ITRS2.0 and Its System Drivers: Focus on System Trends and MTM

ITRS Design International Technology Working Group
Co-chairs: Andrew B. Kahng, Juan-Antonio Carballo
(Special thanks to Wei-Ting Jonas Chan, Siddhartha Nath (UCSD VLSI CAD Lab))

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Agenda

1. **Evolution of ITRS System Drivers. MTM / Integration Focus.**

   Why do we need drivers in the ITRS?

2. **Systems *drive* devices: capturing the right trends ?**

   What drivers are really going to matter in next 10+ years?

   (Answer: Mobile)

3. **Focus on Mobile systems: example first steps**

   Since systems determine technology requirements,

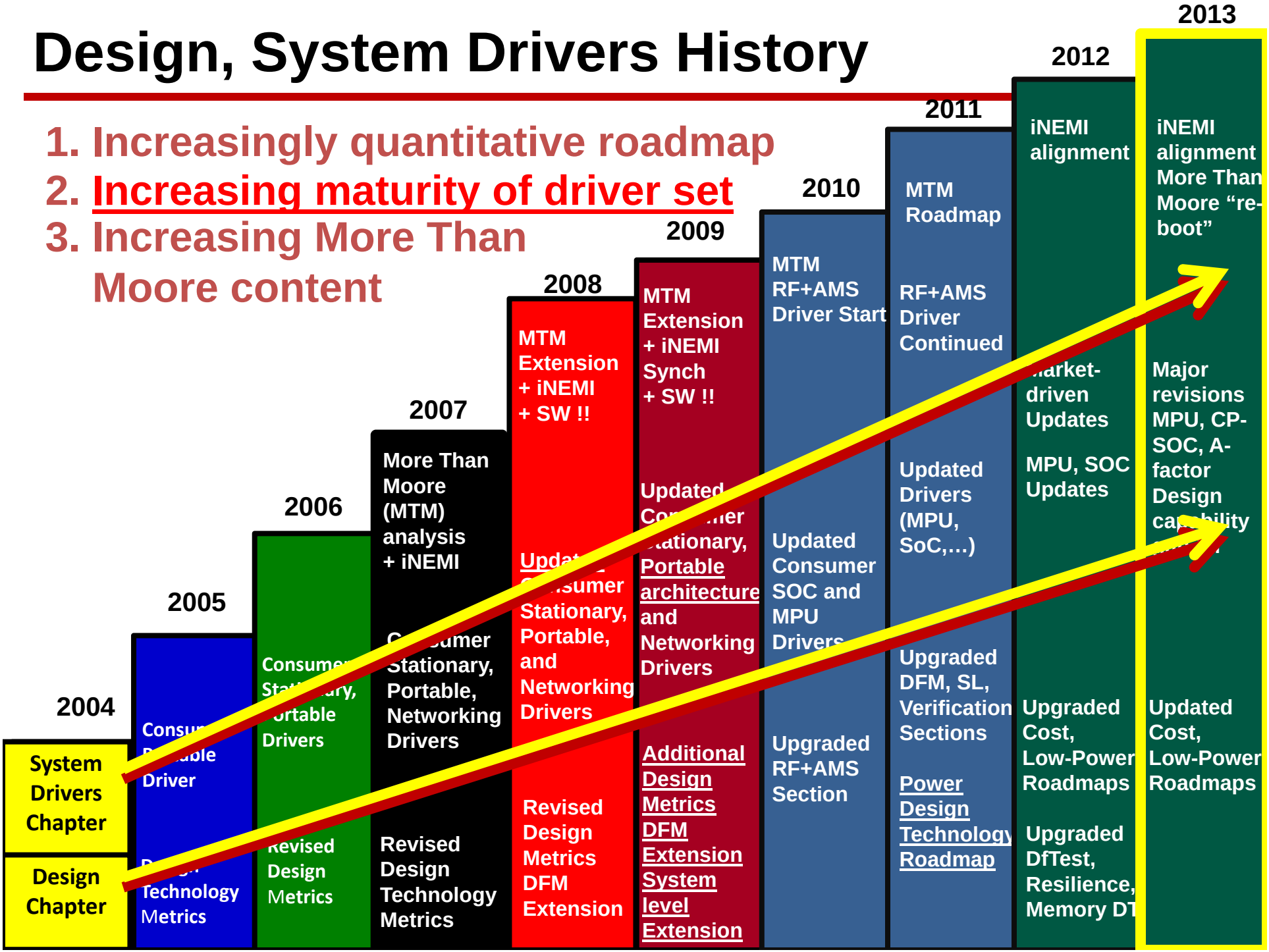
   how do we connect system level to IC level for ITRS drivers,

   and then roadmap the drivers?

4. **Conclusions and looking forward**

Design, System Drivers History

1. Increasingly quantitative roadmap
2. Increasing maturity of driver set
3. Increasing More Than Moore content



The New ITRS

In the 80s and 90s the Semiconductor Industry was constituted by Integrated Device Manufactures (IDM)

- Standard components (e.g. Memory and Microprocessors) were produced by IDM and assembled into systems by OEMs

In the past 10 years the Semiconductor Industry has evolved into a distributed industry

- Design team and manufacturing teams are no longer in a single company
- Custom SoC and SIP are the dominant building blocks of electronic systems
- Design houses and foundries represent the new foundation of the Semiconductor Industry

The 2014/15 ITRS has been restructured to represent the new ecosystem

Beyond 2020

Themes	ITWGs
System Integration	**System Integration**
Outside System Connectivity	**Outside System Connectivity**
Heterogeneous Integration	**Heterogeneous Integration**
More than Moore	**Heterogeneous Components**
Beyond Moore	**Beyond CMOS**
More Moore	**More Moore**
Manufacturing	**Manufacturing**

Definitions of 7 Focus Topics

System Integration—studies and recommends system architectures to meet the needs of the industry. It prescribes ways of assembling heterogeneous building blocks into coherent systems.

Outside System Connectivity—refers to physical and wireless technologies that connect different parts of systems.

Heterogeneous Integration—refers to the integration of separately manufactured technologies that in the aggregate provide enhanced functionality.

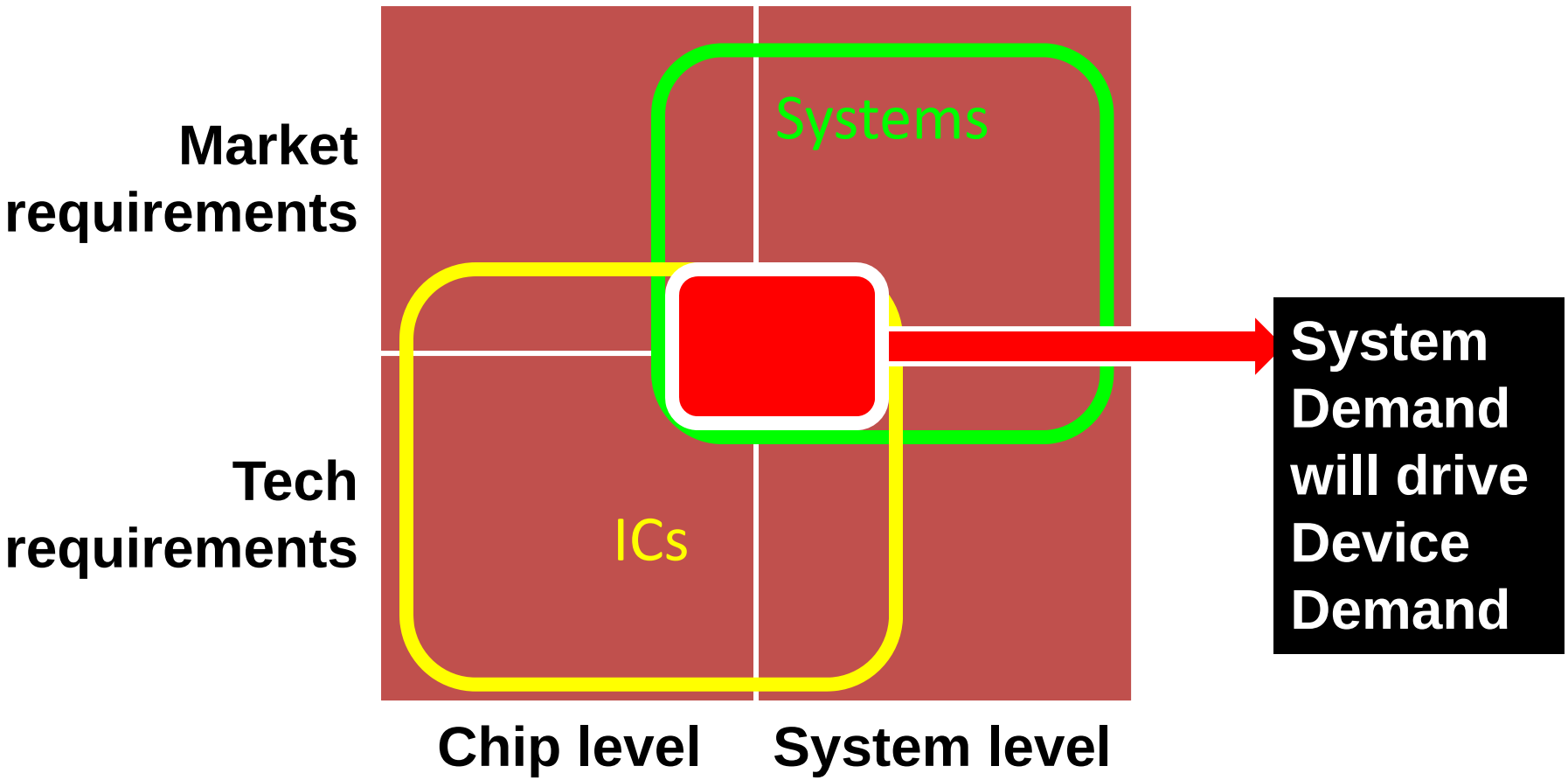
Heterogeneous Components —describes devices that do not necessarily scale according to “Moore's Law,” and provide additional functionalities, such as power generation and management, or sensing and actuating.

Beyond CMOS—describes devices, focused on new physical states, which provide functional scaling substantially beyond CMOS, such as spin-based devices, ferromagnetic logic, and atomic switch.

More Moore—refers to the continued shrinking of horizontal and vertical physical feature sizes to reduce cost and improve performance.

Manufacturing consists of tools and processes necessary to produce items at affordable cost in high volume.

System – Device Domain Space

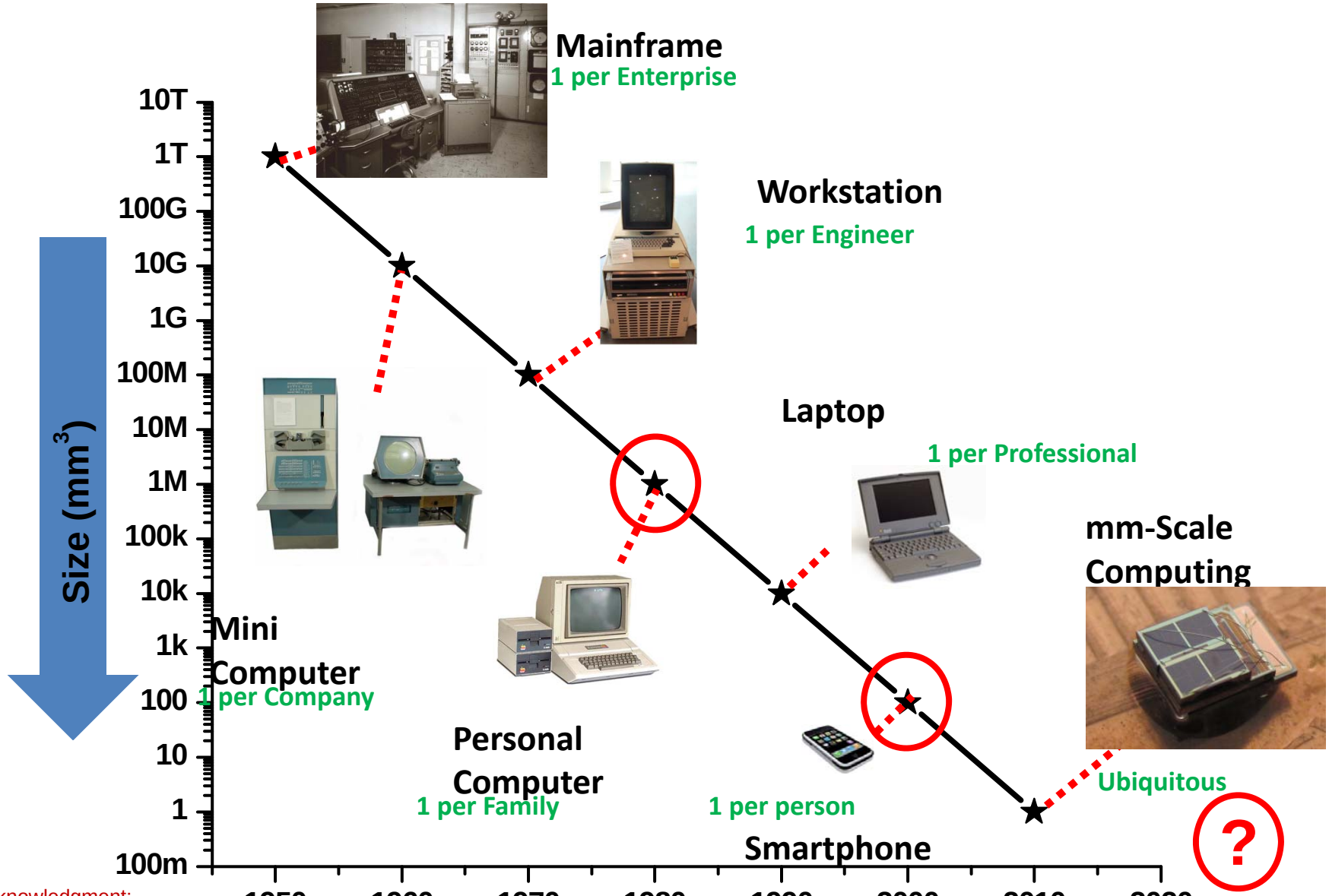


Typical System, Board Parameters

1. PCB Costs
2. Assembly Costs
3. Package Costs
4. Business Costs
5. Cycle Time
6. Reliability
7. Passive components, RF components
8. Display
9. Memory
10. Components / package
11. PCB / substrates / interconnect
12. Electrical and test
13. Power / environmental / thermal
14. Supply chain manufacturing
15. Simulation / tools

But where are the <u>Application</u> and <u>Product</u> requirements?

Bell's Law – Spatial and Production Volumes

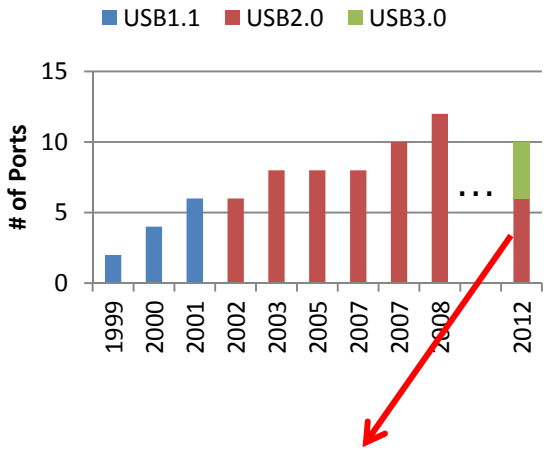


Acknowledgment:
Prof. D. Blaauw, U. Mich

Learning From History: The PC Wave

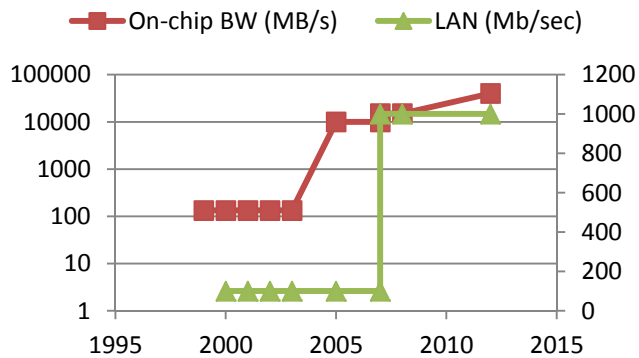
- Goal: understand and predict technology, platform “waves”
- Starting point: analysis of PC system trajectory
- Example: Intel south bridge (ICH, ICH2, …, ICH10, and HM47)

USB peripheral:
#ports reverses in 2012

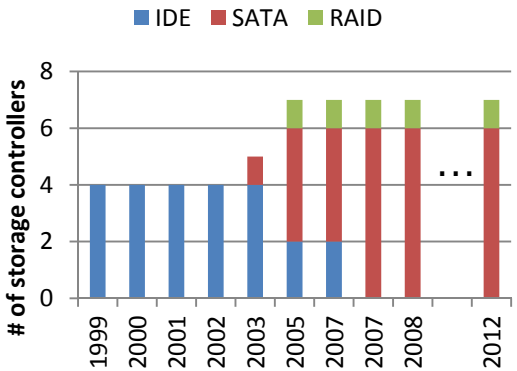


Decrease due to new feature (USB3.0)

Bandwidth:
monotone increase



Storage Capacity:
monotone increase



[Source] Intel and Wikipedia

PC System Integration Trends

SYSTEM level: PC motherboard over last 15 years

- From 1998: L2 cache integrated to CPU (performance)
- From 2009: North bridge integrated to CPU (bandwidth)
- Bandwidth of system bus scales up: ISA → PCI → AGP → PCIe
- From 2011: PCI de-integrated, disappears in latest product
- USB interface scaling: (1) degree of integration, (2) bandwidth

N	Function unavailable
B	Function by on-board ICs
I	Function integrated to chipset

Cache integrated

USB BW scales up

Year	Chipset Model	Chipset Conf	L2 CACHE	AUDIO	AGP	PCIe	PCI	ISA	USB1.1 / 2.0	USB3.0	2nd USB3.0
1997	PIIX4	3-Chip	B	N	N	N	I	I	N	N	N
1998	PIIX4	3-Chip	I	N	I	N	I	I	I	N	N
1999	PIIXE	3-Chip	I	N	I	N	I	N	I	N	N
2001	ICH2	3-Chip	I	B	I	N	I	N	I	N	N
2002	ICH4	3-Chip	I	B	I	N	I	N	I	N	N
2005	ICH6	3-Chip	I	B	N	I	I	N	I	N	N
2006	ICH8R	3-Chip	I	B	N	I	I	N	I	N	N
2007	ICH9R	3-Chip	I	B	N	I	I	N	I	N	N
2009	P55	2-Chip	I	B	N	I	I	N	I	B	N
2011	P67	2-Chip	I	B	N	I	B	N	I	B	N
2013	Z87	2-Chip	I	B	N	I	N	N	I	I	B

North bridge integrated

PCI de-integrated

[Source] Asus motherboard manuals

PC System Integration Trends

- Bandwidth of ethernet interface scales up
- Bandwidth of SATA interface scales up
- IDE interface de-integrated from 2005
- Integration and de-integration both observed in PC platform
- Functional, integration requirements drive design of chipset

N	Function unavailable
B	Function by on-board ICs
I	Function integrated to chipset

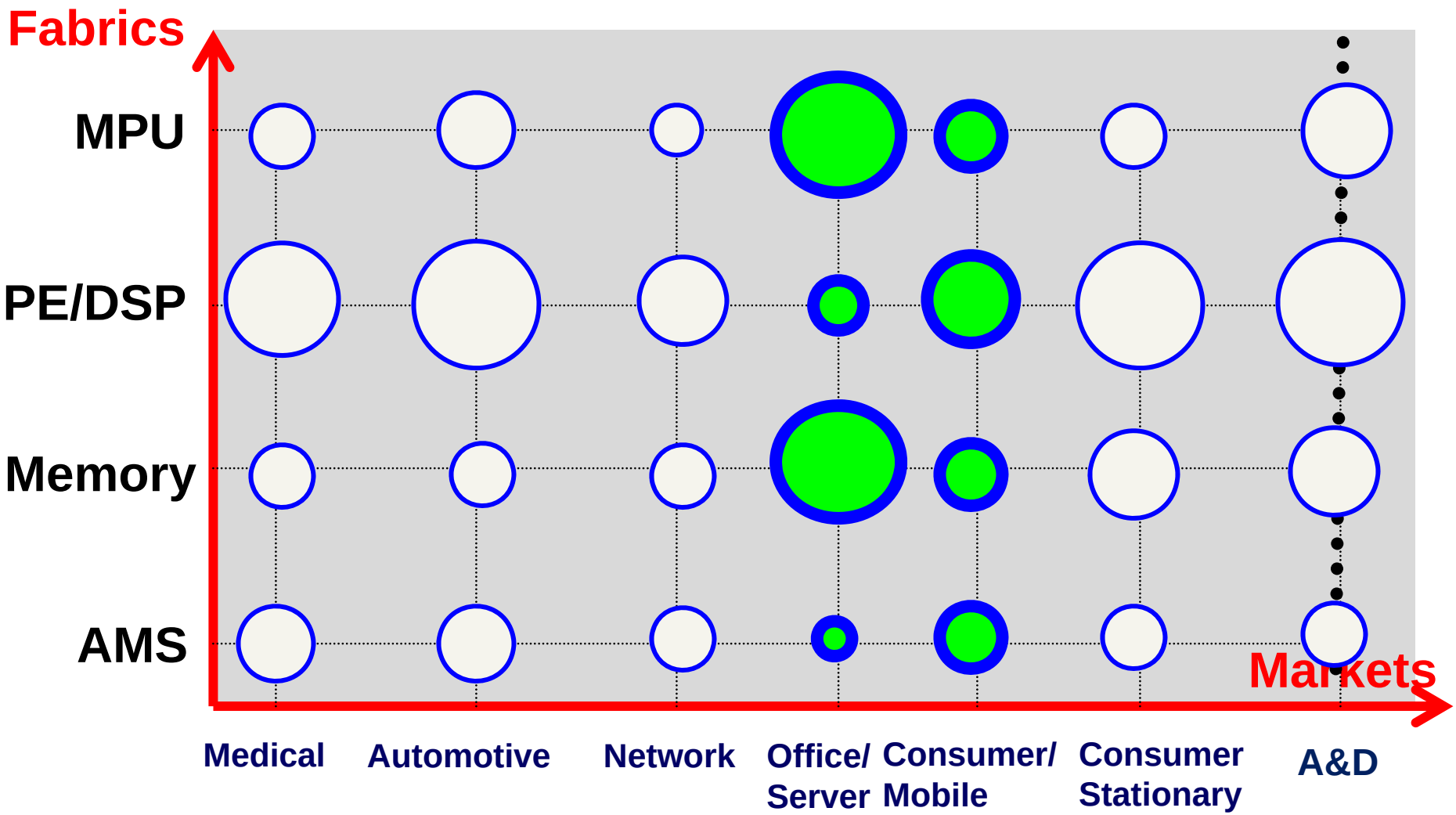
BW of ethernet scales up **IDE de-integrated** **SATA BW scales up**

Year	Chipset Model	10/100M Ethernet	Gb Ethernet	2nd GbE	WiFi	IEEE 1394	IDE	SCSI Controller	SCSI IO	SATA 3G	2nd SATA 3G	SATA 6G	SATA RAID
1997	PIIX4	N	N	N	N	N	I	N	N	N	N	N	N
1998	PIIX4	B	N	N	N	N	I	B	B	N	N	N	N
1999	PIIXE	N	N	N	N	N	I	N	N	N	N	N	N
2001	ICH2	N	N	N	N	N	I	N	N	N	N	N	N
2002	ICH4	N	B	N	N	B	I	N	N	B	N	N	N
2005	ICH6	N	B	N	N	N	N	N	N	I	N	N	N
2006	ICH8R	N	B	N	B	B	N	N	N	I	N	N	B
2007	ICH9R	N	B	N	B	B	N	N	N	I	B	N	B
2009	P55	N	B	N	N	B	N	N	N	I	B	B	B
2011	P67	N	B	B	N	N	N	N	N	I	B	B	B
2013	Z87	N	B	B	N	N	N	N	N	I	B	B	B

[Source] Asus motherboard manuals

ITRS System Drivers – Need to Focus

1. Applications drive technology
2. Need system input: mechanical, thermal, electrical, spatial



Mobile Proliferation

- > 100% penetration rates
- Complex ecosystem of operators, spectrum allocation

France [edit]

France has 75.5 million subscribers in total, or a 115.2% penetration rate (September 2013).[39]

The Regulatory Authority for telecommunication in France is ARCEP.

Rank	Operator	Technology	Subscribers (in millions)	Ownership
1	Orange (Formerly *Itineris*)	GSM-900/1800 (GPRS, EDGE) 900/2100 MHz UMTS, HSPA, HSPA+, DC-HSPA+ 800/2600 MHz LTE	26.768 (Sept 2013)	Orange S.A.
2	SFR	GSM-900/1800 (GPRS, EDGE) 900/2100 MHz UMTS, HSPA, HSPA+, DC-HSPA+ 800/2600 MHz LTE	21.237 (Sept 2013)	Vivendi

Germany [edit]

Germany has 114.124 million subscribers in total, or a 140% penetration rate [21] (December 2011). The Regulatory Authority for telecommunication in Germany is the Bundesnetzagentur (BNetzA).

Rank	Operator	Technology	Subscribers (in millions)	Ownership
1	Telekom (Formerly *D1 DeTeMobil*, *T-Mobil*, *T-Mobile*)	GSM-900/1800 (EDGE) 2100 MHz UMTS, HSPA, HSPA+, DC-HSPA+ 800/1800/2600 MHz LTE	37.492 [28] (August 2013)	Deutsche Telekom
2	Vodafone (Formerly *D2 Mannesmann*)	GSM-900/1800 (GPRS, EDGE) 2100 MHz UMTS, HSPA, HSPA+, DC-HSPA+ 800/2600 MHz LTE	33.890 [31] (May 2013)	Vodafone

Evolution of System Drivers Inventory

1. **Coming years may see a smaller list of key Drivers**
2. **With fab/tech consolidations, <u>Driver</u> applications consolidate too**
3. **Remaining non-Driver applications ride the technology curve**

System Driver (Market based)	Technology Parameters Driven	Likely action
High performance (computing) MPU	Frequency, number of cores, memory architecture	Keep
Mobile / consumer MPU	**Leakage power efficiency**	**Keep**
Low-power computing MPU "Microserver"	Operating power efficiency	**Introduce**
Networking switch	Number of I/Os / total I/O BW	Keep?
Various fabrics (eNVM, MEMS, AMS/RF)	Various fabric-specific parameters	**Keep, expand**
Networking MPU	Number of cores, I/O BW	Keep?

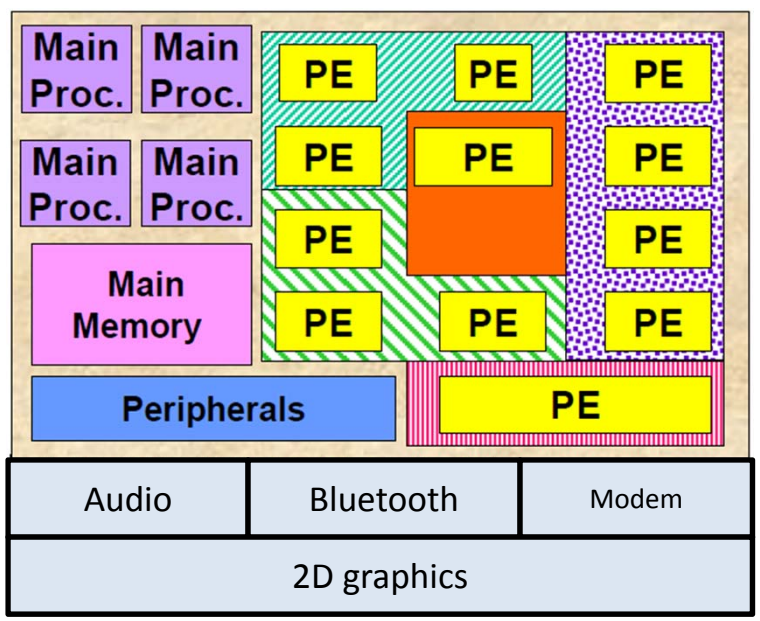
SOC-CP == The Right Driver ??

Likely the most influential driver in next 10+ years

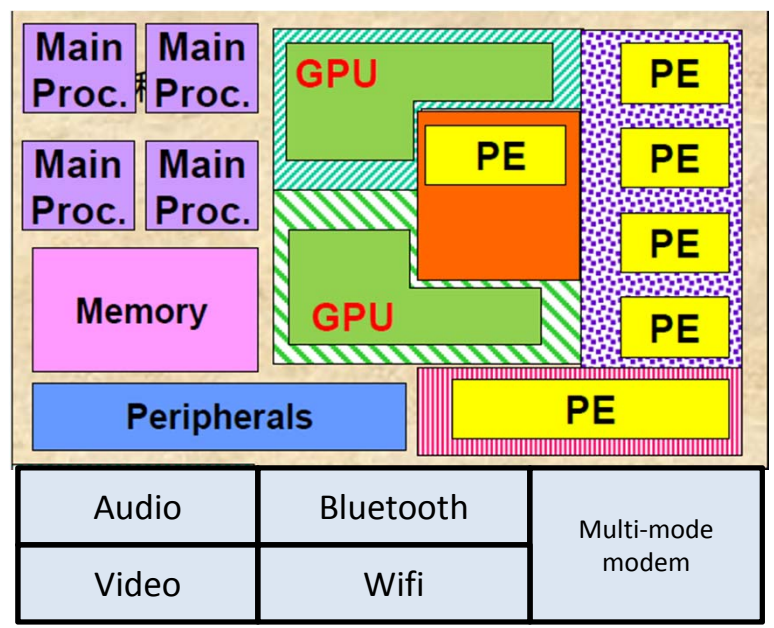
Largest market will drive most technology innovation

- **Reference application of SOC-CP is changing**
  - **WAS: feature phones with basic applications**
  - **IS: smartphones with rich multimedia/gaming applications**
- **GPU now key component in mobile AP**
- **Design challenge of SOC-CP → high diversity of functions**

WAS: SOC-CP for mobile phone
Area: 49mm^2



IS: SOC-CP for smartphone
Area: 140mm^2



Evolution of More Than Moore

Focus: mobile (SOC-CP) ($60B growth till 2025)

- **Concrete, real; most important socket for foreseeable future**
- **Can roadmap "scaling of value" from MTM in this context**

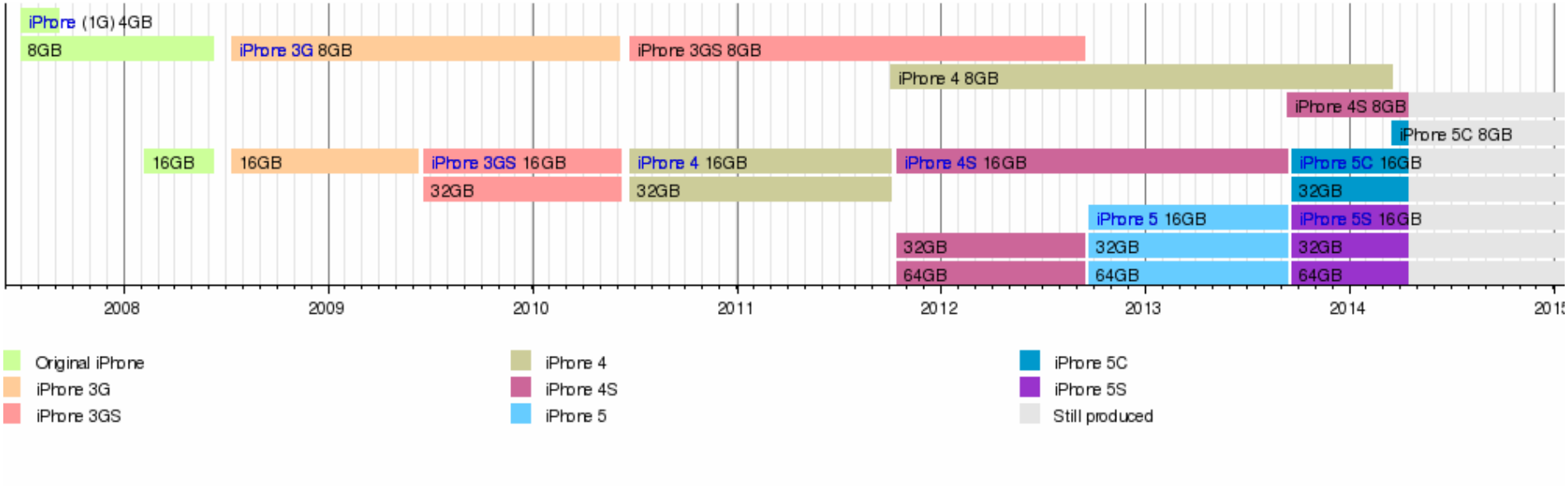
First target: inventory of top MTM IPs

- Look into historical trajectory of teardowns, BOMs
- Can roadmap year in which discrete components are introduced, when they go into silicon

Second target: roadmap of components' evolution over time

- Associated "rules" to define "year of introduction"
  - E.g. 2 products in volume production, like rest of ITRS

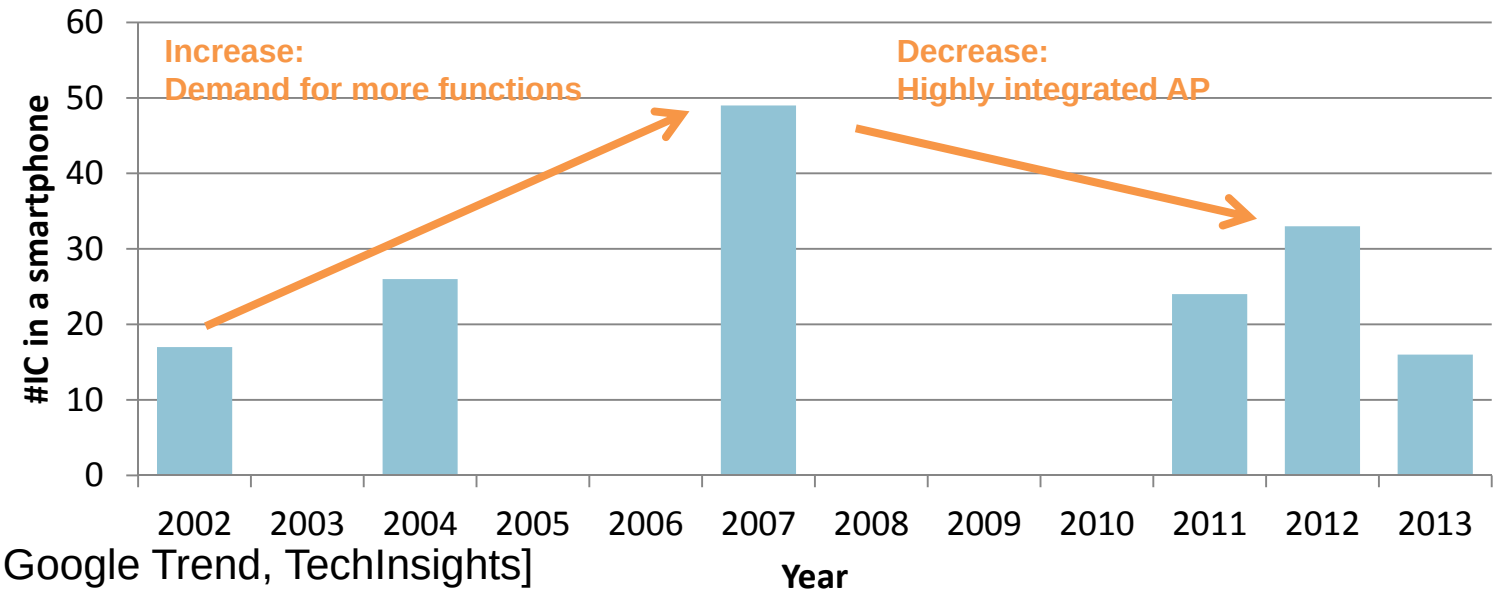
Rise of Flash Content



[Source] Wikipedia; Apple press release library

Rise of the Application Processor

- Before 2007: Smartphones contain growing #ICs from different vendors
- After 2007: Smartphones contain multi-function integrated application processors (APs) (→ decreasing #ICs)



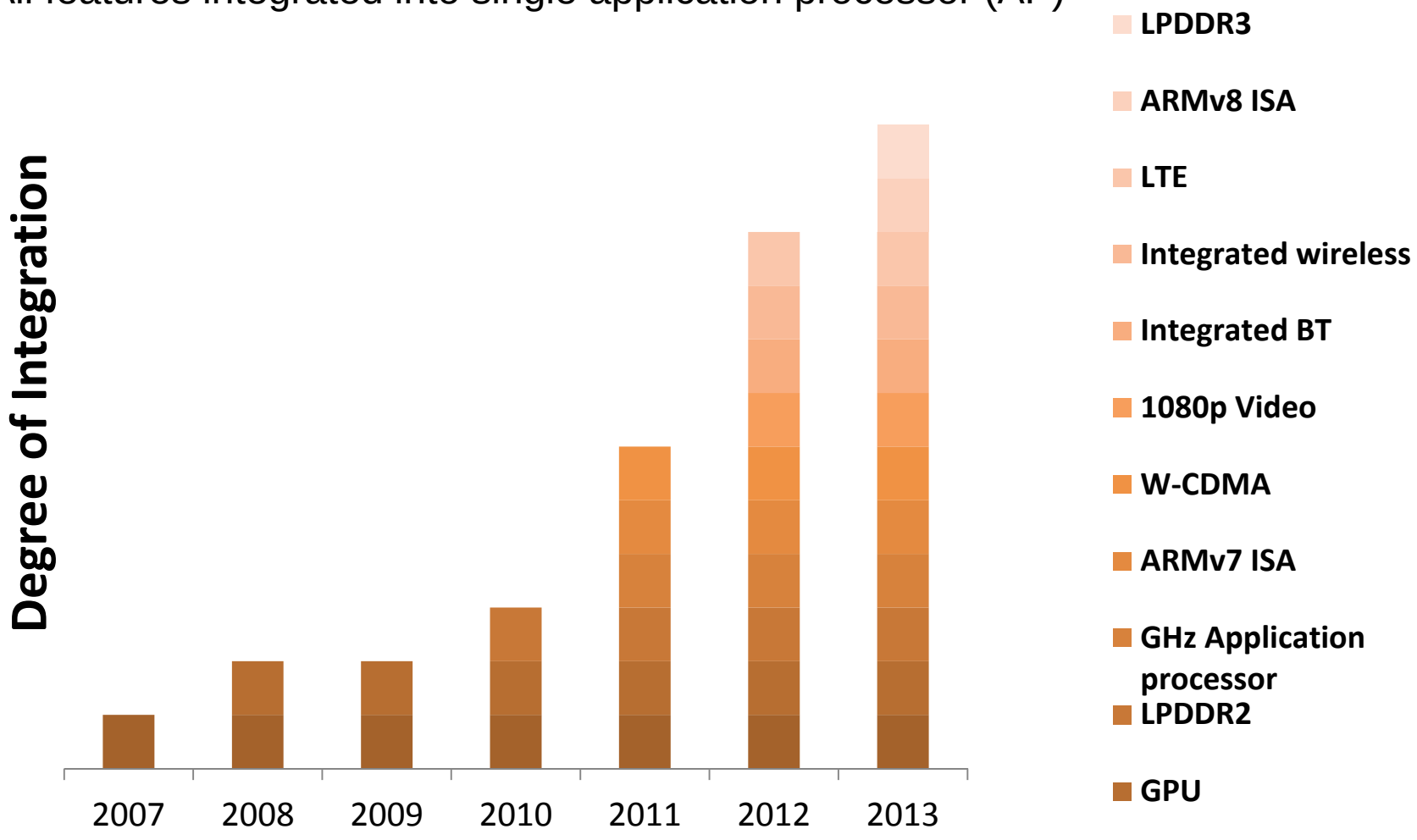
[Source: Google Trend, TechInsights]

Scaling of Application Processor Integration

TREND: Application processors are integrated with more features

WAS: Independent Bluetooth (BT), wireless, multimedia and baseband (BB) ASICs

IS: All features integrated into single application processor (AP)



[Source: Wikipedia]

Example Roadmapping Task: Split of AP SOC

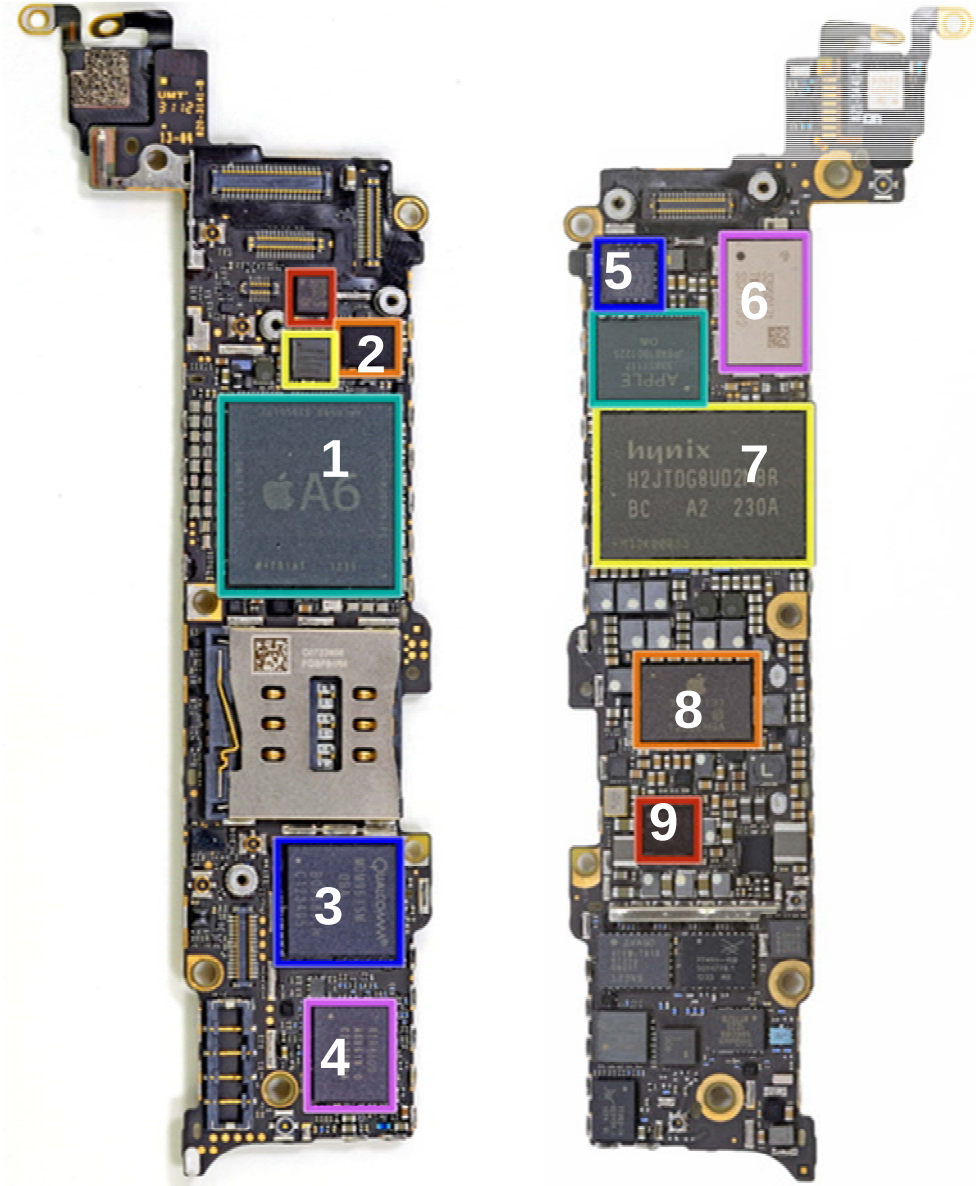
- **Given:** An SOC design with blocks such as CPU, GPU, and memory controller (MC); performance requirements; memory interface technology; and multi-die integration technology.
- **Objective:** Model the number of inter-die connections (in future products) so as to predict the number of TSVs/micro-bumps (and, die area, power, thermal, cost) required.

E.g., interposer vs. stacked ?

(area inflection : ~140-150mm^2)

(there is an integration inflection, as well…)

Teardown – iPhone 5



Side 1 Side 2

1. Apple A6 processor
2. Touch screen controllers
3. LTE modem
4. Multimode RF
5. Three-axis gyroscope
6. WiFi
7. 16GB Flash
8. Audio amplifier
9. Power management IC

[Source: iFixit]

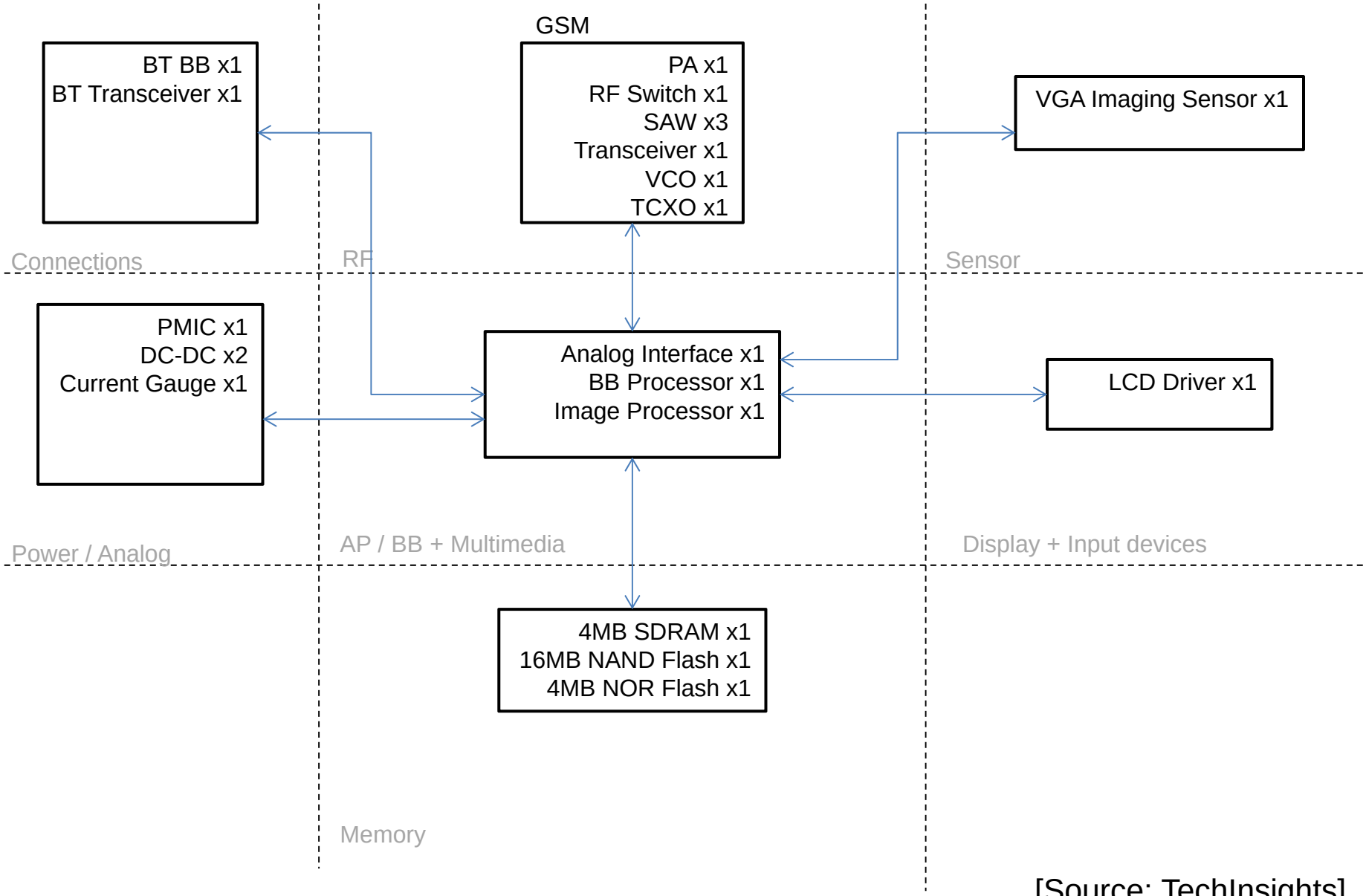
Building Blocks of a Smartphone

Example: smartphone from major manufacturer, 2013

Subsystem	Components	Function
AP	Application Processor	Multimedia, resource management
BB	Baseband	Communication protocols
Memory	Mobile DDR2-S4 SDRAM Memory - 512 MB	Data storage
	MLC NAND Flash Memory - 4 GB	
	Memory Controller	
RF	RF Power Amplifier	Radio signal synthesis / extraction Up/down frequency converting Radio band management
	Power Amplifier Controller	
	WiFi 802.11n / Bluetooth (BT) / FM Radio	
	GSM / CDMA / W-CDMA RxD Transceiver + GPS	
	SP10T Antenna Switch	
	GPS LNA	
Sensor	LED Flash Driver	Image capturing
	5 MP CMOS Image Sensor	
	Accelerometer Processor	Position / orientation detection
	MEMS Sensor	
	Ambient Light / Proximity Sensor	Environment sensing
Display / Input device	Capacitive Touchscreen Controller	Touch control
	TFT-LCD Display Driver	Display
Power / Analog	Power Management IC (PMIC)	Hibernation, power mode management
	Audio CODEC / amplifier	Audio output

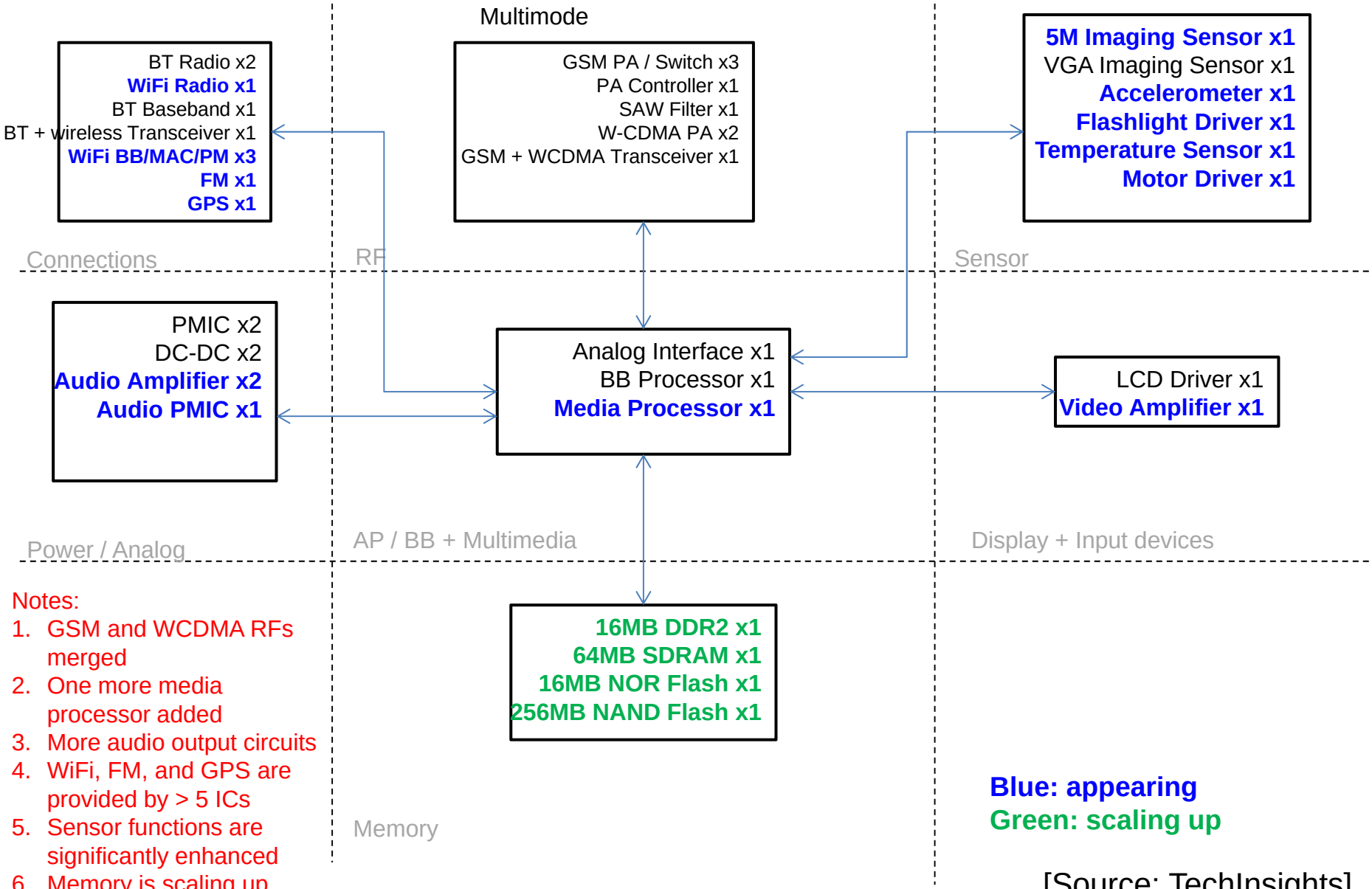
[Source: TechInsights]

Smartphone Block Diagram Evolution -- 2002



[Source: TechInsights]

Smartphone Block Diagram Evolution -- 2007



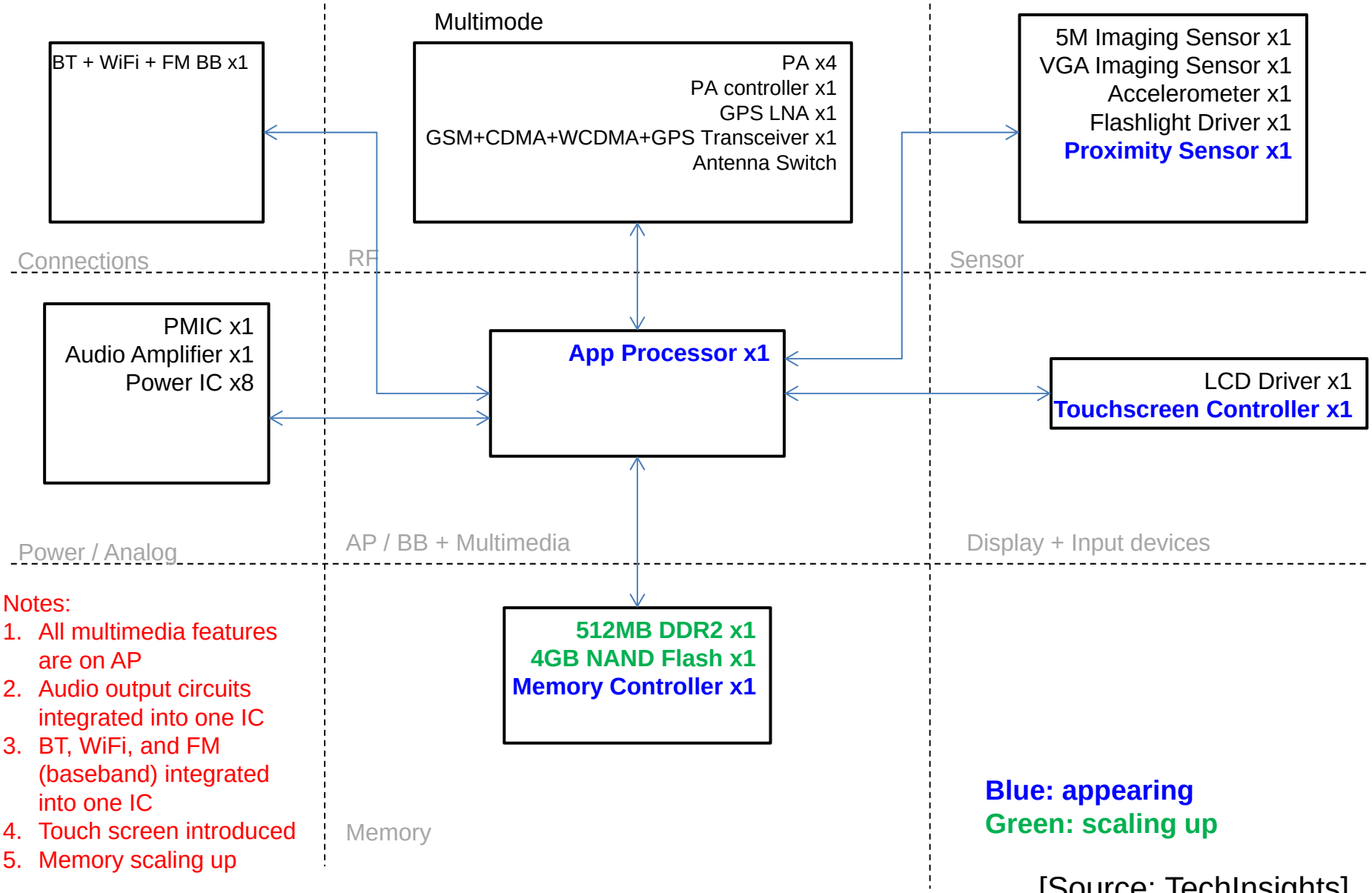
Notes:

1. GSM and WCDMA RFs merged
2. One more media processor added
3. More audio output circuits
4. WiFi, FM, and GPS are provided by > 5 ICs
5. Sensor functions are significantly enhanced
6. Memory is scaling up

Blue: appearing
Green: scaling up

[Source: TechInsights]

Smartphone Block Diagram Evolution -- 2013



Notes:
1. All multimedia features are on AP
2. Audio output circuits integrated into one IC
3. BT, WiFi, and FM (baseband) integrated into one IC
4. Touch screen introduced
5. Memory scaling up

Blue: appearing
Green: scaling up

[Source: TechInsights]

Mixed Technology Nodes Will Merge (*)

Subsystem	Components	Model	**Technology**
AP / BB	Applications Processor + Baseband	Qualcomm MSM8227	CMOS 28nm
Memory	Mobile DDR2-S4 SDRAM Memory - 512 MB	SK Hynix H9TKNNN4GDAR	DRAM process
	MLC NAND Flash Memory - 4 GB	Samsung K9ABGD8UOC	??
	Memory Controller	Samsung S4LJ211X01	??
RF	RF Power Amplifier	TQM7M9053	GaAs HBT
	Power Amplifier Controller	TriQuint (??)	??
	WiFi 802.11n / Bluetooth / FM Radio	Qualcomm WCN3660	?? (Paid report on Chipworks)
	GSM / CDMA / W-CDMA RxD Transceiver + GPS	Qualcomm WTR1605	??
	SP10T Antenna Switch	Skyworks 36524	??
	GPS LNA	Renesas C8236	??
Sensor	LED Flash Driver	AMS AS3646	High voltage process (15V)
	5 MP CMOS Image Sensor	STM 5955AA	CMOS (sensor process)
	Accelerometer Processor	STM V655B	ST MEMS process
	MEMS Sensor	STM CSL23A	ST MEMS process
	Ambient Light / Proximity Sensor	AMS E2703C	??
Display / Input device	Capacitive Touchscreen Controller	Synaptics T1321B	??
	TFT-LCD Display Driver	Orise R242	??
Power / Analog	Power Management	Qualcomm PM8038	?? (Paid report on TechInsights)
	Audio CODEC	Qualcomm WCD9304	??

TBR: In what years will critical merging "inflections" occur ? (2015-2030)

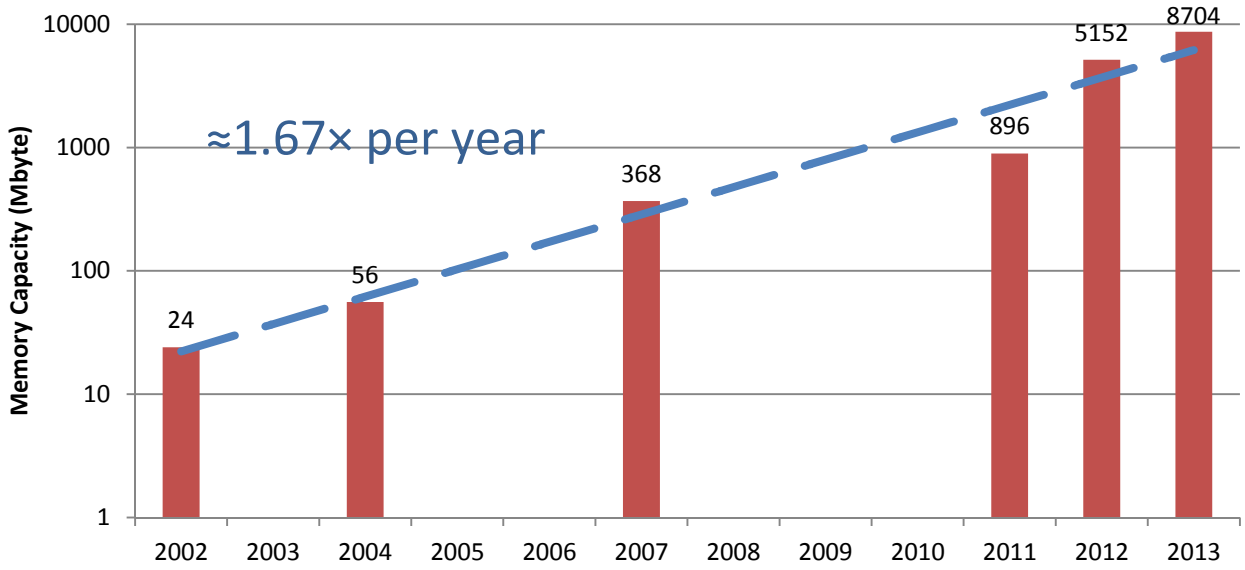
Scaling of Memory Blocks
(Implicit: Long-Term Requirements)

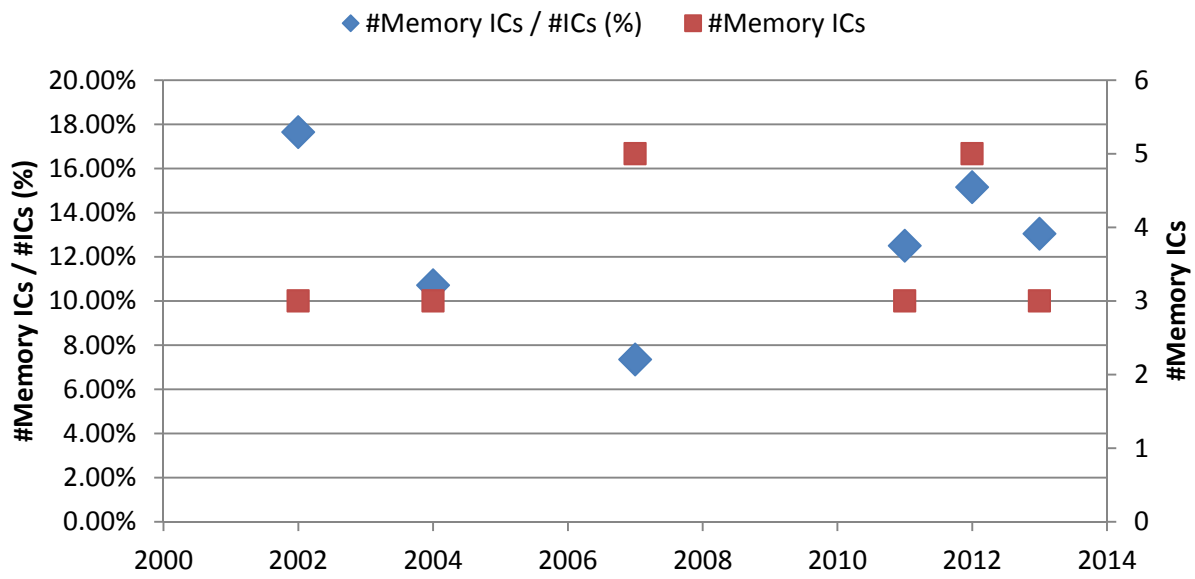
Capacity scaling
≈1.67× / per year

#Memory ICs
Baseline configuration remains similar

1 or 2 DRAM
1 or 2 NAND flash
1 NOR flash

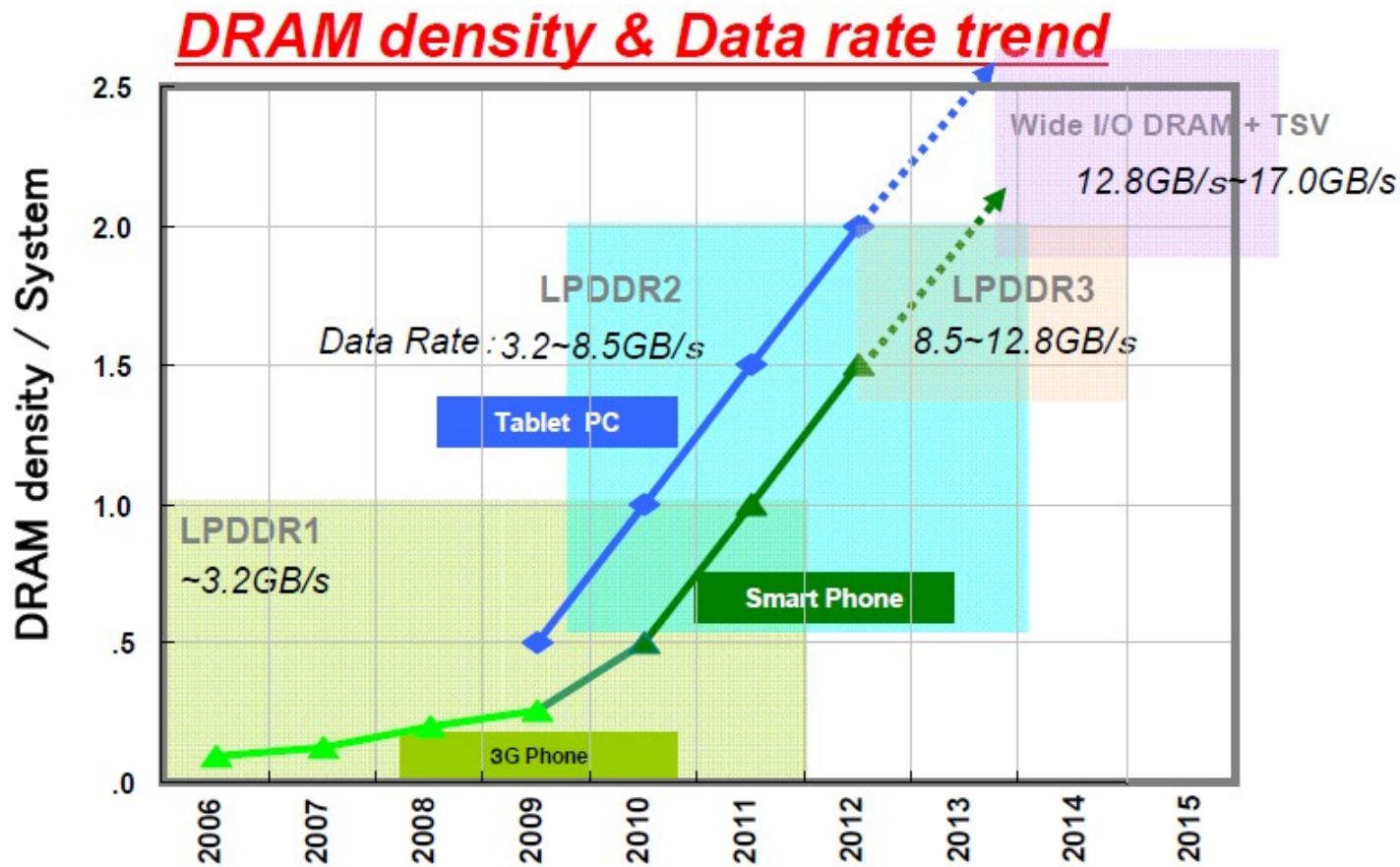
%ICs = Memory ICs
Varies due to different system architecture





[Source: TechInsights]

Scaling of Memory Bandwidth



Wide I/O will start from 12.8GB/s(200MHz) and soon 17GB/s(266MHz).

[Source: http://electroiq.com/insights-from-leading-edge/2011/09/]

Scaling of pJ / Bit

	LPDDR2	LPDDR3	WideIO	LPDDR4	WideIO2
BW (Gbyte/s)	8.5(1)	12.8 (1)	12.8	34(1)	51.2
possible BW evolution (Gbyte/s)	-	17 (2)	17 (3)	Not yet defined	Not yet defined
max package density (Gbit)	4x4	4x4	1x4	Not yet defined	Not yet defined
power efficiency (mW/Gbyte/s)	78	67	42	Not yet defined	Not yet defined
volume maturity	2011	2012	2013	Not yet defined	Not yet defined
relative memory cost for equivalent density 4)	1	~1.1	~1.2	Not yet defined	Not yet defined

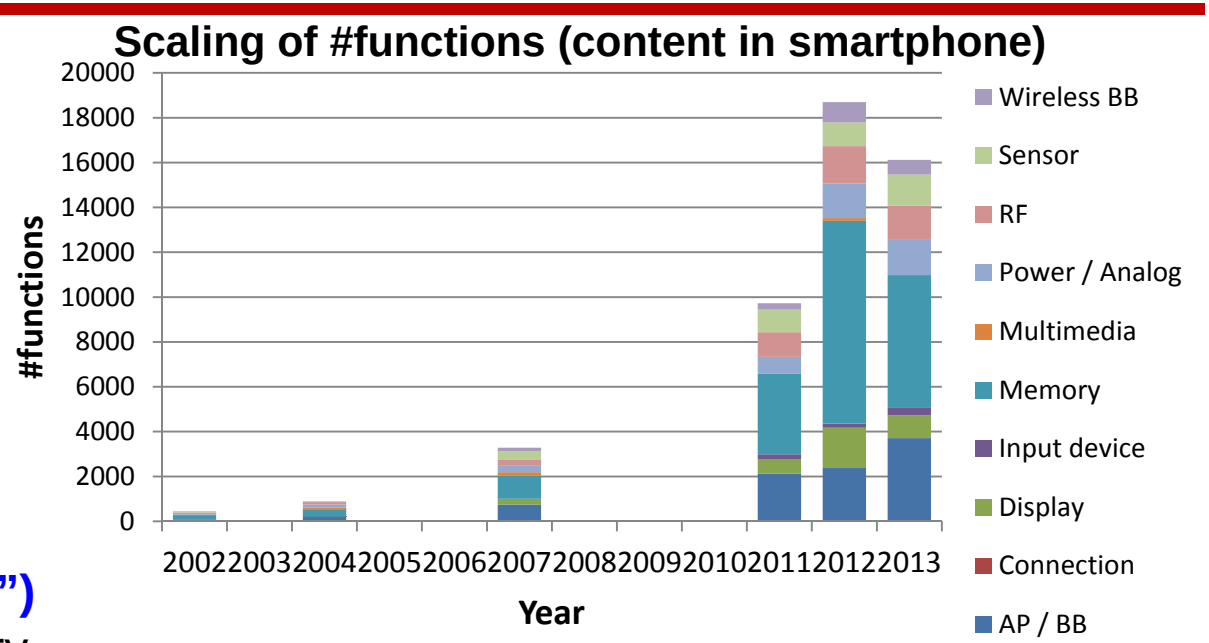
(1) 32b dual channel configuration assumed
(2) LPDDR3E: clock from 800 to 1066MHz. Standardization at JEDEC in progress
(3) WideIO clock frequency from 200MHz to 266Mhz: already specified at JEDEC
(4) Estimates based on memory supplier survey (memory cost only)

[Source: http://electroiq.com/insights-from-leading-edge/2013/02/iftle-134-semi-3d-european-summit-is-the-wide-io-driver-dead/]

Scaling of Subsystem Functions and Bandwidth

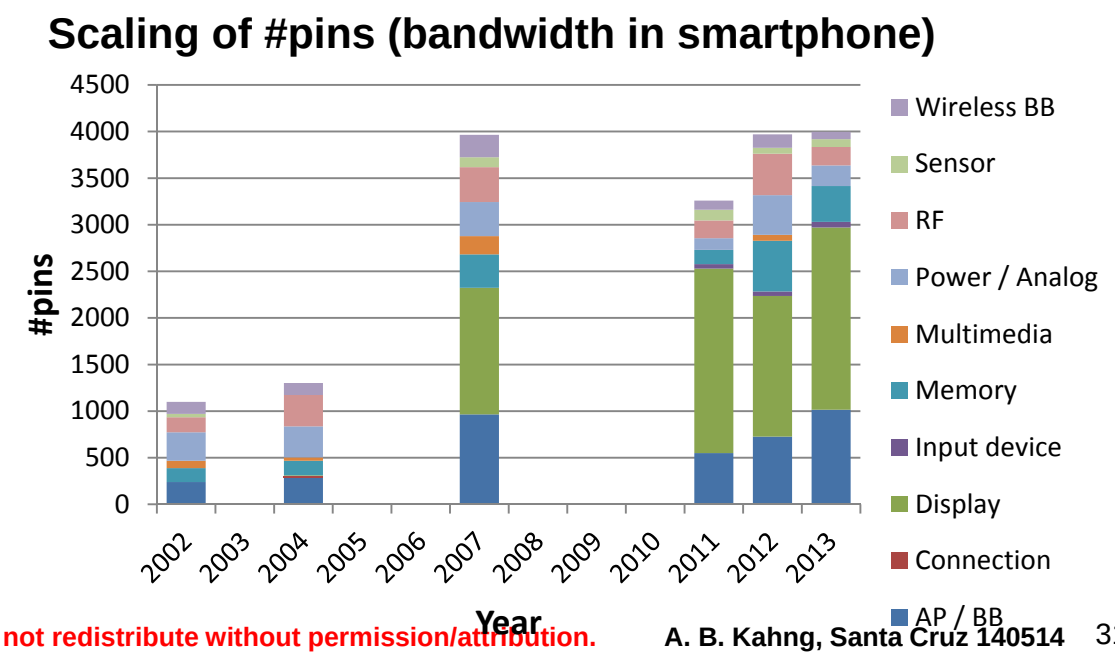
Scaling of #functions

- Metric: #functions = $\frac{Die\ Area}{Normalized\ Transistor\ Density}$
- Memory and AP grow faster than other components



Scaling of #pins ("bandwidth")

- Metric: #pins of ICs in category
- 2007-2013: bandwidth for display has significant jump
- 2007-2013: bandwidth for RF decreases (e.g., more highly integrated RF subsystem)
- Bandwidth of other subsystems remains similar from 2007-2013



[Source: TechInsights]

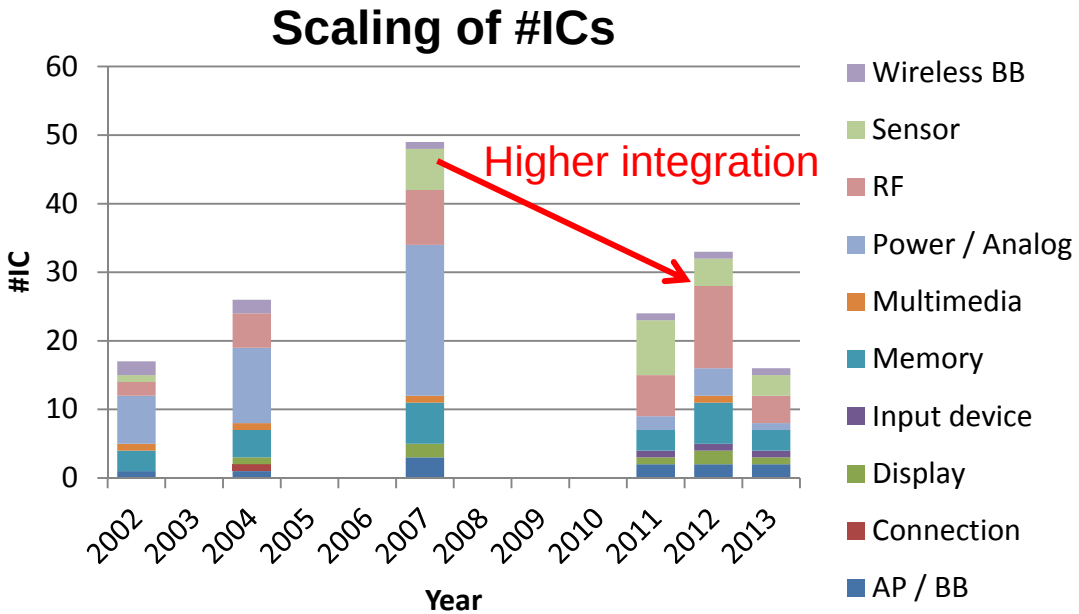
Scaling of #ICs for Each Subsystem

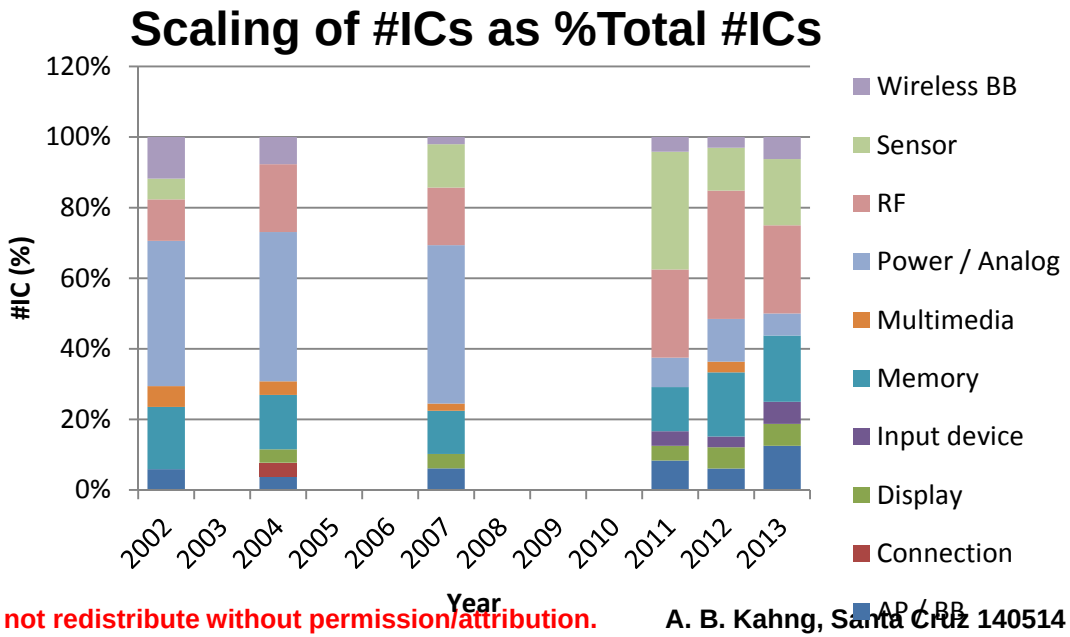
Scaling of #ICs

- 2002-2007: #ICs for each subsystem increases
  - → increasing content requirement
  - → integration cannot keep pace
- 2007-2013: #ICs significantly decreases
  - → integration pace delivers required content in fewer ICs

Scaling of #ICs as %Total ICs

- 2002-2007: %power/analog flat
- 2007-2013: %power/analog drops significantly
  - → highly integrated power/analog
- 2007-2013: %RF increases
  - → multi-mode RF
- 2007-2013: %sensors increases
  - → sensor-rich functionality



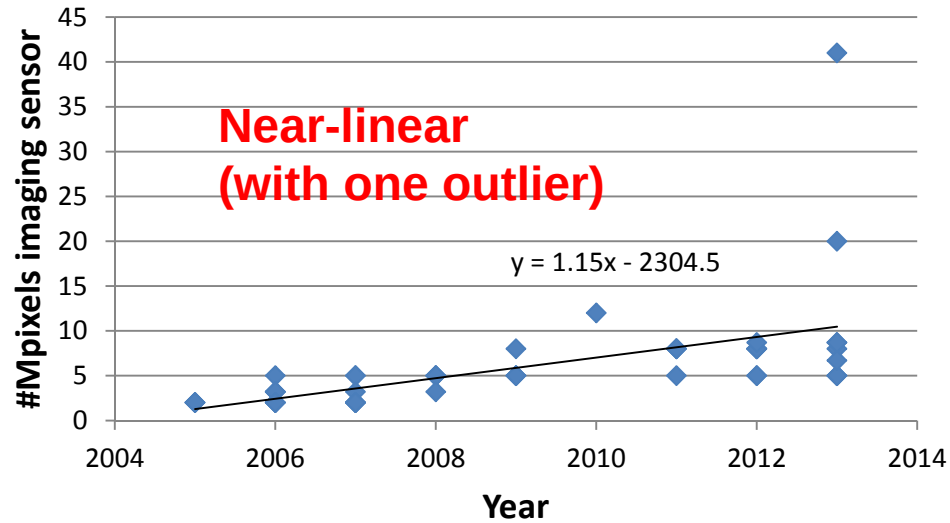


[Source: TechInsights]

Scaling of Display and Imaging

Scaling of imaging sensor

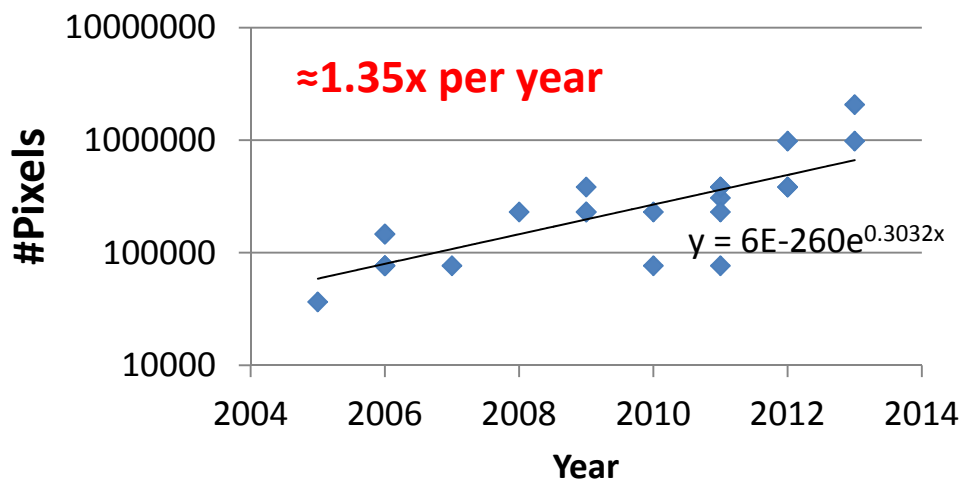
→ Another metric of multimedia processing capacity



Scaling of display size

→ Metric for system bandwidth and memory requirement

→ Also metric for multimedia processing capacity and GPU performance



[Source: Wikipedia]

Scaling of Sensor, RF and MEMS IC in Smartphones

Emerging sensor functions

Accelerometers	Motion Processing (MPU)
Gyroscopes	Memory
Magnetometers	Wireless Communications
Pressure	Display
Humidity	Speakers
Temperature	Microphones
eNose	Camera
Galvanic Skin Response	pH Sensor
Heart Rate	Blood Pressure

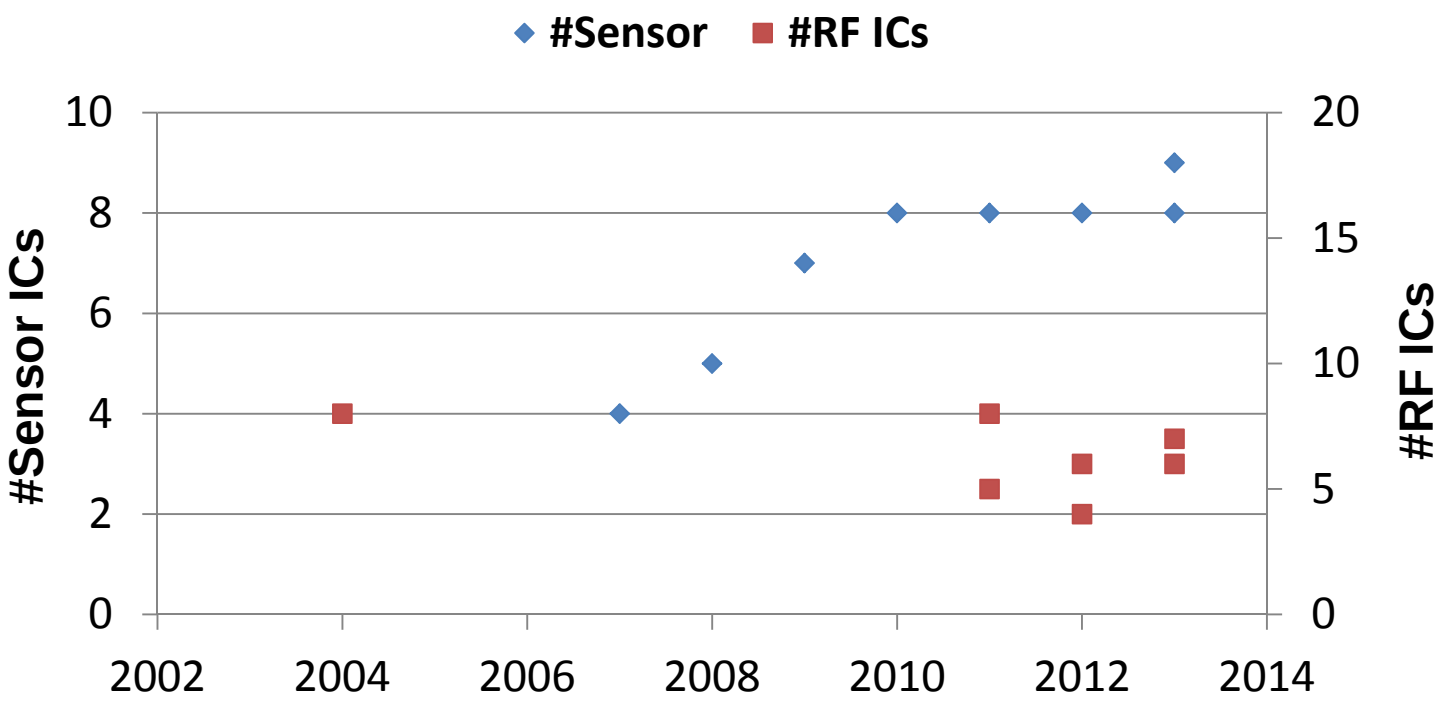
- **Road<u>mapping</u> task = develop mapping functions ⇔ available technologies ⇔ application-specific performance, size, power requirements ⇔ identified gaps ⇔ required new device and manufacturing technologies**
- **(Still need to place future sensor functions onto a timeline)**

[Source: ITRS MEMS ITWG]

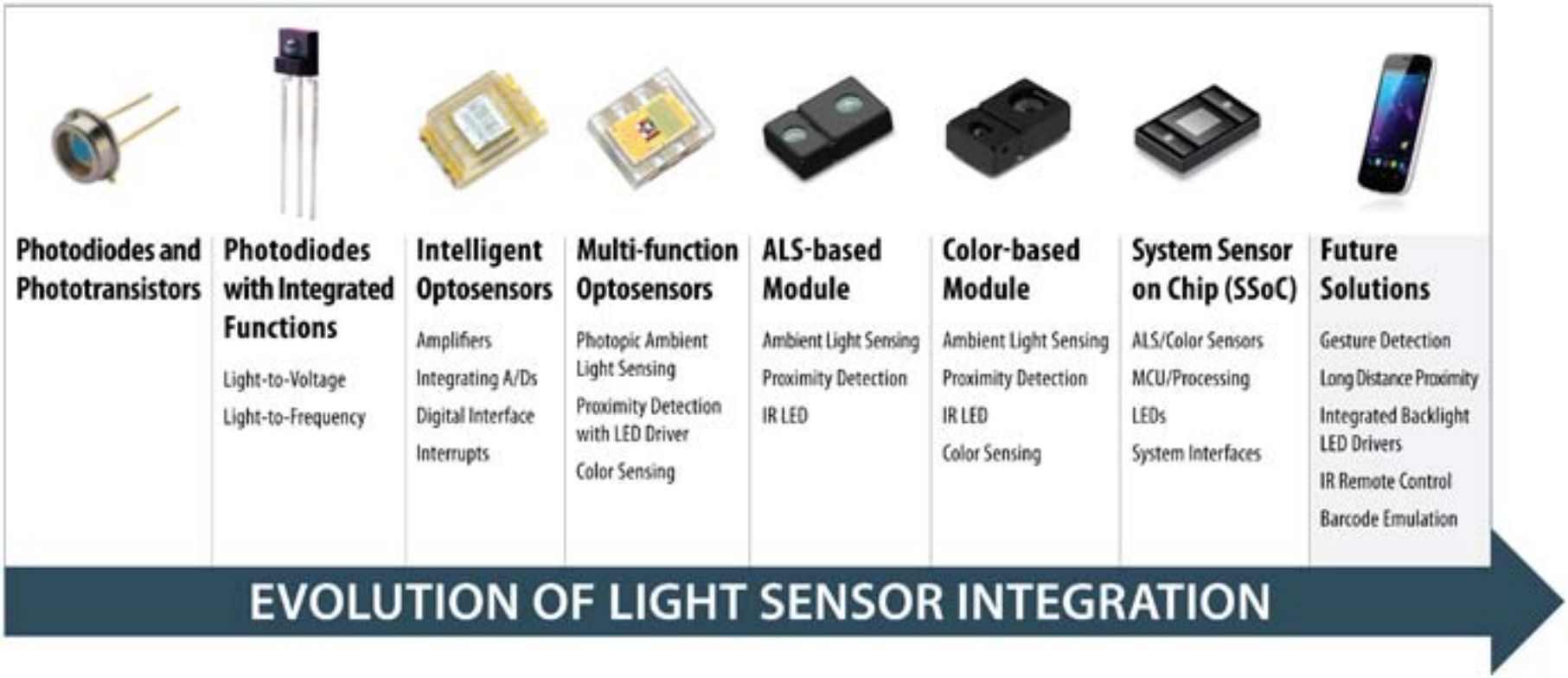
Scaling of Sensor, RF and MEMS IC in Smartphones

- **#Sensor ICs: slow but steady growth**
  - **Recently introduced sensors → gyroscope (2010), fingerprint (2013)**
- **#RF ICs: no clear trajectory**
  - **Two trends seem to cancel each other out**
    - **(–) Technology improvement → fewer RF ICs**
    - **(+) Multi-standards support → more RF ICs**

[Source: Wikipedia, Chipworks]

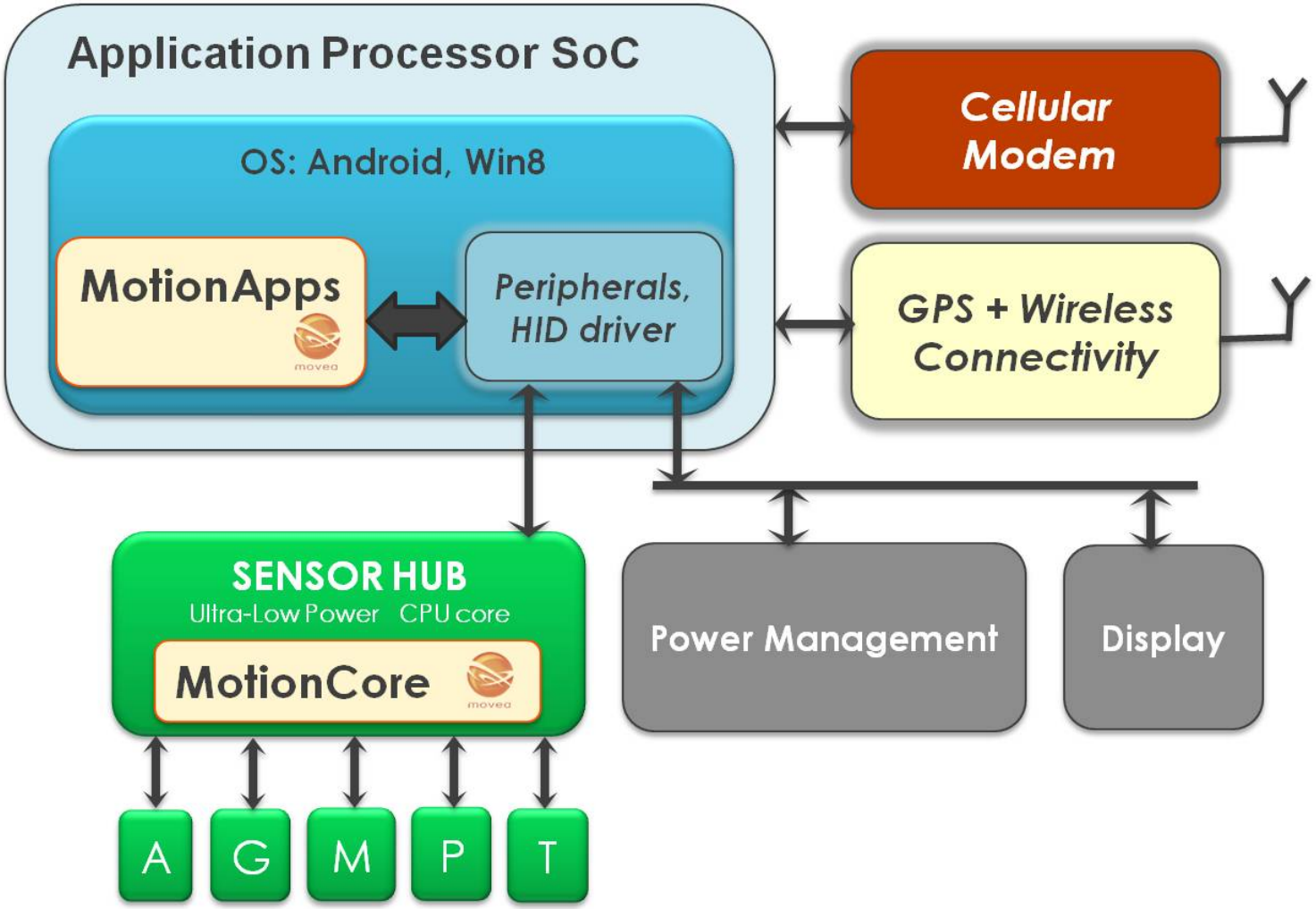


Sensor Roadmap in Smartphones



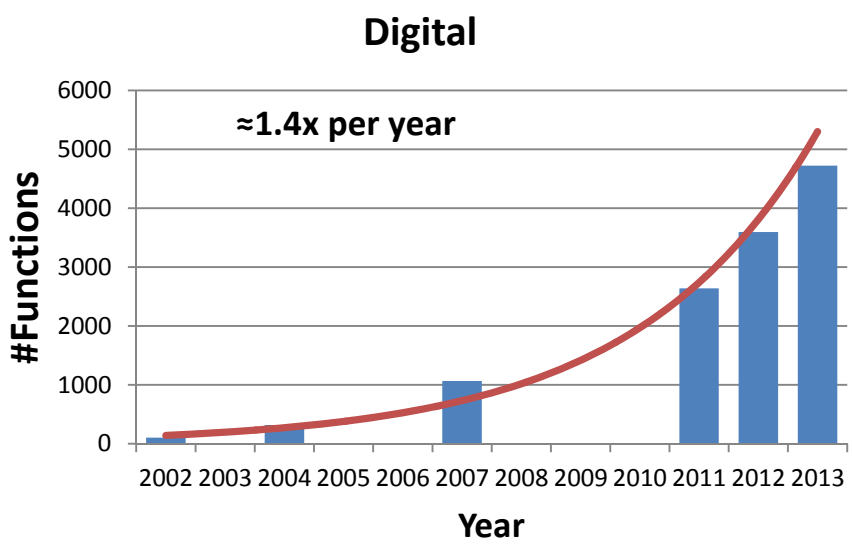
[Source: http://www.ecnmag.com/articles/2013/05/evolution-light-sensor-integration]

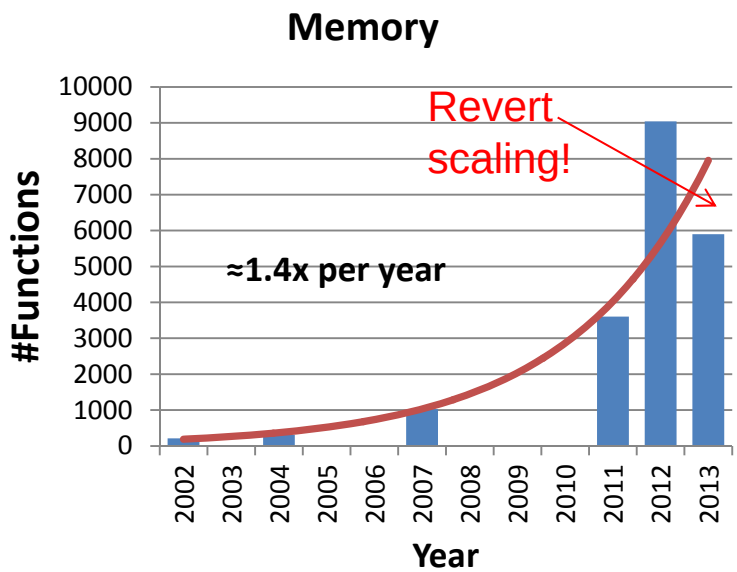
Sensor Integration in Smartphones -- 2013

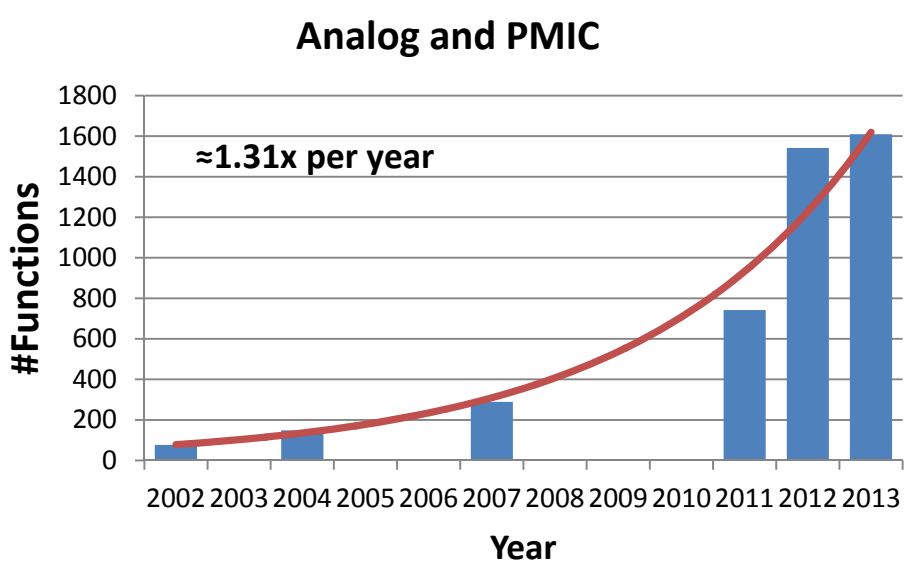


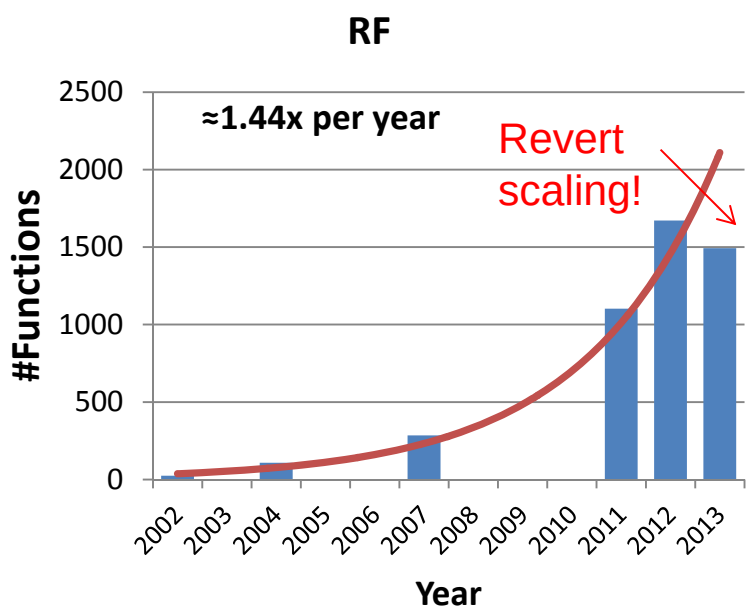
[Source: http://electronicdesign.com/boards/sensor-fusion-play-and-profit]

Notional: 4 Scaling Sub-Laws in Smartphone?









Toward System Driver Integration Roadmaps

- **One Example = Smartphone**
  - **High-value, high-volume driver for next 10+ years**
- **First step: Analysis of data**
  - **Doable with effort**
  - ***Same spirit as 2013 A-factor recalibration from Chipworks data***
  - **Similar first steps needed for IoT, cloud ("AWS"), …**
- **Next steps: Looking <u>forward</u> with <u>models</u>**
  - **#APs vs. #sensors (gesture recognition, security, …)**
  - **Thermal and memory power limits vs. how far a bit can physically move**
  - **Human psychophysical limits (display size/resolution, rate of scrolling, bandwidth, form factor, …)**
  - **Sub-laws of scaling: digital, RF, analog/PMIC, memory, …**
    - **MTM = arena for reconciliation**
  - ***Q: Package-level (DRAM+AP), chip-level (multimedia + LTE BB), TSV-level (CIS + image proc) integration: how do these drive SOC evolution, with what inflection points?***
  - ***Q: What drives analog IPs to merge? What drives digital IPs to merge?***

Toward System Driver Integration Roadmaps

- **Important: find the key metrics to roadmap!**
  - **Proportion of memory in overall BOM**
  - **#die-to-die wires / $**
  - **BW / ($-Watt)**
- **Important: don't get stuck on "applications pull"!**
  - **Unforeseen new possibilities enabled by technology push**
- **Important: integration can reverse itself!**
  - **16nm and analog don't like each other ☹**
  - **There will be dis-integration …**

    (e.g., how to split the ModAP SOC)
  - **… and MTM is all about "how do you re-integrate"**

    (POP, Si interposer, TSV (COCOS, COWOS), …)
  - **A&P and bump pitch, BW/pin etc. metrics become critical**
- **Important: A journey of a thousand miles begins …**

THANK YOU !