the discovery of Moore's law in 1965, and the fourth is commercialization of microprocessor in 1971. These are key events which have created dramatic evolution of semiconductors.

Origin of Moore's Law



Gordon Moore
"Cramming more Components into Integrated Circuits"
Electronics (April 15, 1965)

This Figure created by Gordon Moore was published in Electronics magazine in 1965. From this trend, Moore found that "the number of components in a chip doubles every year". Also, he predicted that it would be possible to integrate 1000 times more than the current level in 10 years. This is the origin of "Moore's Law".



As an example of semiconductor innovation, let's see the evolution of the chips of Sony's game machine PS-2. It started in 1999 with two chips based on 0.25 μm technology. Chip shrink progressed almost every year, and in 2004 they were finally integrated into one chip based on 90 nm technology. With such evolution, lower price, higher performance, and lower power were realized.

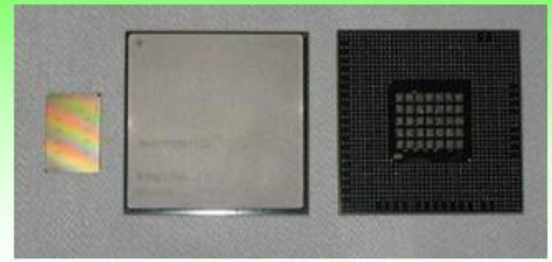
Outline of CELL Processor

★ Joint Project of IBM, Toshiba & Sony Started in March, 2001

★ Five Papers Presented at 2005 ISSCC

★ Multi Core Architecture:

- *One RISC Type 64bit CPU Core*
- *8 Signal Processor Core*
- *Operating Frequency : 4GHz*
- *Performance : 256G FLOPS*

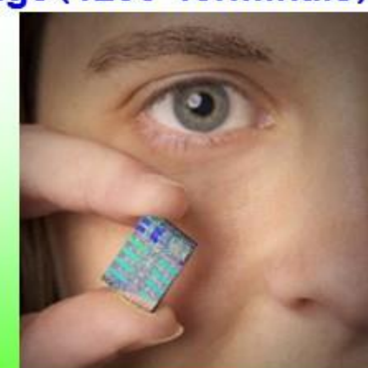


CELL Chip(221mm2) & Package（1236 Terminals）

★ Technology

- *90nm SOI*
- *Gate Length 46nm*
- *Low K*
- *Cu 8Layers*
- *234M Transistors*

300mm Wafer



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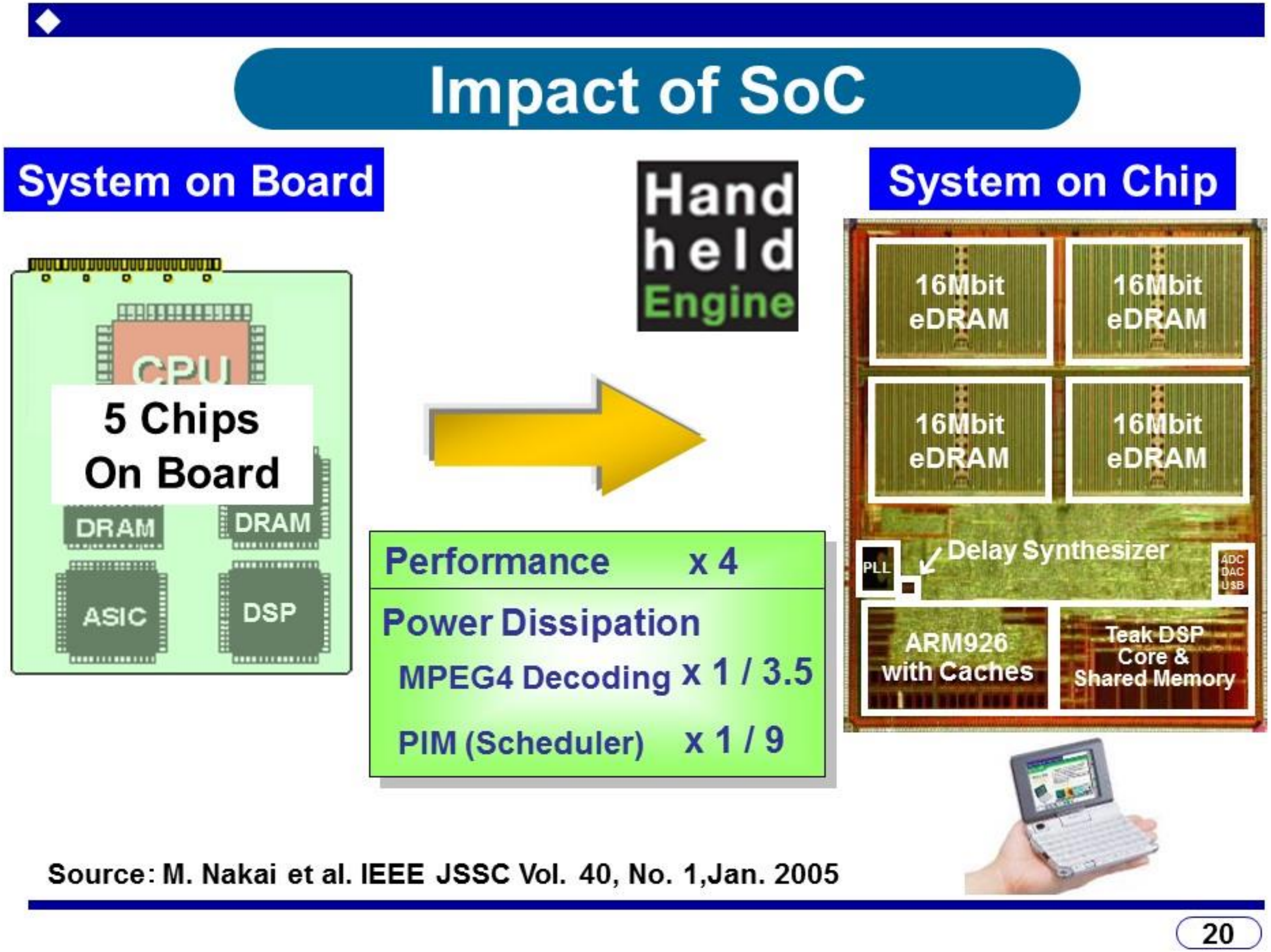
Cell Processor is an epoch-making MPU used for Sony's next-generation game machine PS-3.
Since 2001, IBM, Toshiba and Sony jointly developed it, and it was presented at ISSCC in 2005. Multi-core architecture was used for achieving 256 GFLOPS of performance. It was state-of-the-art product based on 90 nm SOI technology with 230 million elements.



The figure shows the impact of SoC. The figure on the left shows five chip system mounted on a board (SoB). The right is the integration of those devices in one chip (SoC). As a result, the performance is quadrupled and the power consumption decreased to 1/3.5 or 1/9 depending on the task. This is the power of SoC to achieve "low power and high performance".

Major Issues of SoC

- ★ Design Productivity is Lagging
- ★ Process Machines Getting Expensive
- ★ Tooling Cost is Escalating
- ★ Testing is Complex and Expensive

Will SoC be Profitable?

- Yes in Some Cases, but Not Always
- SiP Will Supplement SoC
- Field Programmability to Play Important Role

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SoC is not almighty, but there remains several issues which are summarized in the yellow box. Therefore SoC may not always be profitable. It is the SiP that complements it, and furthermore field programmability will play an important role.

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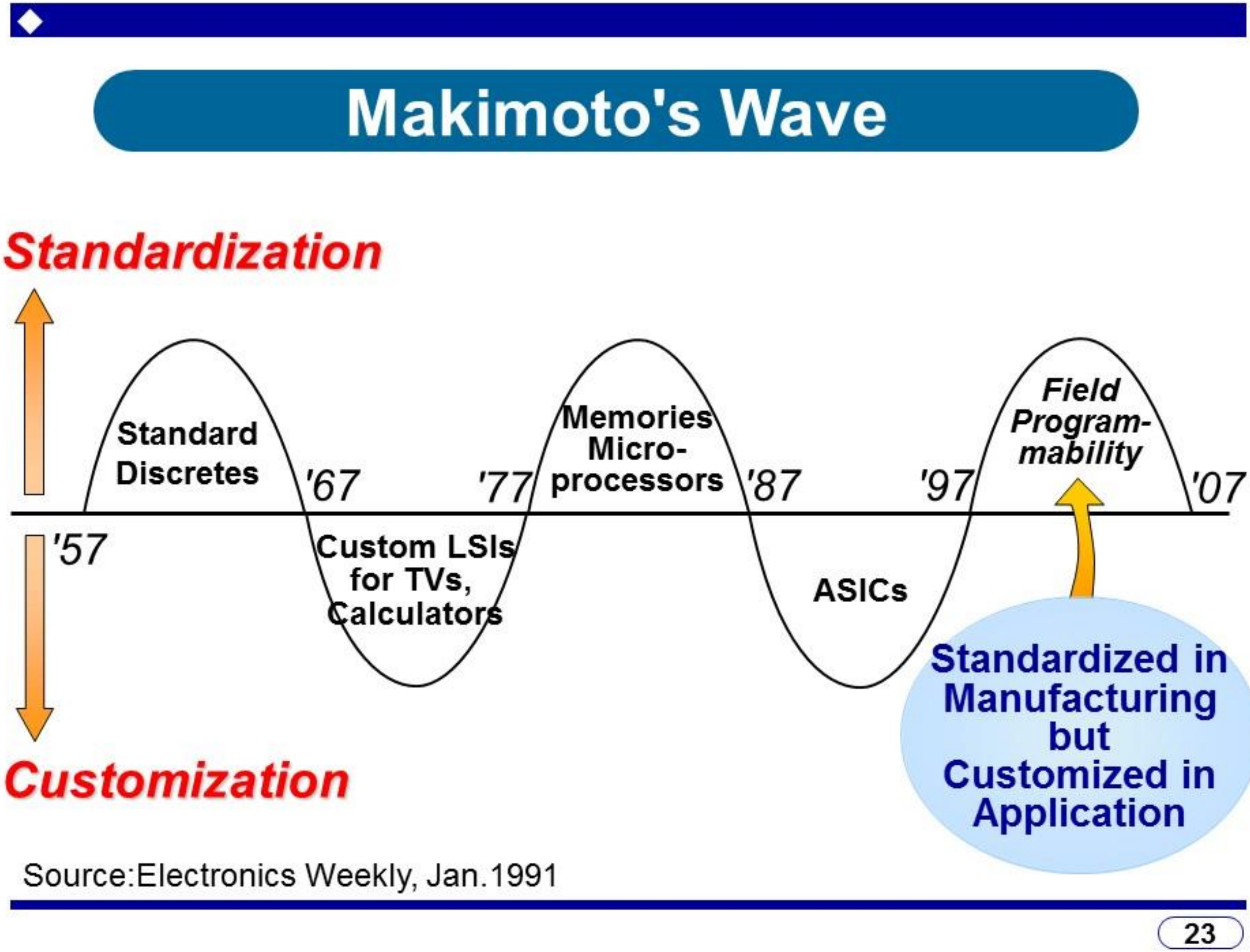
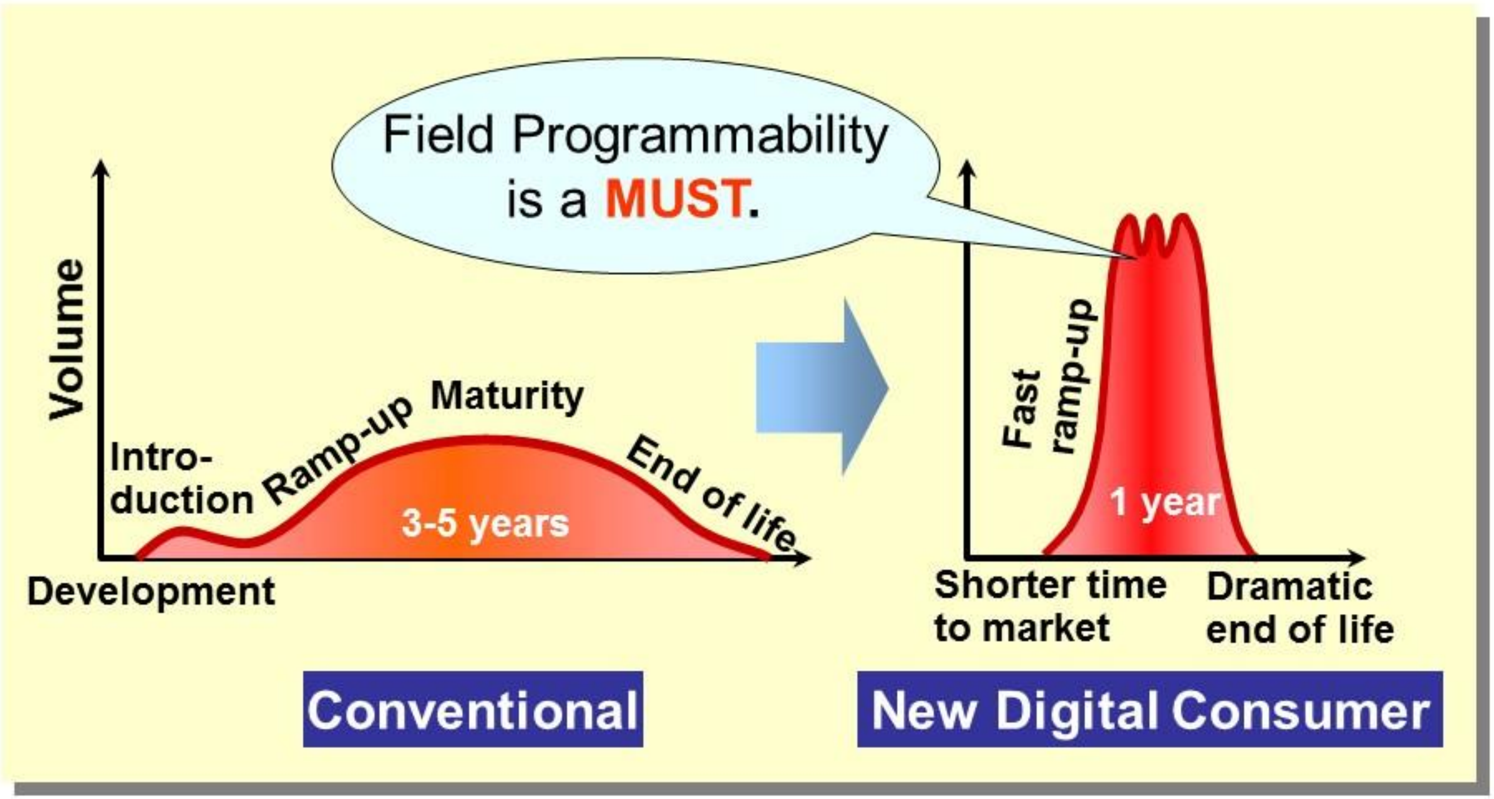


In the semiconductor industry, standardization and customization alternate direction roughly every ten years. It was named "Makimoto's Wave" in the Electronics Weekly by David Manners in 1991. At the time of this speech, field programmable devices were in the prime time, and were the basis of reconfigurable computing.

Dramatic Change in Product Lifecycle



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Why do you need field programmability? It is because product life cycle is changing dramatically. Product life in analog age was 3-5 years. In the case of digital consumer products, on the other hand, the market rises rapidly, the peak period is short, and there comes a dramatic end of life. Field programmability is a MUST to cope with such rapid changes.

Wide Spread Applications of FPGA

Medical Imaging

- Toshiba
- GE Medical
- Siemens
- Phillips

High Performance Computing

- Cray
- SGI
- Mercury
- Linux NetworX

Data Analytics

- Netezza
- Teradata
- Exegy
- XtremeData

Many of these are using FPGAs today:
Cray, SGI, Mercury, LinuxNetworX offer x86 platforms with FPGA accelerators

Source: Altera

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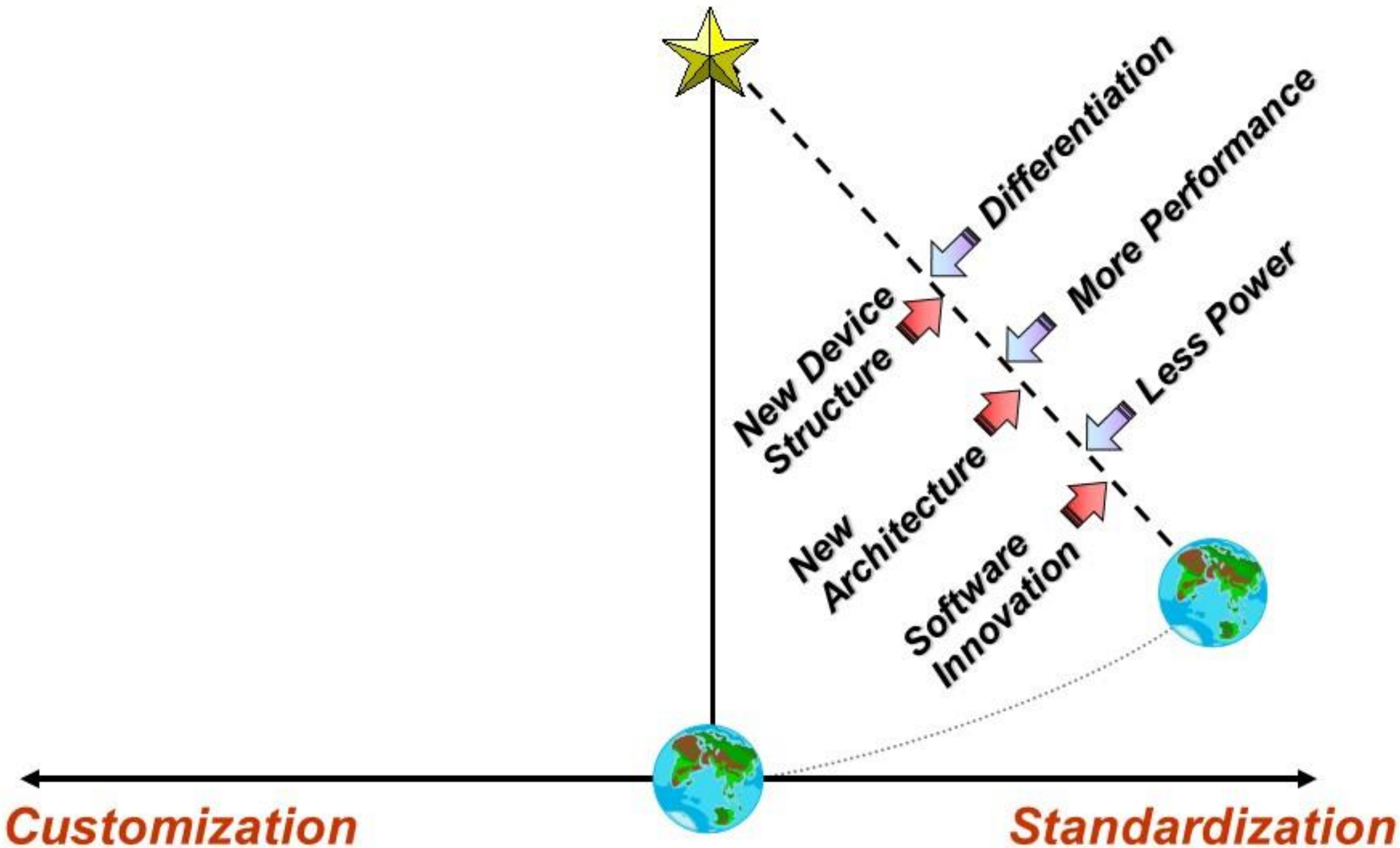
FPGAs are representative of field programmable devices and their applications are rapidly expanding. A representative cases are shown here; Medical image processing , high performance computing, and high speed data analytics. By adopting the FPGA, optimization for specific system applications become possible.

Pendulum Swinging to Standardization



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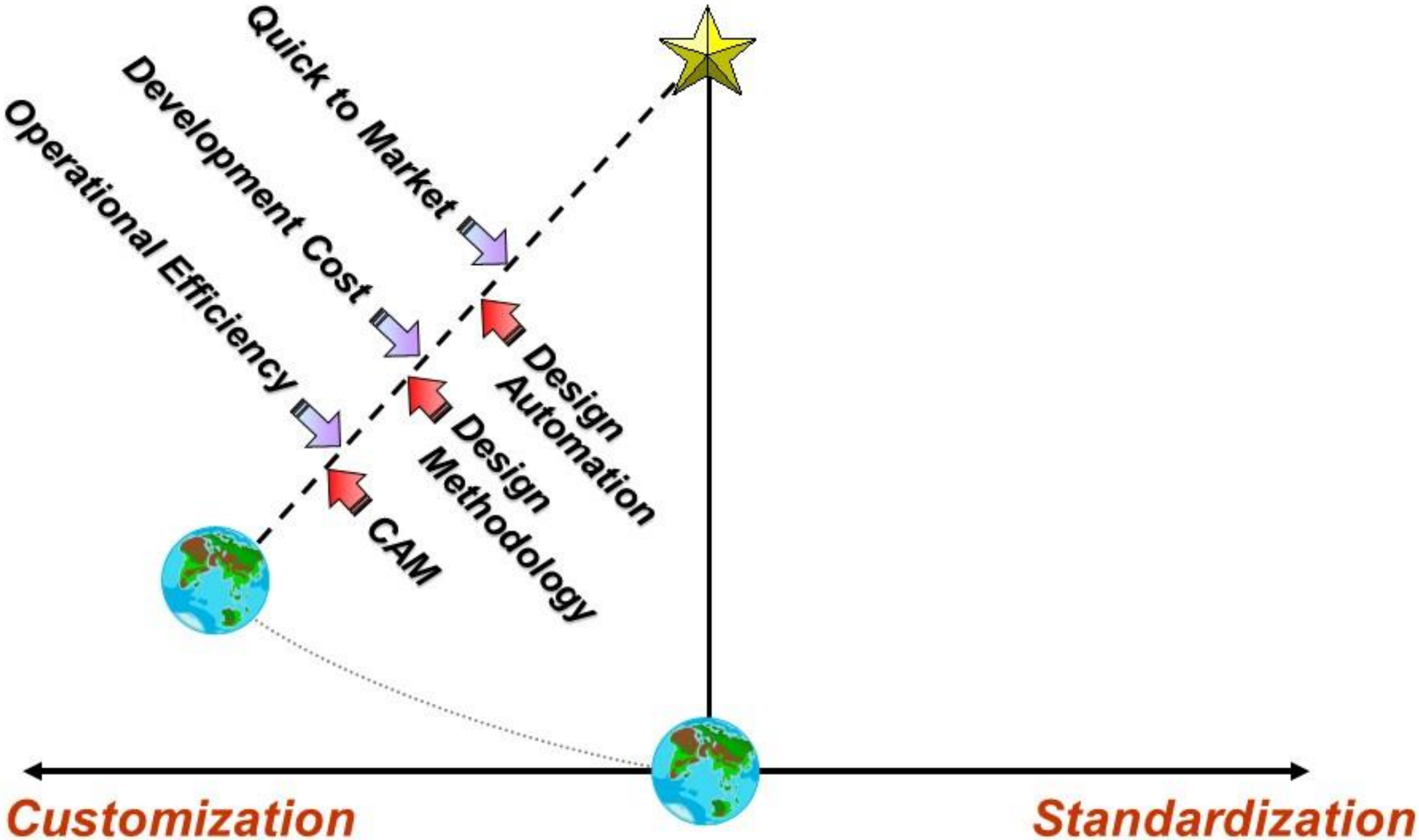
Let's think about why standardization and customization alternate direction in the semiconductor industry. Imagine a long pendulum swinging right and left. New devices such as FPGAs and new architectures such as MPU push this pendulum toward standardization. However, if it goes too far, the pendulum is pulled back to the opposite side by various forces shown in the figure.

Pendulum Swinging to Customization



Progress in design automation and design methodology pushes the pendulum toward customization. However, if it goes too far, it will be pulled back to the other side by the customer needs such as “quick to market" and "lower development cost". In this way, the pendulum keeps swinging between right and left in order to maximize “customer satisfaction” which is the eternal goal.

Quiz

How long is the Semiconductor Pendulum?

A: Less than 1 km

B: Between 1 km to 1,000 km

C: Between 1,000 km to 1,000,000 km

D: More than 1,000,000 km

[Suppose classical kinetic model is valid]

It is a time for a quiz. “How long is the semiconductor pendulum? Please choose one from A to D. We assume that classical kinetic model is valid here."
In the middle of a serious story, if you give a little rest time, it has the effect of softening the atmosphere of the venue.

Answer

Basic Equation $T = 2\pi\sqrt{\frac{L}{g}}$

$g = 9.8\ m/s^2$

$T = 20$ years

$L \cong 10^{14}$ km

= 10 light years

Here is the answer of the quiz. This is an isochronous expression of the pendulum. Solving this equation with gravitational acceleration (g) and period (T = 20 years), the length L is 10E14 km. This is about 10 light years! I think that the semiconductor pendulum is the longest one ever conceived in the history.

Answer

Basic Equation $T = 2\pi\sqrt{\frac{L}{g}}$

$g = 9.8\ m/s^2$

$T = 20$ years

$L \cong 10^{14}$ km

$= 10$ light years

Reference

Sirius: 8.6 light years

Procyon: 11.4 light years

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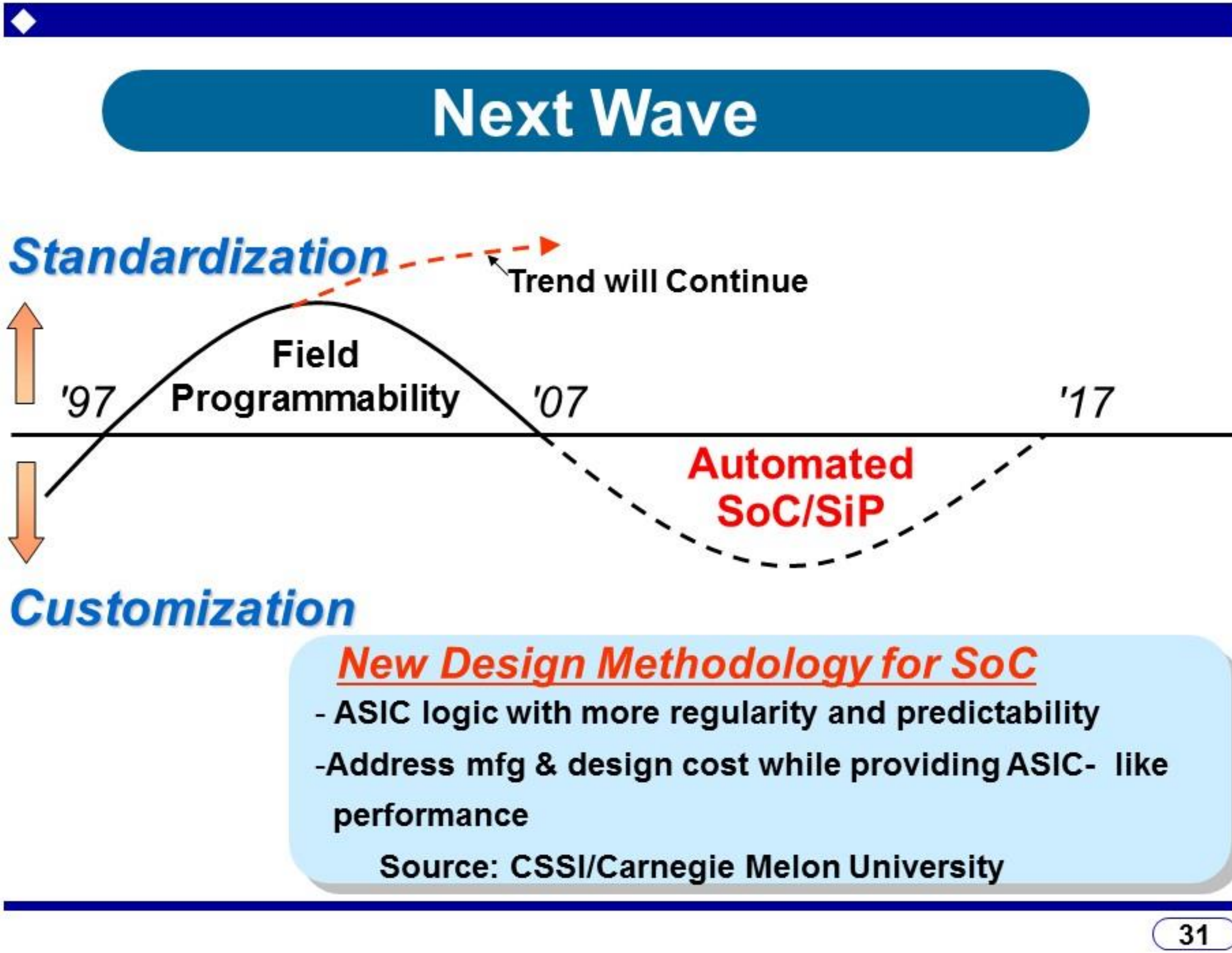
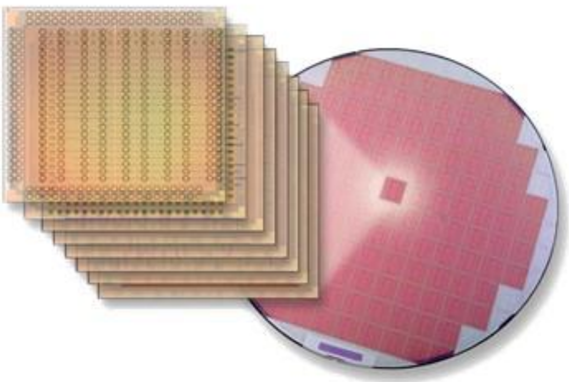
For reference, the distance from the earth to the Sirius is 8.6 light-years and 11.4 light-years to the Procyon. Please compare these figures with the semiconductor pendulum.
Comment: Although this quiz does not make much sense, it seemed to have stimulated intellectual curiosity. I received many comments that it was very interesting after the speech.



The original version of Makimoto's Wave ends in 2007. The figure shows the next cycle as a "custom-oriented cycle" until 2017. The lead role is SoC / SiP. A new design methodology is needed for SoC to achieve performance similar to ASIC while reducing design and manufacturing costs.
By the way, the biggest hit product based on SoC is Apple's smartphone / tablet.

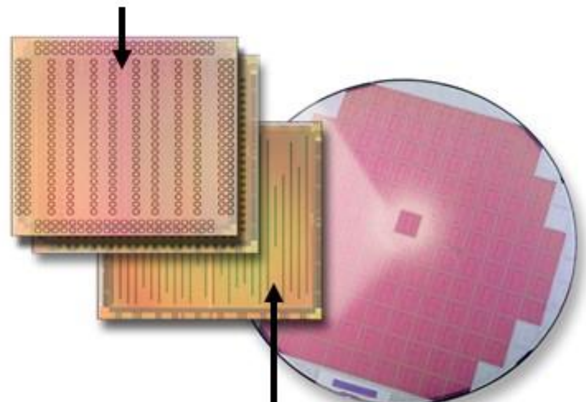
Standard Cell vs. Structured ASIC

Standard Cell ASIC:
All Layers Are Custom



Full Set of Masks for Standard-Cell ASIC

Structured ASIC:
Customization Through Top Layers



Base Layer

Structured ASICs Minimize NRE & Turnaround Times

Source: Altera

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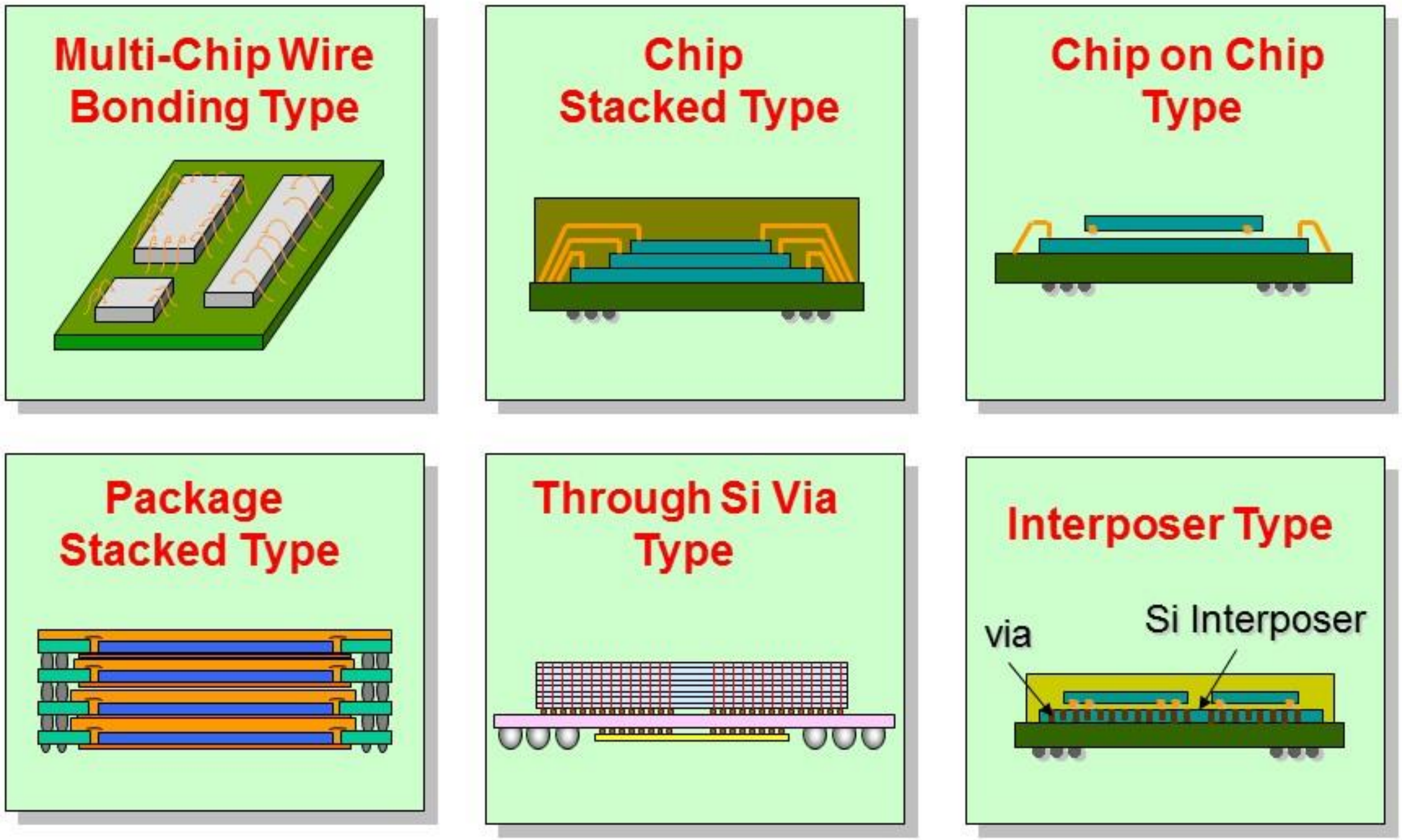
In SoC, it is required that "design is simple but performance is close to custom products" by introducing new methods. This example shows Altera's Structured ASIC. In the normal standard-cell ASIC, all layers are customized, but in the case of Structured ASIC only the top wiring layer is customized. The design cost is greatly reduced, and the TAT is also minimized.

Examples of SiP



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Examples of SiP or System in Package are shown here. They all have advantages and disadvantages. The choice has to be made by taking into consideration the application, cost, performance, and TAT, etc.

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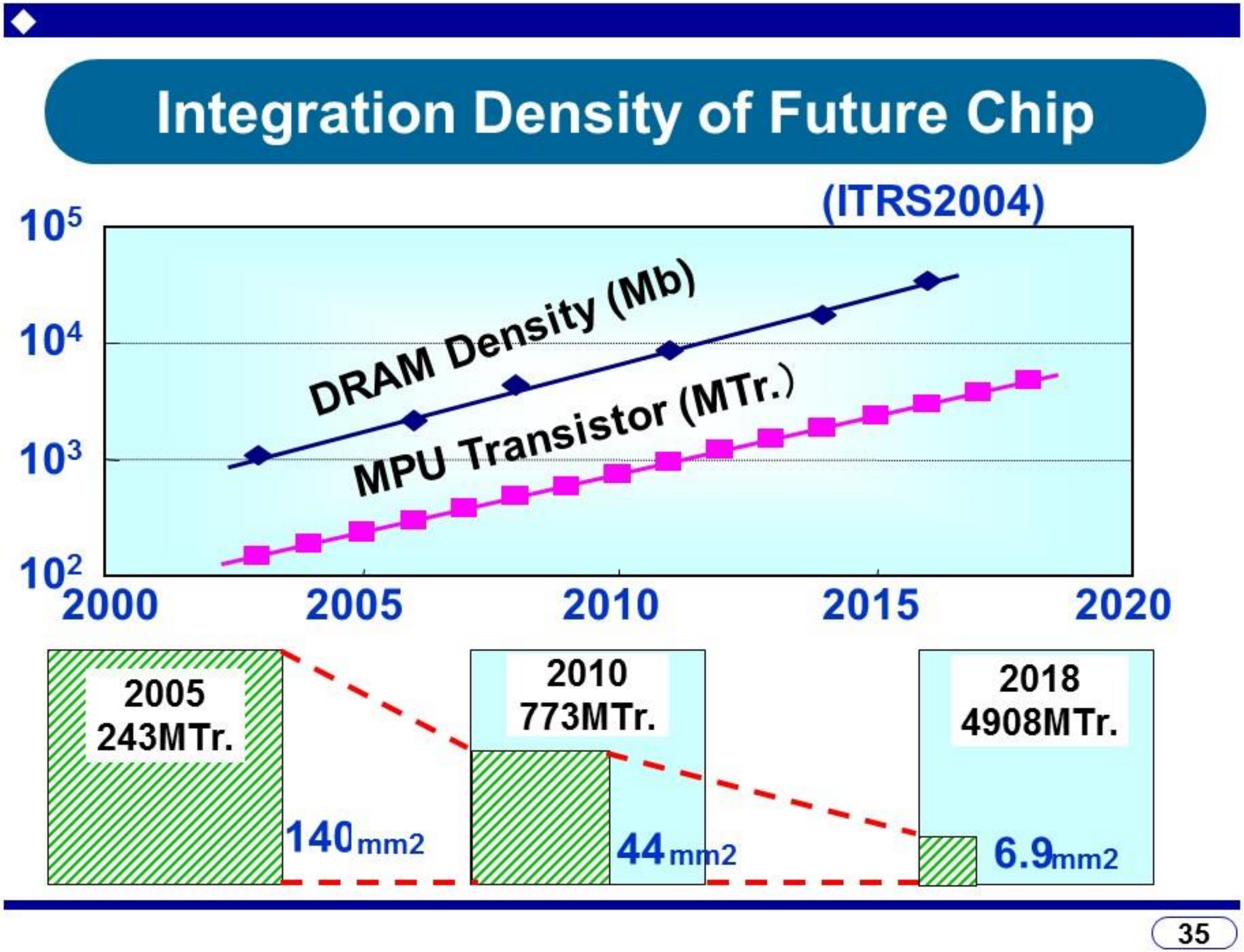
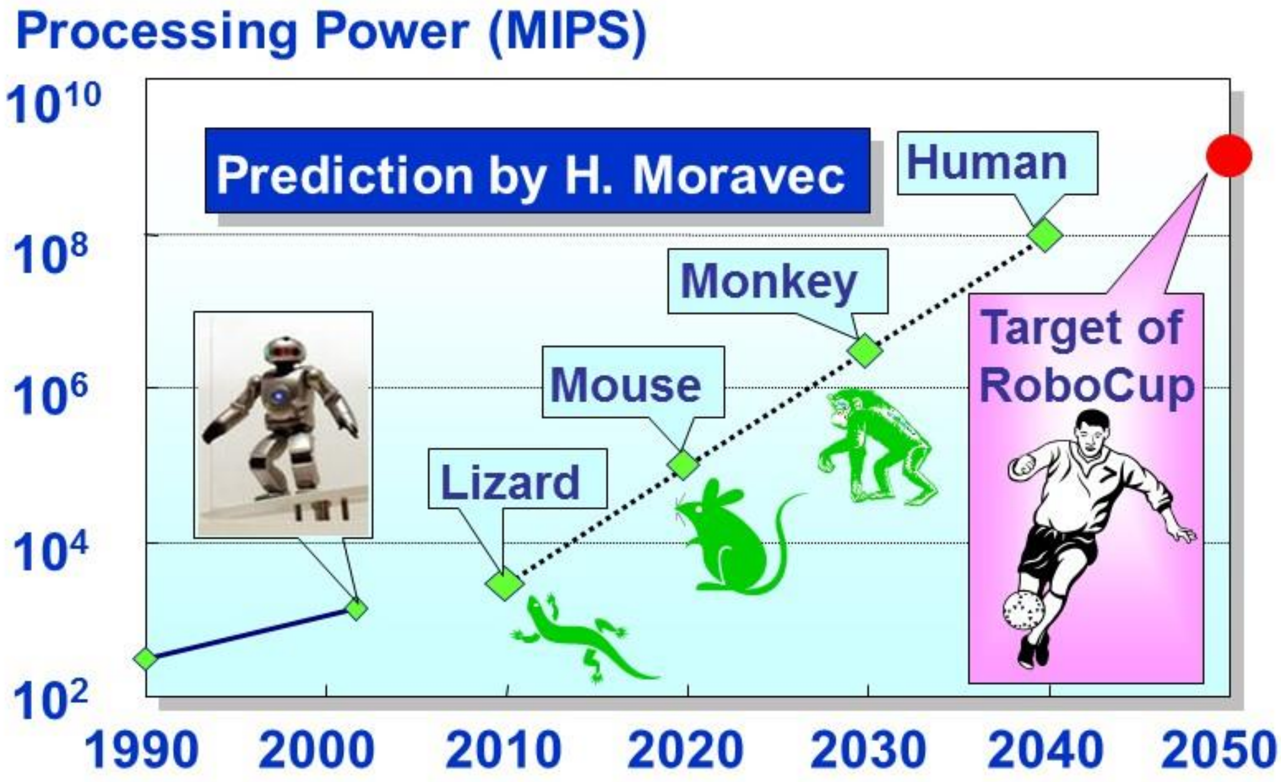


According to ITRS, integration density will continue to increase exponentially. The figure shows the number of DRAM bits and the number of transistors of MPU. Taking this visually, the chip size of 140 mm² in 2005 goes down to 6.9 mm² in 2018. Assuming the same chip size, the number of transistors becomes about 20 times more, meaning the functionality of a chip becomes 20 times more.

Evolution of Robot Intelligence



Source:H.Moravec of Carnegie Melon University

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What is the application that requires such high functionality as shown on the previous page? There is no such need for PCs and smartphones but for robots. At the time of the speech, the intelligence of a robot is less than that of a lizard, but it will reach to the level of a monkey in 2030 and the human level in 2040. All the functions that can be integrated on the chip will be exhaustively used in the robot.

Chips & Sensors for Robots

VLSI chips

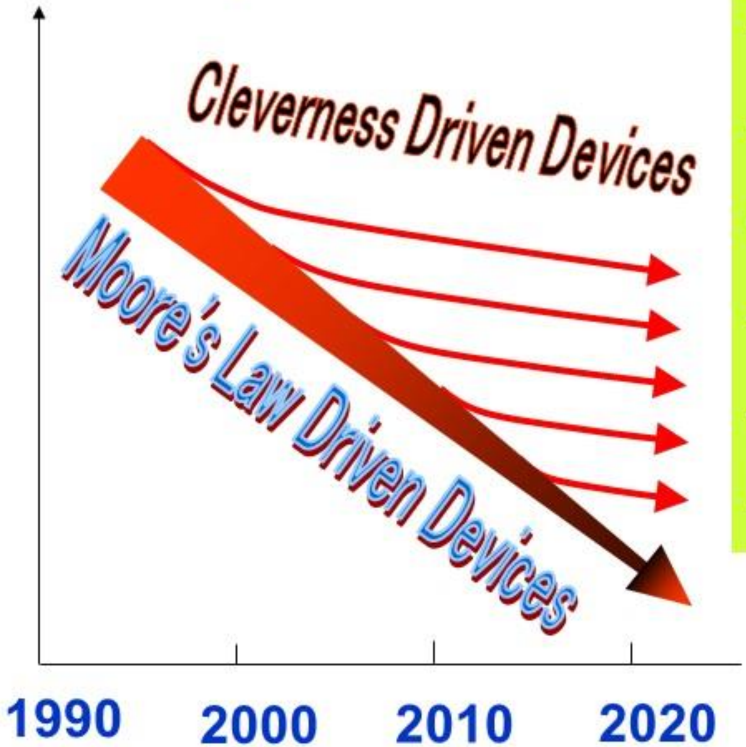
- 64bit CPU x 3
- 16bit MCU x 29
- DRAM 192MB
- Flash 16MB

(QRIO)

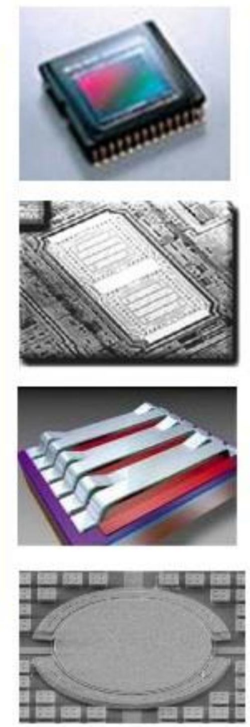
The figure shows LSIs and sensors used for Sony's robot. An autonomous robot grasps the surrounding situation with sensors, and makes an appropriate judgment. A total of 79 sensors are used, and the processing capacity of the LSI is equal to or greater than that of a PC. Since the robot is battery operated, low power consumption is essential, and it will become a future technology driver.

Diversifying Directions of Chip Technologies

Geometry of Devices



- Optical Sensors
- Inertial Sensors
- Force Sensors
- Display Devices
- Actuators
- RF Devices etc.



Source: Analog Devices, UC Berkeley

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This figure was first presented at IEDM 2002 showing "diversification of semiconductor technologies" The miniaturization direction shown by a thick red line has been the major trend so far, but from now on, the importance of functional devices such as sensors, not dependent on miniaturization, will increase. Since the ITRS 2005 it came to be called "More Moore" and "More than Moore" directions.

Summary

★ Digitalization of Consumer Electronics Getting Momentum Resulting in the Market Convergence

★ Chip Innovation Boosting Figure of Merit;
3 Orders of Magnitude in the Next Decade

★ Programmability/ Configurability Becoming Key For Future Architecture

★ Next Cycle of Makimoto's Wave: Automated SoC and SiP

★ Robotics to Provide New Opportunities

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This is to summarize the speech.
After this speech, I got a contact from the organizer of the ISC or International Supercomputer Conference which would be held in Germany in the following year, and was asked to talk there on the similar subject. After my return home, I received a formal invitation and I accepted it.