

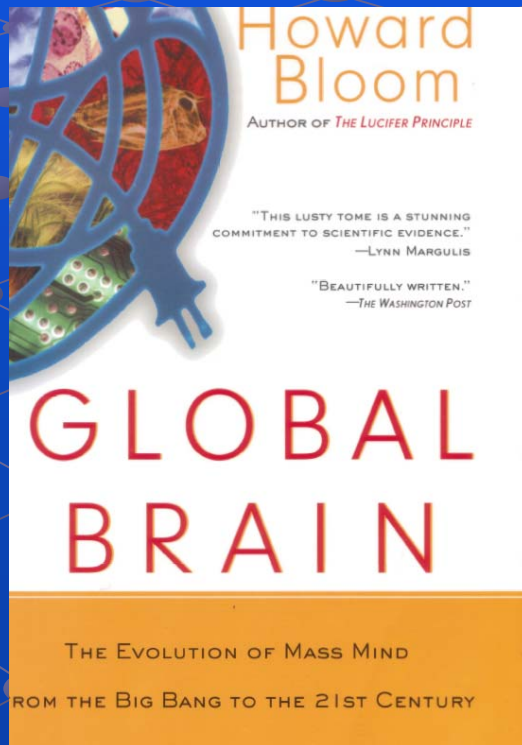
# ITRS under the Increasing Complexity: In Search of a “Global Brain”

Institute of Innovation Research at Hitotsubashi  
University &  
NISTEP (National Institute of Science & Technology  
Policy)

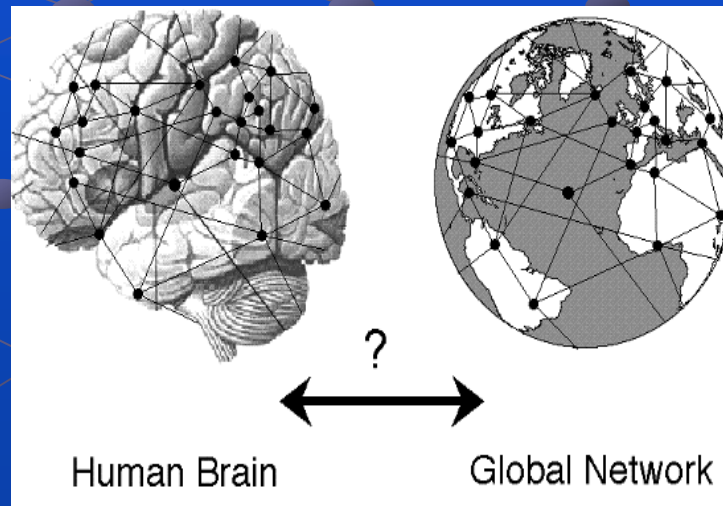
Hiroyuki Chuma

# “Global Brain”

- “A world wide neocortex – complete with whales – is not a gift of the silicon age. It is a phase in the ongoing evolution of a networked global brain which has existed for more than 3 billion years.” (Bloom (2001))
- “A planet pulsing with a more –than-massive data-sharing mind.” (op. cit.)
- “Social animals are linked in networks of informational exchange.” (op. cit)

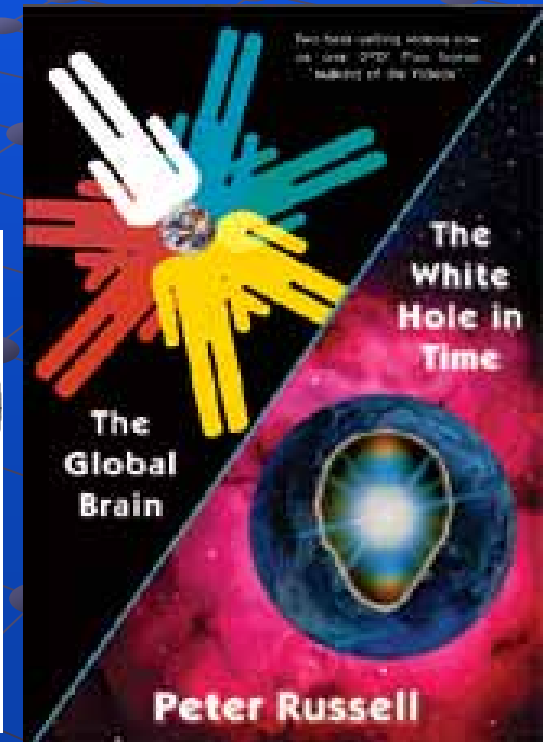


2001



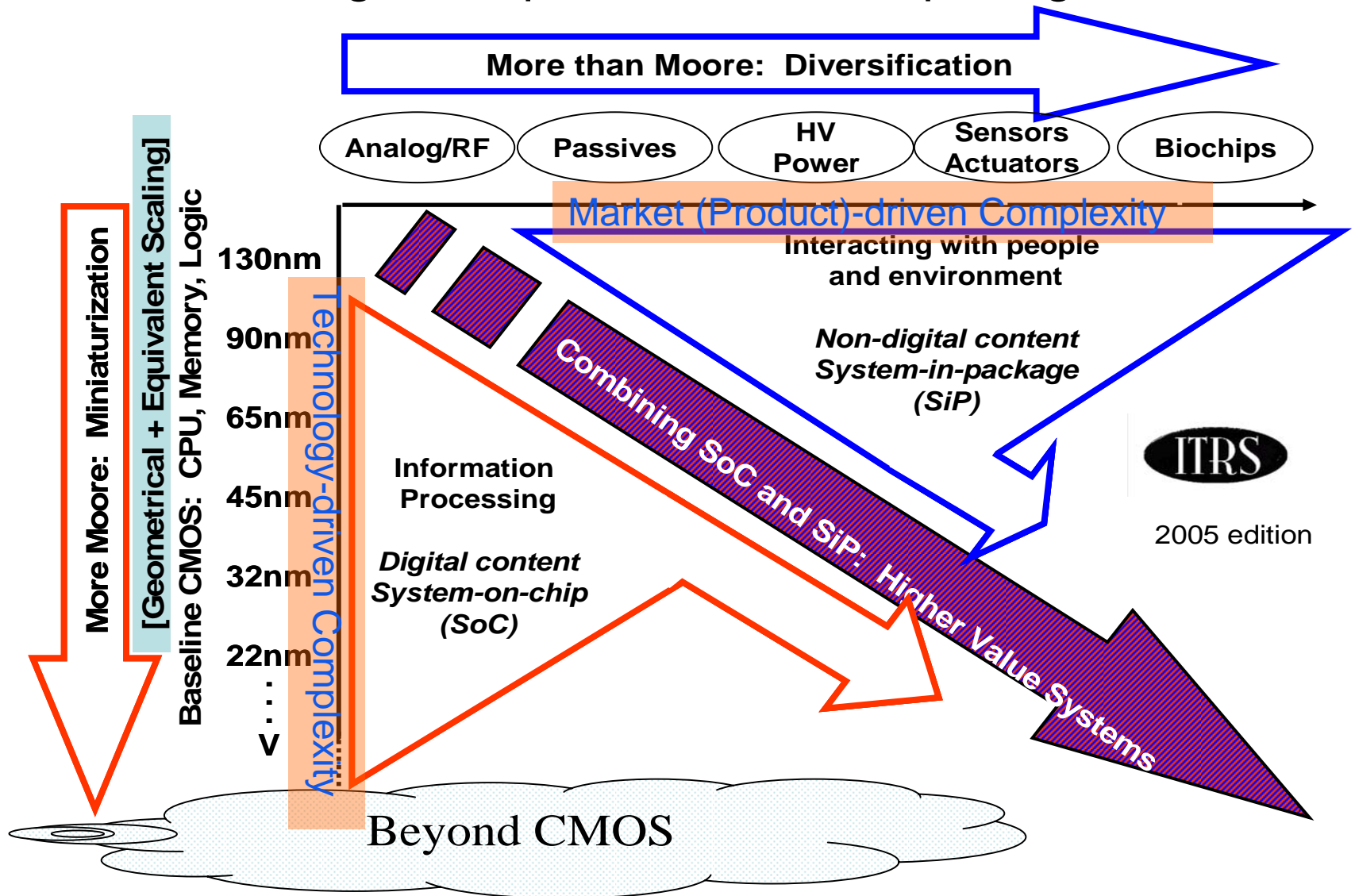
Human Brain

Global Network

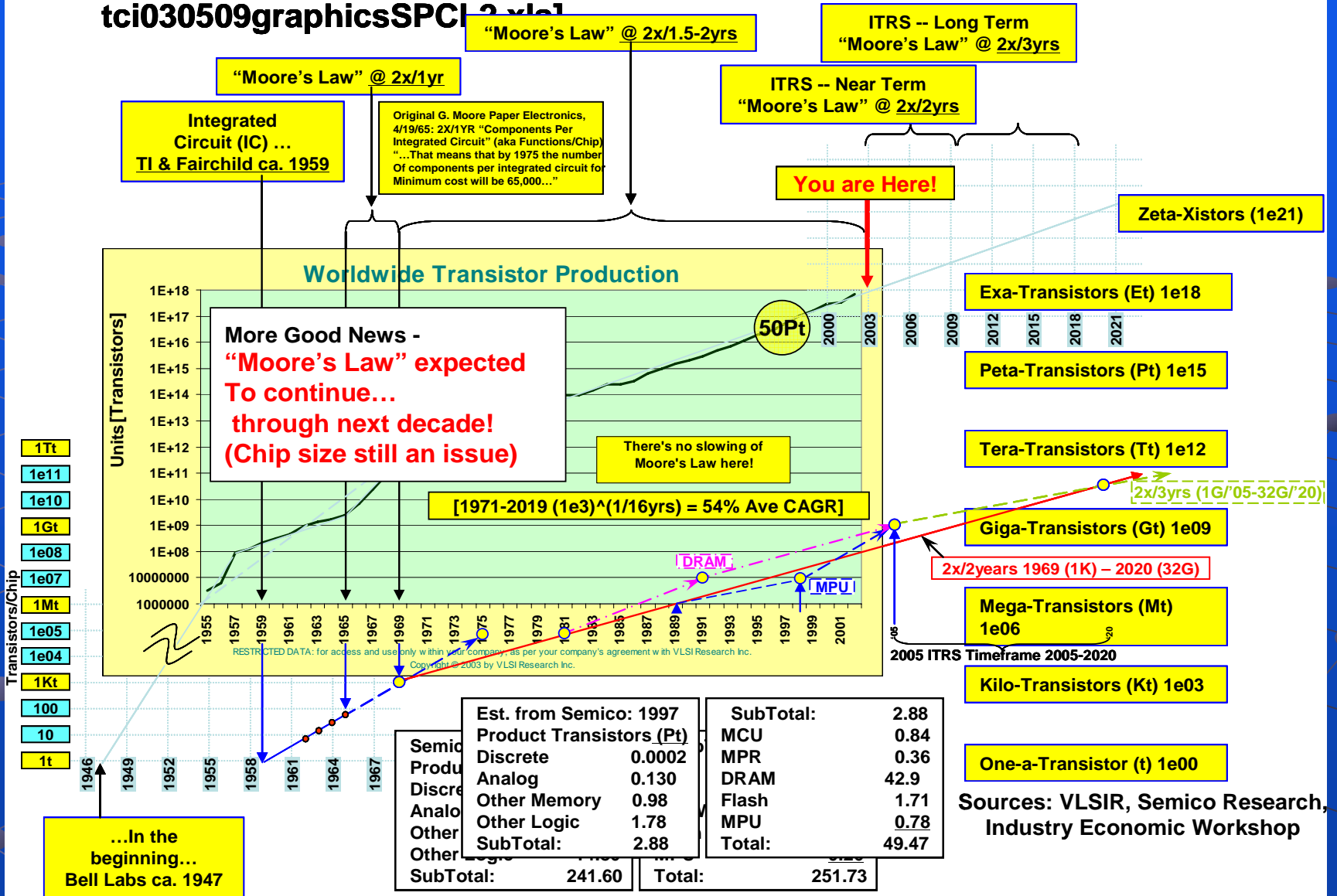


1983

# Pursuing the race for added value for the end customer by combining on-chip ULSI and off-chip integration



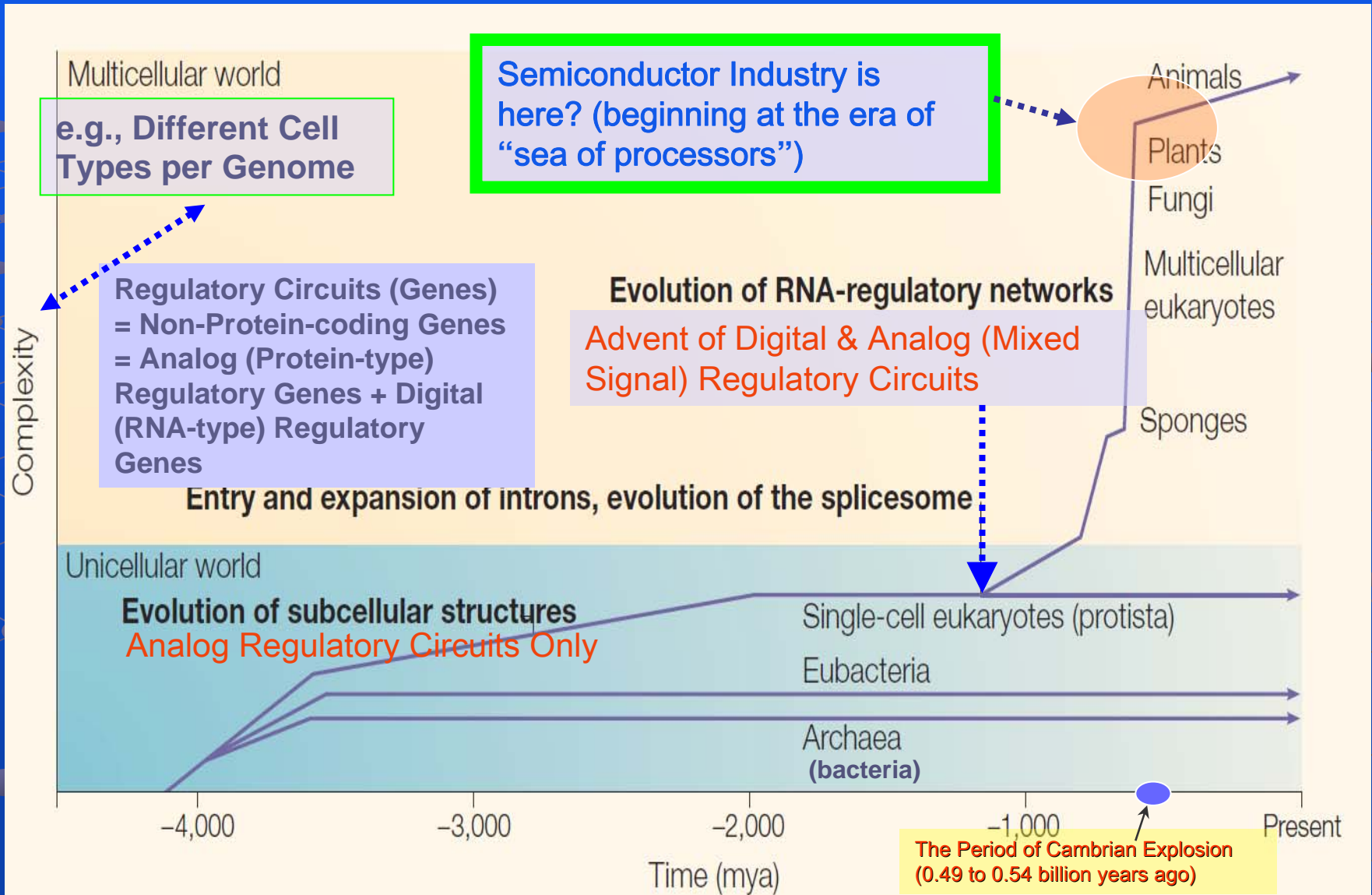
# Transistors – VLSI Research May'03 [source: tci030509graphicsSPCL2.xls]



from "Follow-up from ITRS Maastricht & San Francisco meetings – European IRC proposal" (2006)

# John S. Mattick(2004), “RNA regulation: a new genetics? ”

([www.nature.com/reviews/genetics](http://www.nature.com/reviews/genetics): Simplified Biological History of the Earth)



# Stylized Facts

- Increasing **Complexity** in Technology & Market
- Increasing ***ex ante & ex post*** Indeterminacy
- Inescapable **Acceleration** of Cumulative Knowledge-Administration as well as Knowledge-Creation Processes
- Emergence of the New “Gordian Knot” : **Inter-Organizational Knowledge (“Global Brain”)** Coordination and Conflicts of Interest (Incentive) Problems (H. Bloom, *Global Brain* (2001))

# Complexity in Cumulative Knowledge-Administration scales faster than One in Knowledge-Creation?

- “We do not see a slowdown in Moore’s law as the main obstacle to further progress in the IT industry. Rather, it is the industry’s exploitation of the technologies that have been developed in the wake of Moore’s law that has led us to the verge of a complexity crisis.”

(IBM Autonomic Computing White Paper, “An architectural blueprint for autonomic computing,” (June, 2006))

- “Papert’s Principle: Some of the most crucial steps in mental growth are based not simply on acquiring new skills, but on acquiring new administrative ways to use what one already knows.”

(M. Minsky, *Society of Mind*(1986) and *The Emotion Machine* (2006))

# Complexity in Semiconductor Markets: Cause-and-Effect (1)

- Globalization of Various Markets and Consumers' Diversified & Upgraded Preferences
  - Emergence of Thick & Wide Global Markets
  - Increasing Comparative Advantage of Pure-Play Firms (due to the increasing necessity for inter-organizational corroboration)
  - Increasing Difficulty in Managing Vertically Integrated Firms (due to the explosive expansion of "range of optimization")

Galambos, L. (2005), "Recasting the organizational synthesis: structure and process in the twentieth and twenty-first centuries," *Business History Review* vol.79.

# Complexity in Semiconductor Markets: Cause-and-Effect (2)

- Advent of the Structural Similarity between Semiconductor Markets & Devices (as an effective counter-measure for the complexity in market & technology)

- Small-World Property (due to Loose but Intricate Connectedness)

- Scale-Freeness (due to Modularity: Eventually combinatorial explosion occurs)

Note: Newman, Barabasi, and Watts (2006), *The Structure And Dynamics of Networks*

- "Accelerating-Network" Property (due to the fact that the total number of connections between nodes scales faster than the total node number)

Note: S. Mattick and M. J. Gagen (2005), "MATHEMATICS/COMPUTATION: Accelerating Networks," in *Science*, Vol. 307. no. 5711, pp. 856-858

# Striking Analogy between Organisms and Semiconductor Chips (1)

## ● Structural Diversity in Primordial (or Early) Prokaryotes

→ due to Gene Duplication, Deletion or Divergence

(Semiconductor Devices: due to the Increase in Number of Transistors and Advent of New Transistor and/or Capacitor Structure)

# Striking Analogy between Organisms and Semiconductor Chips (2)

## ● Most of Morphological & Phenotypic Novelties in Eukaryotes

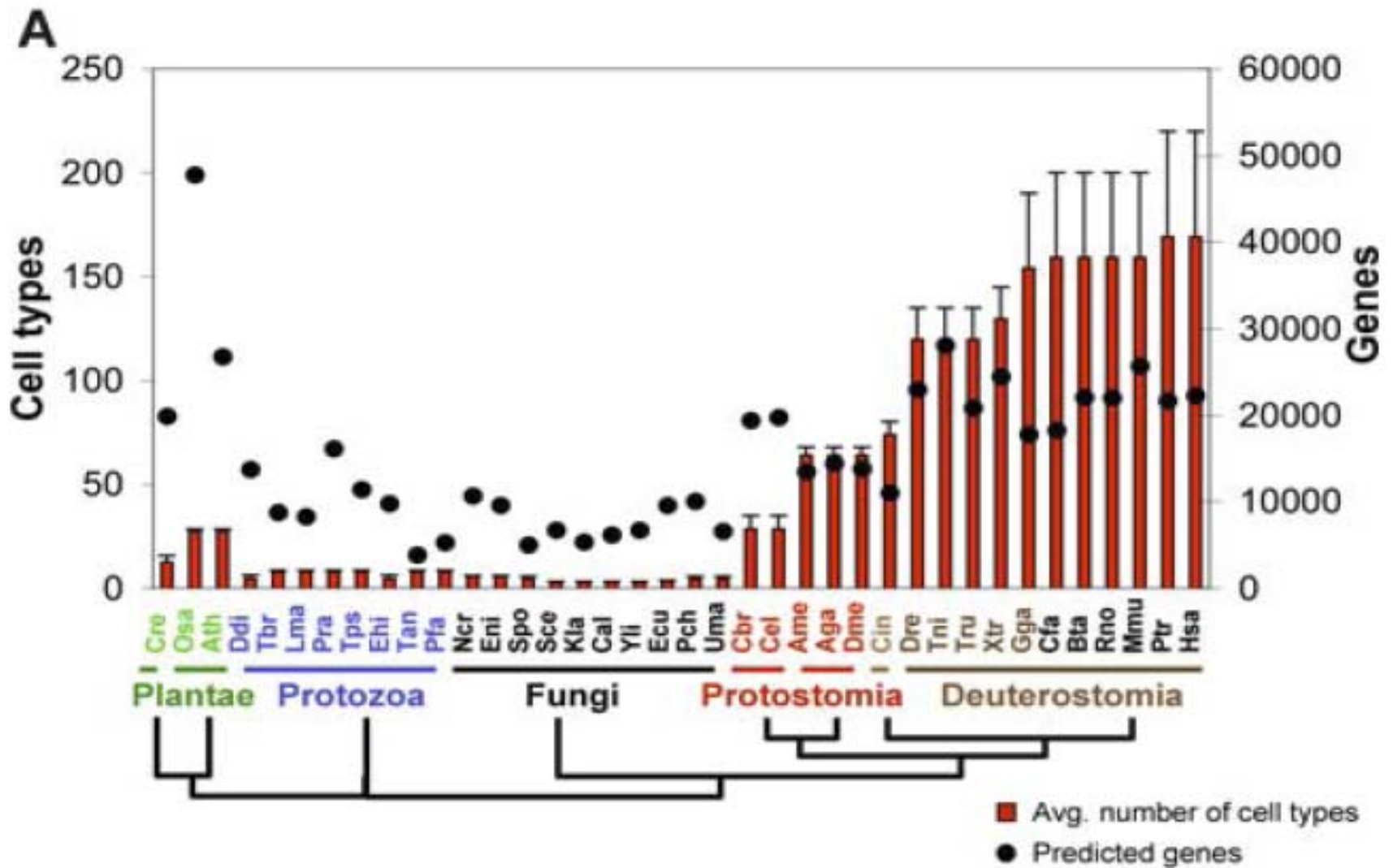
→ due to the Evolution in Regulatory Circuits or Layers embedded in (Non-Protein-coding) “**Toolkit Genes**” (vs. (Protein-Coding) “**House-keeping Genes**”)

(**Semiconductor Devices**: due to the Creation of New Control Circuits via Multi-layered Intricate Interconnecting Methods)

# Genome Size ≠ Biological Complexity

**Biological Complexity** (e.g., Different Cell Types per Genome)  
= G(Housekeeping Genes, Toolkit Genes)

- (1) Each number of housekeeping or toolkit genes scales as a power-law of the total number of genes in the genome (i.e., genome size).
- (2) In a power law:  $y=cx^\alpha$ ,  $\alpha$  of toolkit genes is around 2.0, while one of housekeeping genes is around 0.5. (Nimwegen (2003), "Scaling laws in the functional content of genomes" in *TRENDS in Genetics*, Vol.19 No.9 , 479-484)
- (3) "The numbers of regulators (or combinations thereof) must generally scale faster than the number of genes." The complexity of organisms tends to be constrained by the architecture of their regulatory networks. (Mattick and Gagen, *op.cit.*)



Vogel and Chothia (2006), "Protein Family Expansions and Biological Complexity" in PLoS Computational Biology, Volume 2, Issue 5, pp. 370-382

# Number of Transistors per Chip ≠ Semiconductor Chip Complexity

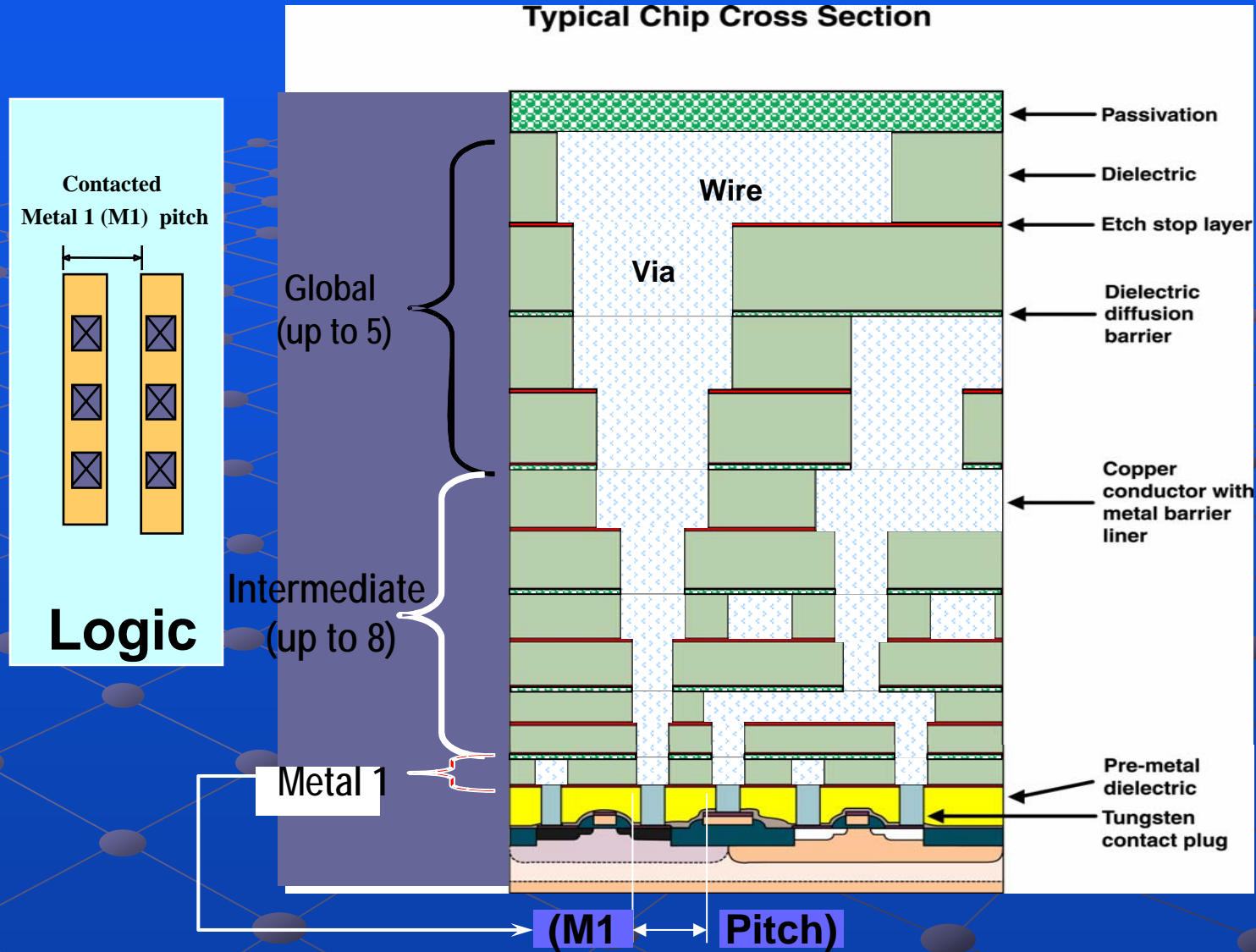
**Chip Complexity** (e.g., Ex ante & ex post flexibilities)

=F(Transistor Blocks, “Regulatory Circuits”)

“Regulatory Circuits” = Intra- & Inter-block Connections

- (1) The number of transistor blocks follows Moore’s (power) law.
- (2) The number of “regulatory circuits” needs to follow More-than-Moore’s (power) law? **Otherwise “LSI Design Crisis” would occur!**
- (3) The number of “regulatory circuits” scales faster than the number of transistor blocks!!

# CMOS Interconnect Structure



# “Demand Submergence” in the Era of More-Than-Moore

- Prevalence of “Metasearch” (=Search for Search Methods) over the boundlessly diversified & uncharted landscape
  - Suppliers puzzled by consumers’ widely diversified and kaleidoscopic preferences
  - Consumers (customers) plagued by their uncontrollable revealed preferences
  - Emergence of “Demand Submergence”

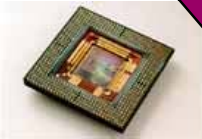
Wanted: **CUSTOMERS**, who breathe, eat, and live in.....

## Global & Regional Political & Macro-Economic Environments

...and who **BUY**,  
based on varying  
levels of  
Purchasing Power,  
**PRODUCTS**



**Customer Demand**



**Electronic End Equipment**

**Semiconductors**

**Semiconductor  
Equipment  
&  
Materials**

Ecosystem or  
Foodchain?

Sources: NASA.gov ; SEMI

# New Tendencies in the Era of “Demand Submergence” (1)

## ● From “Stereotype Marketing” to “(Jungian) Archetype Marketing”

(G. Zaltman (2003), *How Customers Think*)

→ Arm-in-arm information exchange & sharing between suppliers and consumers (or customers)

→ Era of Application-driven as well as Technology-driven Roadmap

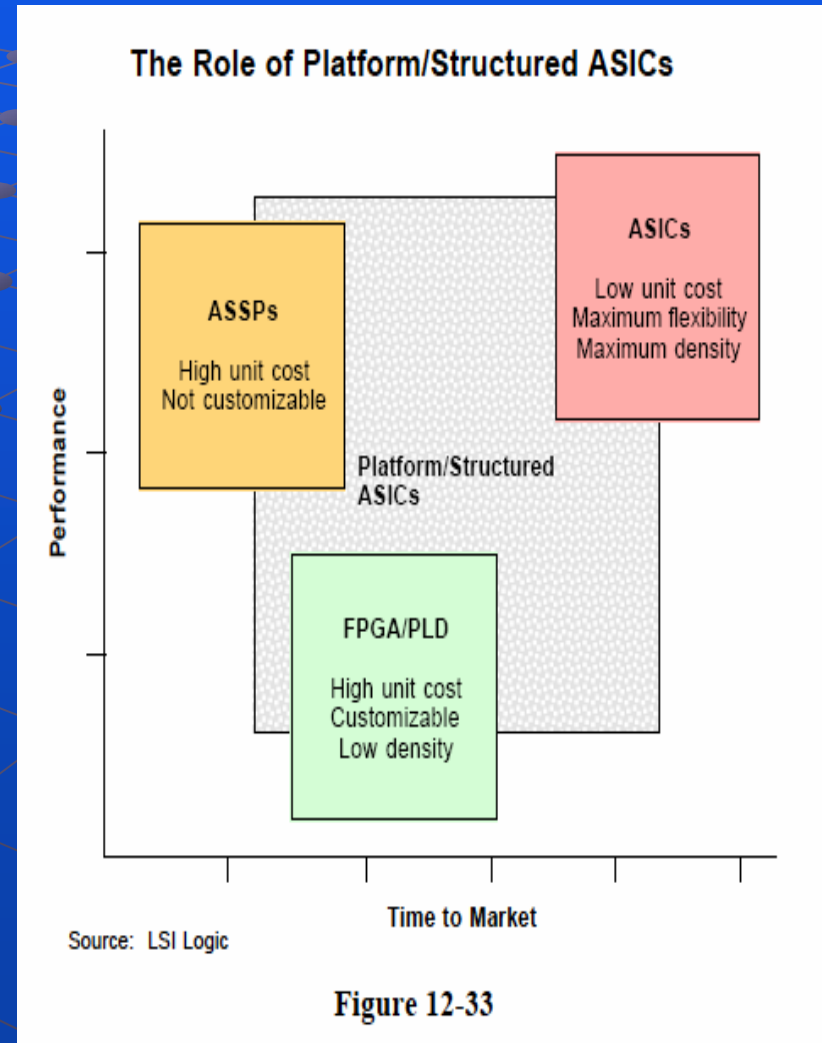
# New Tendencies in the Era of “Demand Submergence” (2)

- *Ex ante and ex post* nimbleness (resiliency) as a core source of competitiveness

→ Strong demand for ASSP or FPGA/PLD

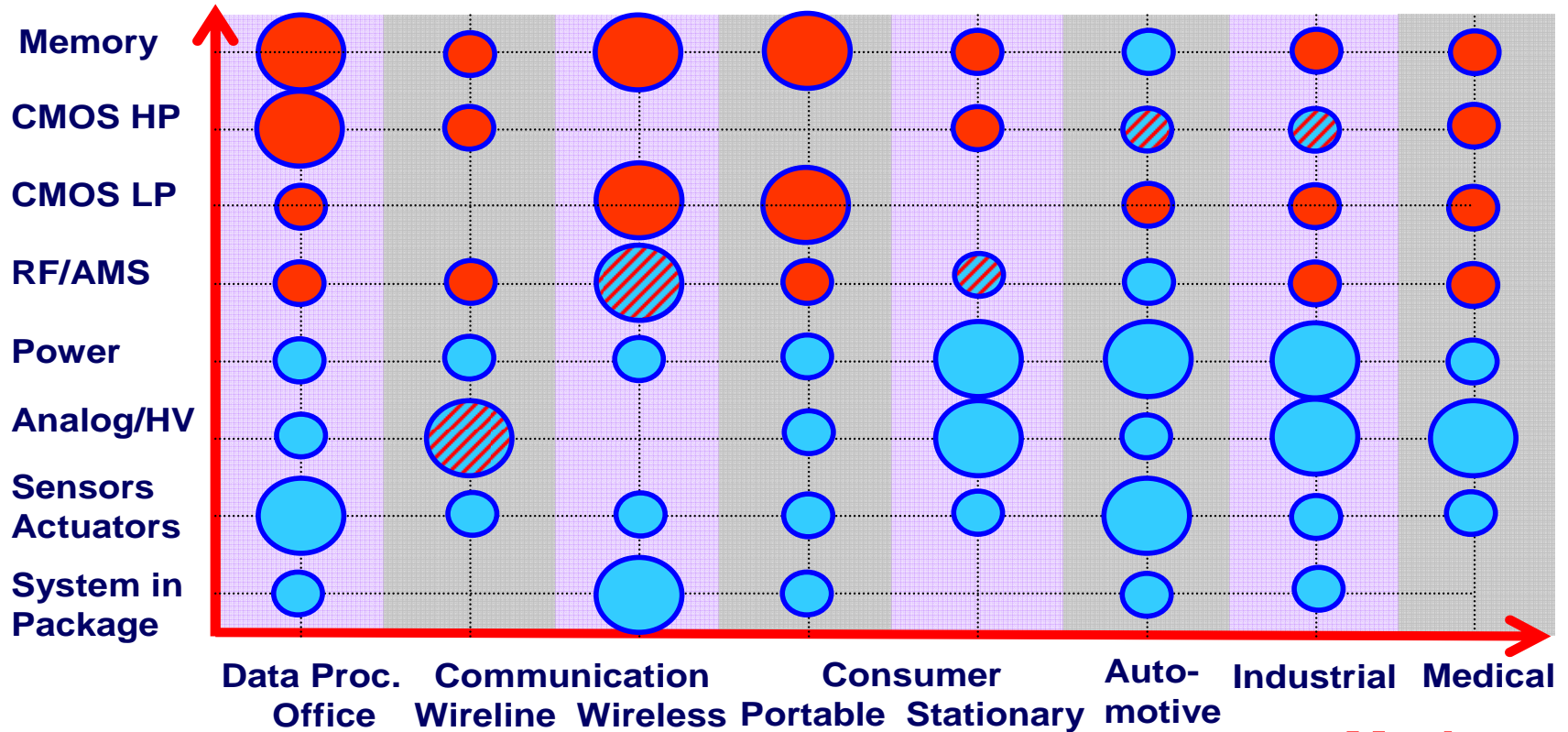
→ Processor-block centric SOC design to increase software programmability (C.

Rowen (2004), *Engineering the Complex SOC: Fast, Flexible Design with Configurable Processors*)



# Market Drivers for Technology Roadmap

## Technologies



### Legend:

More Moore (scaling)

More than Moore (non-scaling)

mixed

Bubble size = driver impact

## Markets

from "Follow-up from ITRS Maastricht & San Francisco meetings – European IRC proposal" (2006)

# Inescapable Phenomenon Induced by Increasing Complexity (1)

● **Sub-systemization of Various Existing Systems at a splitting pace**

→ Increasing incapability to make a self-contained market evaluation of own products as well as R&D performance

# Inescapable Phenomenon Induced by Increasing Complexity (2)

- Strong Demand for Inter-Organizational Wisdom (“Global Brain”) Mobilization (in addition to Extensive Investment Cost & Risk Sharing)
- Absolute Necessity for “Global Brain”

# Main Principles in Coping with Complexities (1)

- Knowledge Sharing & Networking via Inter-Organizational Visualization
  - Enhancing Inter-Organizational Knowledge Compatibility & Interoperability
  - Resolution-Enhancement in Inter-Organizational “Common Knowledge”

# Main Principles in Coping with Complexities (2)

- **Creating a Social Mechanism to avoid the insignificant duplication of R&D activities**
  - **Introducing Consortia, Alliances, or (Technology and Application) Roadmap as Public Goods**

# In Search of a “Global Brain”

- ITRS has been greatly contributing to the evolution of a networked “Global Brain” by decidedly indicating a significant technology-milestone.
- For us to go further into a harmoniously developed Global Brain, ITRS has been again required to make redoubled organizational efforts to swiftly develop the right semiconductor devices in the right time.
- Through these continuous efforts, ITRS could be one of prominent clans within such a Global Brain Network.