

A Brief History of ARM

(And what it taught me about
~~starting a business~~)

Lee Smith, ARM Fellow

Presentation to *Cambridge University*
Entrepreneurs, 9th February 2008

*(With many thanks to John Biggs and Mark Collier
who provided most of the historical slides)*

A brief history of me

- Lee Smith, ARM Fellow
 - 1971-1974 BA, MA (Mathematics) (Cantab)
 - 1974-1976 Scientific Officer, Daresbury Laboratory Computing Group
 - 1976-1978 University of Edinburgh, Computer Science Department (started a PhD I never finished)
 - 1978-1983 Lecturer (temporary then permanent), UoE CS Department (joint coordinator of the MSc in *Computer Systems Engineering*)
 - 1983-1984 Acorn Computers R&D, led an experimental CAD project
 - 1985 Acorn, a year of chaos (and learning about business ☹)
 - 1986-1987 Acorn R&D, formed and led an internal tools group
 - 1987-1990 Acorn, formed a group to sort out the compiler mess
 - 1991-1993 ARM, Managed all software-related activities + systems administration; member of the management committee
 - 1994-1997 ARM, Managed most software-related activities
 - 1998-2001 ARM, Managed the Compilation Tools Group
 - 2001-date ARM Fellow
(various cross-functional, forward-looking technical roles)

What I do as an ARM Fellow

- My main concrete expertise is in code generation tools – compilers, linkers, link-time optimizers, and so on
- I have more abstract expertise in ‘system architecture’
 - I have applied that to the *ARM Architecture*, the *Application Binary Interface for the ARM Architecture*, aspects of ARM’s *development tools* product architecture, as well as to CG tools’ code base
- I work in many cross-group, multi-disciplinary teams
 - Help to ensure that ARM’s sprawling portfolio of products work together coherently for our customers
 - Needs: sober judgement, experience, *relevant* cross-group knowledge and expertise, long-term abstract view
 - Peer into the future, help to develop strategies to guide the acquisition and development of technologies and products to support present and future commercial opportunities

Pre-history

From little Acorns...



(By John Biggs)

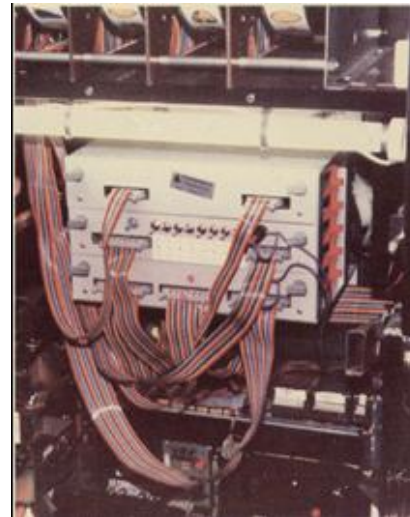


A long time ago

(on a distant planet, it might appear...)

“A” was for Acorn...

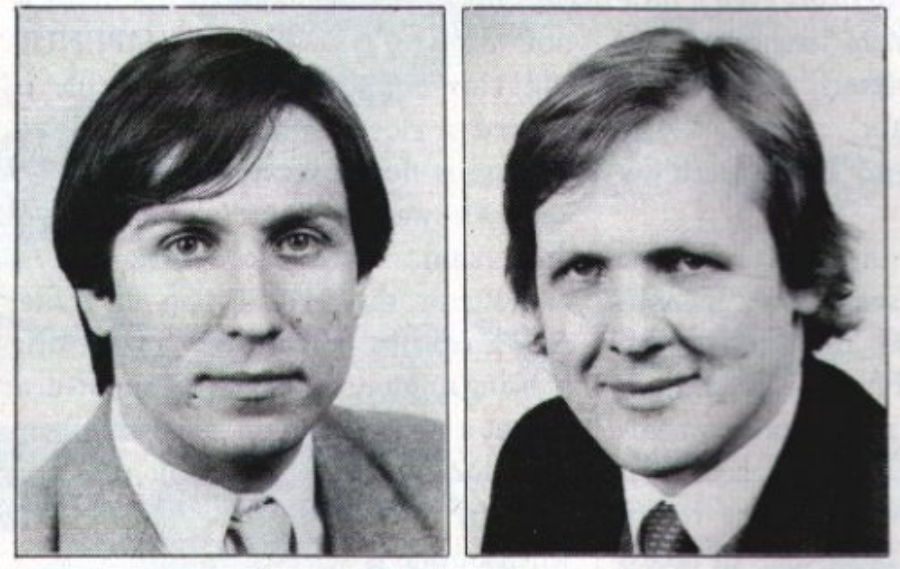
- 1978: Cambridge Processor Unit
 - Founded on 5th December 1978 by Hermann Hauser & Chris Curry
 - First contract was with “ACE Coin Equipment” to develop Fruit Machine hardware!
- 1979: Acorn Computer Ltd
 - CPU Ltd acquired Orbis and changed it's name to “Acorn Computer Ltd”



Acorn needed more CPU power!

- Evaluated new 16 bit processors from Motorola, Nat-Semi etc
 - All a bit slow and *much* too expensive (*if they worked at all!*)
 - “Can’t build a £500 micro around a £100 CPU” - *Steve Furber*
- Acorn asked for samples of Intel’s 80286 but were refused!*
- As a direct result of this refusal a team was set up in Acorn’s Advanced R&D labs to build it’s own 32 bit “Acorn” RISC Machine (ARM)

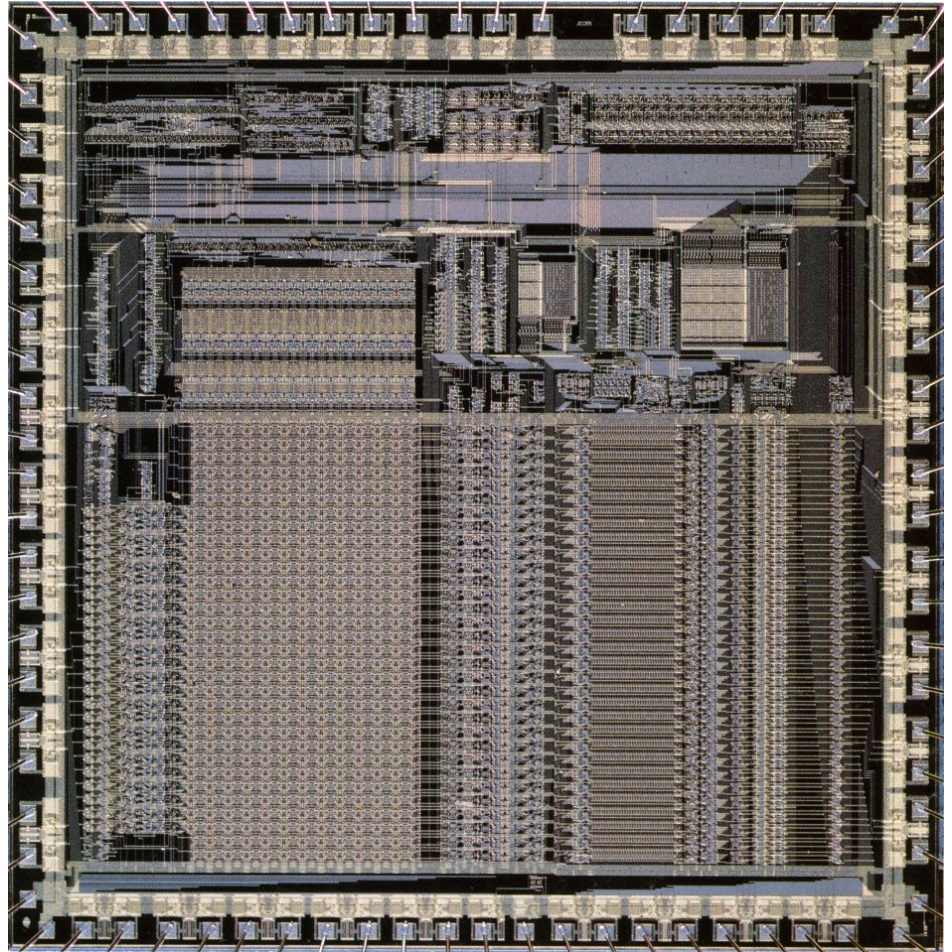
- Roger Wilson designed the 6502-like instruction set
- Steve Furber designed the hardware to implement it



* I wonder if Intel now regret that?

First ARM Silicon: 26th April 1985

- 1985: “ARM1”
 - 3.0 μ m (2 Layer Metal)
 - 25K Transistors
 - 6MHz
 - 120mW
 - 50mm²
- 2005: “ARM7TDMIr4”
 - 65nm (4 Layer Metal)
 - 100K Transistors
 - 350MHz (60x speed)
 - 9mW (1/780th energy)
 - 0.1mm² (1/500th area)



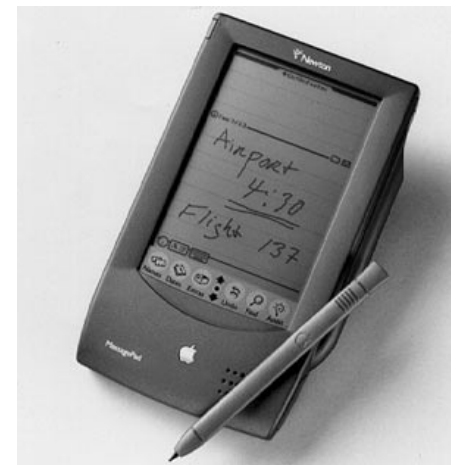
ARM7TDMI is now a “commodity” IP core in many of today’s SoCs

The need for Low Power

- The ARM was designed to be small (cheap!)
 - So low power was a happy accident!
(*serendipity!*)
- The need for low power was driven by battery powered hand-held consumer electronics
- Active Book/EO's Personal Communicator
 - Designed around an ARM2aS
 - Finally shipped with an AT&T Hobbit
- Apple's Newton Message Pad
 - Prototyped with the AT&T Hobbit
 - Final design used an ARM610



EO Personal Communicator



Apple Newton Message Pad

ARM starts up (1991-1993)

... and some important lessons ...

ARM Founded 27th Nov 1990

- £1.5M cash from Apple
- £250K cash from VLSI
- £1.5M of IP & 12 engineers from Acorn
- Proof of concept Acorn Archimedes
- No patents, no independent customers, product not ready for mass market
- A barn, some energy, belief*, experience[†]
 - 1 Partner VLSI Technology
 - 1 OS Acorn RISCOS
 - Some SW development tools



*“We’re going to be the global standard” – [†]Robin Saxby

ARM Founders:

1990

2007

Four Hardware guys:

- | | | |
|---------------|--------------------------------|---------------------------------|
| ■ Tudor Brown | - Lead Video & Memory Designer | - ARM COO & Director |
| ■ Mike Muller | - Leading systems architect | - ARM CTO & Director |
| ■ Pete Harrod | - Floating point guru | - ARM Consultant Engineer (CPU) |
| ■ Al Thomas | - Architecture Guru | - Deceased (1993) |

Four VLSI guys:

- | | | |
|------------------|------------------------|----------------------------------|
| ■ Jamie Urquhart | - Head VLSI design | - Venture Capital Partner / NED |
| ■ Harry Oldham | - Senior VLSI Designer | - ARM Fellow (Retired 2007) |
| ■ Dave Howard | - VLSI Designer | - ARM Consultant Engineer (VLSI) |
| ■ John Biggs | - VLSI Designer | - ARM Consultant Engineer (R&D) |

Four Software guys:

- | | | |
|------------------|---------------------------|------------------------------------|
| ■ Lee Smith | - Lead Software Tools | - ARM Fellow (Development Systems) |
| ■ David Seal | - Algorithm Designer | - ARM Fellow (R&D) |
| ■ Harry Meekings | - C Compiler Guru | - Retired (2002) |
| ■ Andy Merritt | - Software Tools Engineer | - Voluntary worker (2001) |

And last but not least - one “Damaging Director”:

- | | | |
|---------------|----------------|-----------------|
| ■ Robin Saxby | - Founding CEO | - President IET |
|---------------|----------------|-----------------|



Labour pains on exiting Acorn ...

- Twelve men in a leaky lifeboat at the start of a recession ...
 - We didn't know one another very well or we didn't much like one another ...
- *No commercial experience between us, other than Robin who hadn't yet started and whom the team had met but once!*
- *Little management experience and no grand vision to bind us (the "global standard" aspiration was articulated later)*
- *No national or international 'stars'*
- Our mood ranged from fearful (a recession was visible) to elated (we left Acorn and got jobs without writing CVs!)
- *So I watched, and being a nerd, measured ...*
 - Collected timesheet data
 - Analysed it, then Tudor* and I worried (a lot!)

* Tudor Brown, currently ARM's Chief Operating Officer

Our problem (in December 1990)

- We were averaging 39 hours per person-week ...
- Unfortunately, only 7.5 hours was productive ...
- And only 5 hours hit the ARM600 project ...
- Tudor* estimated that delivering ARM600 to Apple in July 1991 would need 25 project-hours per person-week (63%† of company time on the project)

- Oh dear ...

* Tudor Brown, currently ARM's Chief Operating Officer

† Today, about 60% of ARM employees are engineers and about 80% of their time is project time, so we achieve about 50%. We have to compensate for higher overheads with better tools, training, process, and so on.

Our solution (in January 1991)

- Wednesday 2nd January 1991 (IIRC) we held a whole company meeting (in a tiny room!) ...
- “*We will all lose our jobs in exactly 7 months ... unless ...*”
 - I revealed the shocking truth and promised weekly updates ...
- By mid-March the hand-drawn 3-colour graph showed
 - Hours per person week: 39 → 41
 - Productive hours per person week: 7.5 → 35+
 - Project hours per person week: 5 → 30+
- The following are very powerful
 - Gentle persuasion 😊
 - Accurate feedback about *team* performance
 - A common plight with collective responsibility for it
- But, unrealistic targets don't work and ultimately de-motivate
 - “Target 2000” (1400-1750 would be more realistic)

In retrospect ...

- The armed forces routinely solve the same problem
 - They take raw recruits in who
 - Don't know one another
 - Don't like one another
 - Don't know anything useful ...
 - And they put soldiers/sailors/etc out who are
 - Highly motivated
 - Able to form world class teams
 - Prepared to die for their friends and colleagues
- Businesses can (and must) solve this motivational problem
 - Often with appropriate training, much of it on the job
 - Training is not just acquiring knowledge!

Back to business

(ARM's initial business, that is ...)

Your mission, should you choose to accept it

Mission

Design competitive, low power consumption, high performance, low cost processors which become the accepted standard in the market they address.

In support of this mission ARM Ltd will develop peripheral cell designs, software, and software tools and provide a design service to third parties.

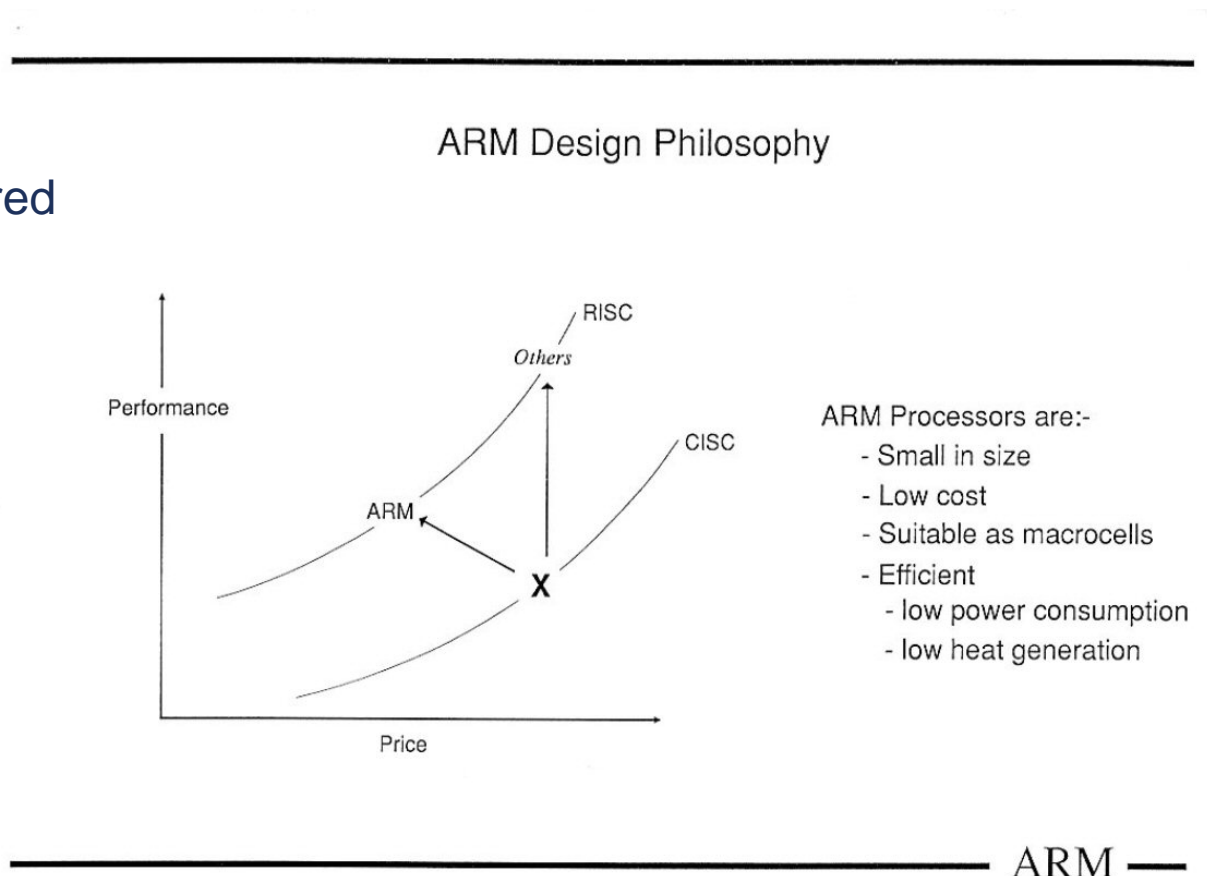
Our design philosophy

- Note the genius of this depiction of *ARM Design Philosophy*

- In one simple picture it explained how ARM differed from all of its actual and potential rivals

- The picture is almost as cogent today, in 2008

(Even though it is no longer about CISC vs RISC)



Robin's approach

- Robin was advised:
 - “Joint ventures don't work”
- SWOT Analysis
 - 5 yr Strategy
 - 1yr operation plan,
 - Monthly reporting
- Mean & lean “Cash is King”
 - Tight cost control – pay freezes '92
 - Profitable, generating cash since '93
- Customer focussed
 - *Partnership model*
 - First USA, Europe then Japan
- Think Global, act local!
- *Everything in proportion*

ARM LTD SWOT 18.12.90 CONFIDENT

STRENGTHS:	
Basic Technology:	low power low cost (component & system) simple small
Established Team:	flexible responsive dynamic successful (so far) enthusiastic extensive systems experience
WEAKNESSES:	
Poor Commercial Starting Point:	market share market profile revenue marketing expertise
Limited Resources	
Third Party Support :	ICE / logic analyser cross compiler HDL technical support
Characterisation & Test	
Reliance upon Foundry	
OPPORTUNITIES:	
Emerging Markets (applications)	portables embedded control automotive rad-hard
(places)	: Japan / Far East Europe OMI / ESA
Partnerships:	Silicon Manufacturers Silicon Users Silicon Distributors
Apple	
Consultancy	
THREATS:	
Big Rivals	
Patents	own none.
Small team - reliance upon individuals	
Existing Commitments - yielding low revenue	
Single Customer at present	
No Control over Income	

The next slide shows this SWOT more clearly

Critical Success Factors then

- Cost control - don't run out of cash
- Get customers of any type - all customers are better than nothing
- **Be global from the start** - *UK is not going to support a business like this*
- Be totally responsive to customer demands and visit the customer as required
- Excellent focus on delivery
- Great product - all aspects
- Product potential
- Robin's network
- **Partnership model**
- Small team, simple design
- Serendipity

This remains cogent today!

ARM Limited SWOT 18.12.90

<p><u>Strength</u></p> <p>Technology</p> <ul style="list-style-type: none"> •Low Power •Low Cost •Simple •Small 		<p>Team</p> <ul style="list-style-type: none"> •Flexible •Responsive •Dynamic •Successful •Enthusiastic •Extensive systems expertise 		<p><u>Weakness</u></p> <p>Poor Start Point</p> <ul style="list-style-type: none"> •Market share •Market Profile •Revenue •Marketing expertise 		<p>Resources</p> <ul style="list-style-type: none"> •Limited Resources •Lack of third party development tool support •Characterisation/test •Reliance on foundry manufacturing 	
<p><u>Opportunities</u></p> <p>Markets</p> <ul style="list-style-type: none"> •Portables •Embedded Control •Automotive •Radiation Hard 		<p>Places and partnerships</p> <ul style="list-style-type: none"> •Japan/Far East •Europe OMI •Silicon manufacturers •Silicon Users •Silicon Distributors •Apple •Consultancy 		<p><u>Threats</u></p> <ul style="list-style-type: none"> •Big Rivals •Own No Patents •Small team relying on individuals •Existing Commitments yielding low revenues •Single customer at present •No control over income 			

Source : Robin Saxby

The partnership model

- Persuade apparently competing parties to cooperate
 - “Coopetition” shares costs
 - ARM’s initial licences carefully segmented by ARM
 - By 1997 a Samsung executive addressed the ARM Partner Meeting *“Together we are stronger ...”*
- Multiply ARM’s effort in a highly geared way
 - When ARM had 150 employees there were more than 1500 people working in ARM partners on ARM technology and products
 - 10:1 gearing
- ARM had/has an evangelical or catalytic role

Lessons I learned from ARM ...

- For a (high risk) start-up cash really is king
 - Spend the capital and the company will die
 - Raising more during a global recession will be *very* hard
 - Cash is more important than efficiency
- When a business grows organically very quickly (60% p.a.)
 - It's more important to take opportunity *NOW* than to invest in long-term efficiency ...it's worth 1.6x in a year, 2.5x in 2 yrs, 6x in 4 yrs ...
 - In effect you discount the future at the rate of growth
- When the growth slows down ...
 - Must become more efficient, must invest in the long term
 - Inefficiency will kill you in the long run
- I speculate that when growth is very low and a business is very established ...
 - Only efficiency matters, eclipsing all other concerns even cash

And more lessons from Robin ...

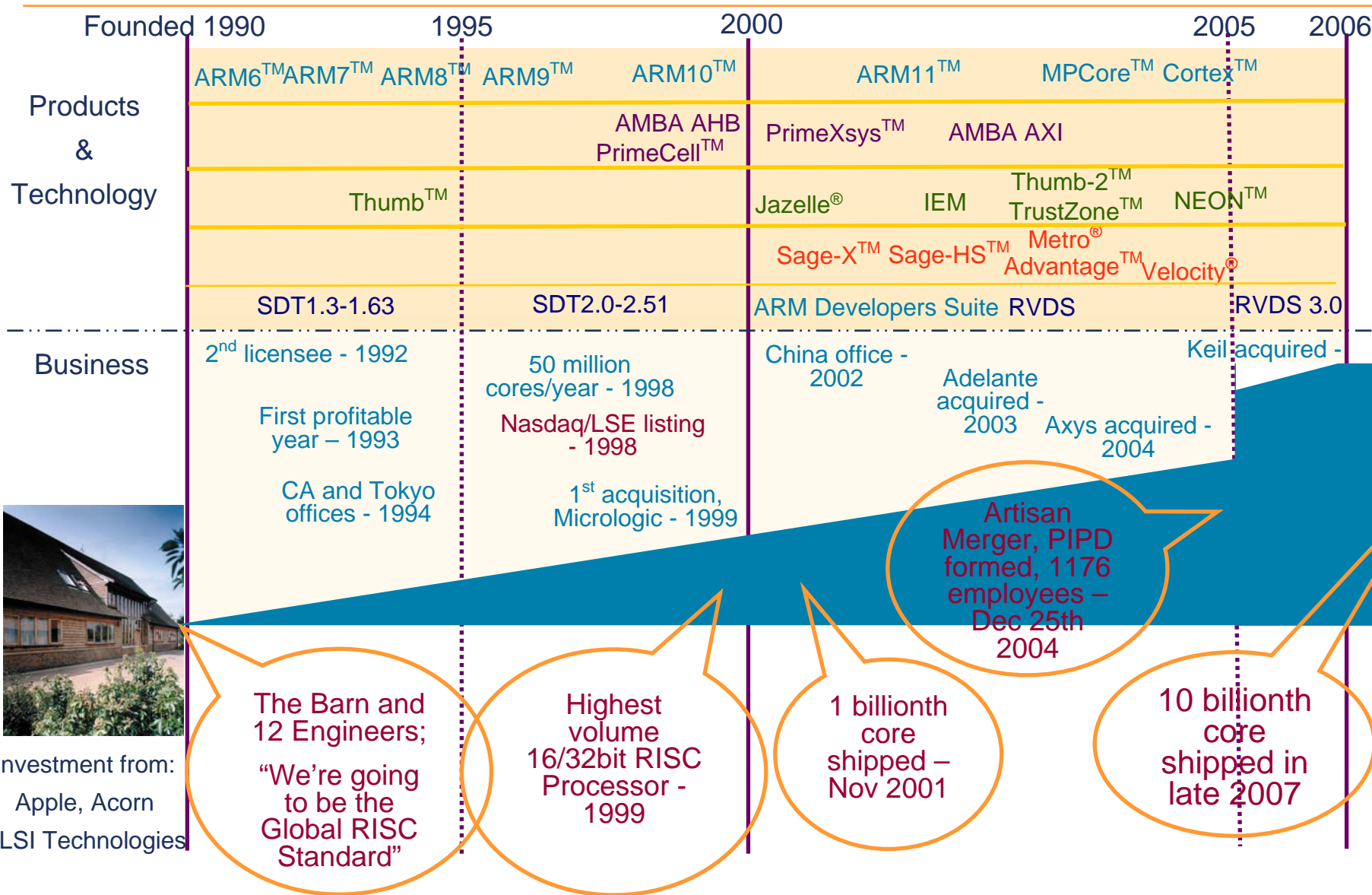
- Keep process and bureaucracy in proportion
 - Unfortunately, you need process *and* bureaucracy
- Saxby's Law (circa 1992), re-stated by Smith
 - Spending *any money* needs justification
 - Spending £10K needs 1 A4 page of justification (approx 600 words)
 - So spending £100 needs 6 words of justification ☺
- Be customer-driven, but not literally
 - Some customers represent whole markets or segments
 - E.g. Nokia 'represents' mobile phones, Bosch 'represents' automotive control, (neither uniquely), etc, etc.
 - Listen to as many representative customers as you can find
 - Ignore or aggregate the views of unrepresentative customers (unless you want to make a business of consultancy!)

The infamous “ARM Barn”



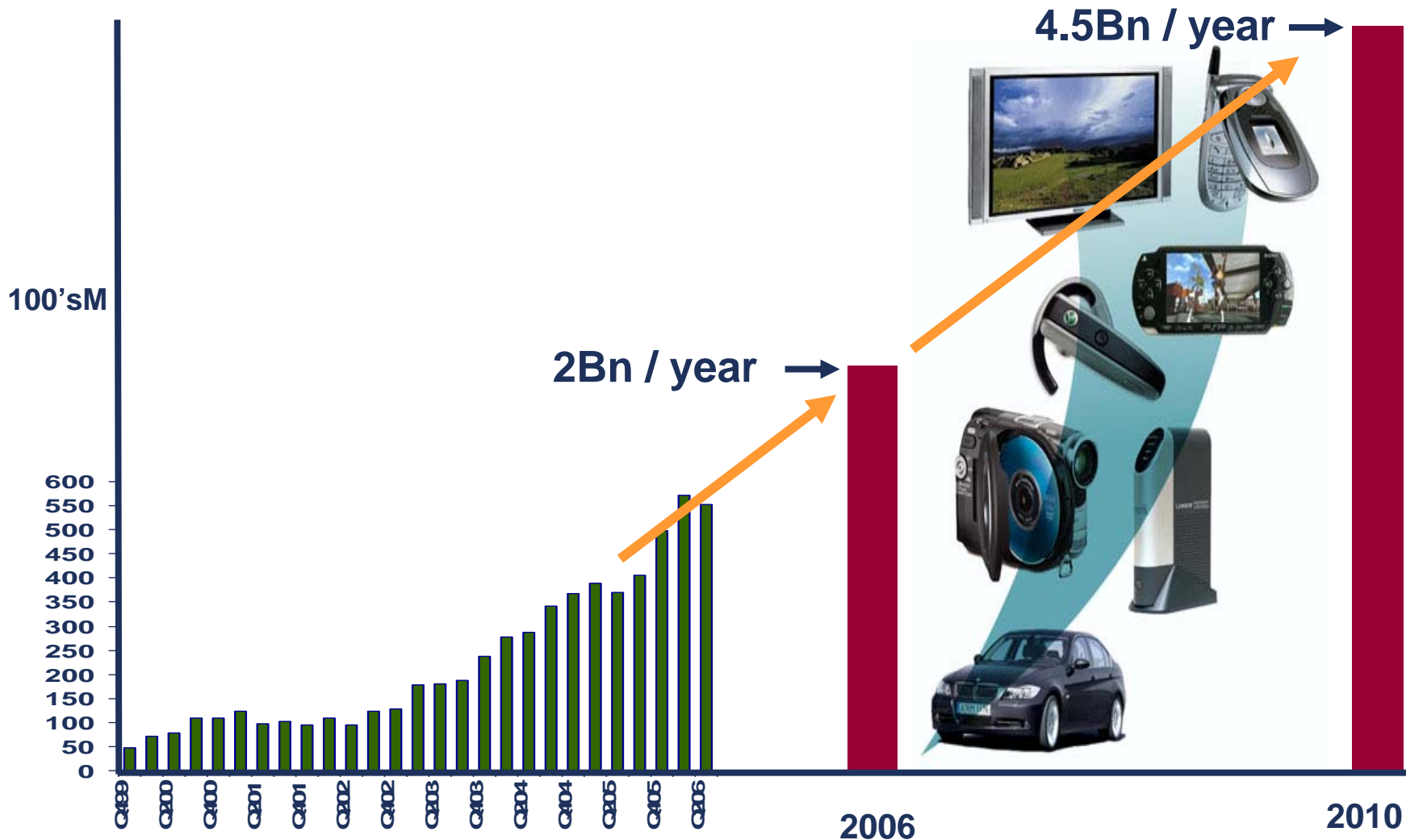
ARM Ltd. headquarters

Some milestones



Unbelievable volumes: 4.5Bn units p.a. by 2010?

69 partners shipping (out of 184) at end H2 06



For comparison: Critical Success Factors now

- Industry growth
- Ability/credibility of the Board and Divisional Management
- Raising barrier for new entrants
 - Global reach
 - Increasing Investment in R&D
 - Strengthening Patent portfolio
 - Driving Industry standards
 - ARM brand awareness: Magazines, press releases, Trade shows etc.
- Increasing switching costs
 - Large pool of engineers qualified in the ARM architecture
 - Complete product offering: software to cell libraries
 - Commercial relationships
- Product differentiation by segment
- Technical innovation and quality
- The people: smart, flexible and hard working!

Back to the past

(To some times when there was nearly no future
to go back to ...)

Adolescent growing pains (1994-1997)

- In March 1994 ARM moved to Fulbourn Road (“Waterworks”)
 - Headcount increased from 42 to 70+ in 6 months, more than doubled in under a year, and some chaos followed
 - Projects had begun to fail, customers expected (much) more
 - The barn ethos of self help and self support broke down
 - Many recruits from more corporate environments could not work effectively unsupported
 - The proportion of project time declined, overheads increased
 - Too many voices competed for (management) attention
 - Icarus syndrome ... (fly too high and the wax melts ...)
- ARM worked through these problems, but not without lots of stress and some ‘blood on the carpet’
 - An unhappy time for me personally
 - A required transition from 50 employees to 350 (c.f. Hopper’s *Law of 7*)
 - A dangerous stage for growing businesses – too big for informal control, too small for big business processes

From IPO to redundancies (1998-2002)

- For me personally a technically exciting time, largely insulated from corporate ARM
 - Chief architect of the ARM Developer Suite, a landmark product and a precursor for *RealView* tools
 - Physically located in Bateman Street, a very pleasant overflow site (until site consolidation in 2001)
- I began to perceive the end of 60% organic growth
 - Revenue growth had dropped to 45% in 2001 (just 3% in 2002)
 - This raises technical as well as business challenges
- The redundancies shattered our sense of invulnerability
 - C.f. soldiers when they first lose colleagues in battle ...
- But, in time, we emerged stronger and more mature

Middle aged maturity (2003 – now)

The median lifespan of a company is not much
more than 30 years

ARM is now 17 years old
(10 years as a quoted plc)

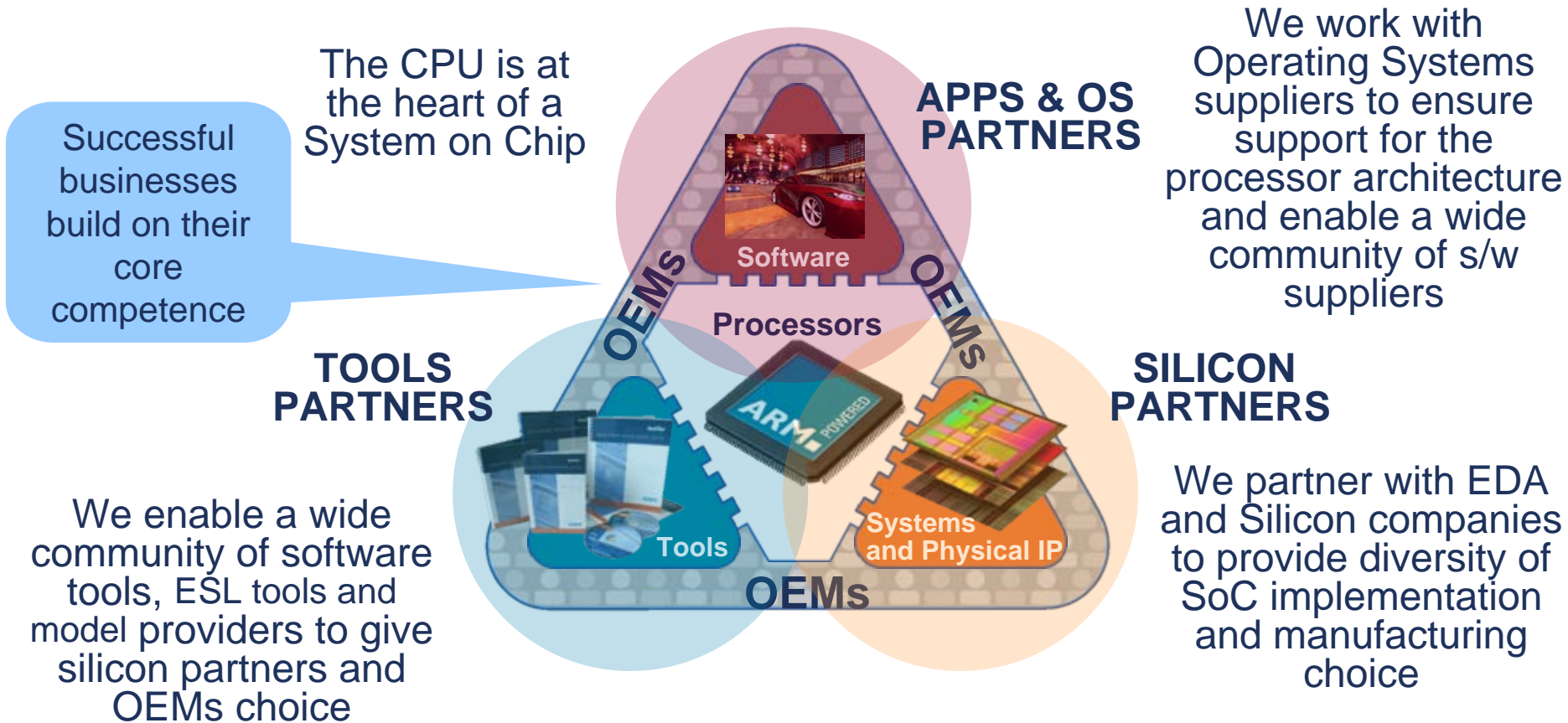
...

Critical Success Factors - now

- Industry growth
- Ability/credibility of the Board and Divisional Management
- Raising barriers against new competitors
 - Global reach
 - Increasing Investment in R&D
 - Strengthening Patent portfolio
 - Driving Industry standards
 - ARM brand awareness: Magazines, press releases, Trade shows etc.
- Increasing switching costs
 - Large pool of engineers qualified in the ARM architecture
 - Complete product offering: software to cell libraries
 - Commercial relationships
- Product differentiation by segment
- Technical innovation and quality
- **Last, but not least, our people:** smart, flexible and hard working!

Strategy

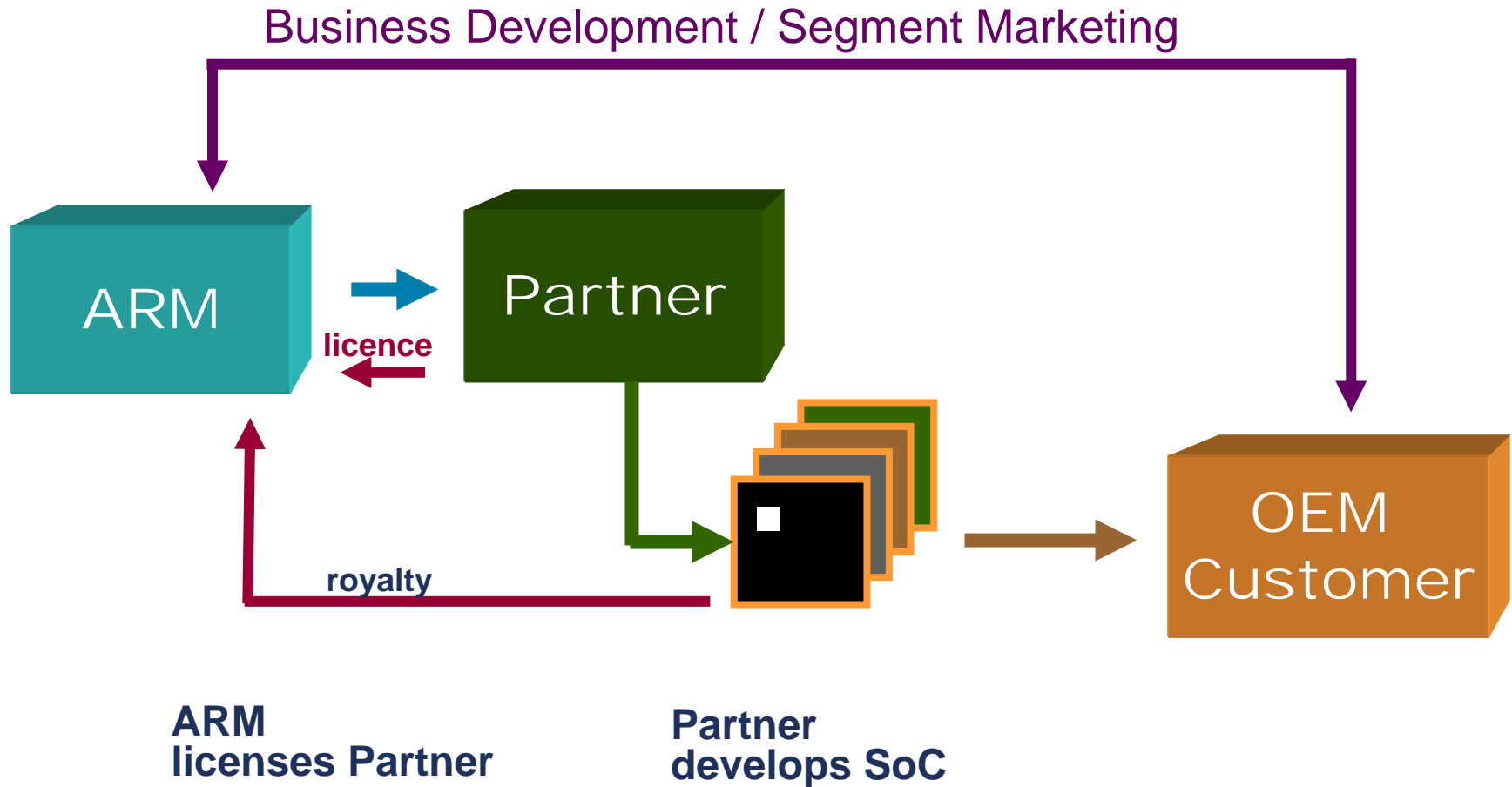
Our strategy is to create a partnership with our customers and broader community of third parties, to enable the creation of end products more efficiently through ARM than from any other source



On Marketing and Communications ...

- We have way better slide-ware now than in the early days
 - Compare the previous [Strategy](#) slide with the earlier [ARM design philosophy](#)
- But which do you find more compelling?
 - I'm not so sure ...

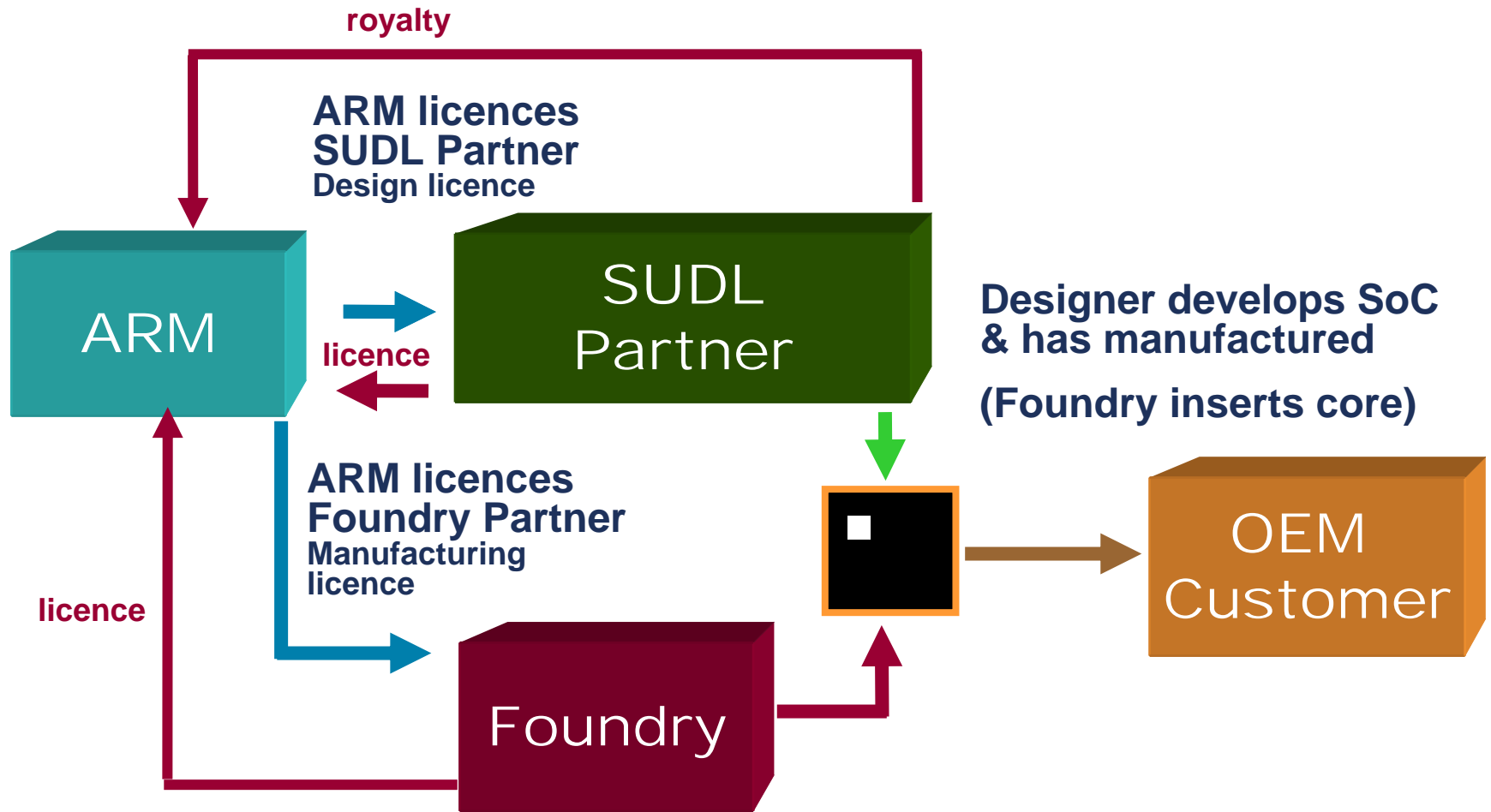
Core Business Model



Licence fee covers proportion of development costs

Royalty shares by rewarding success.

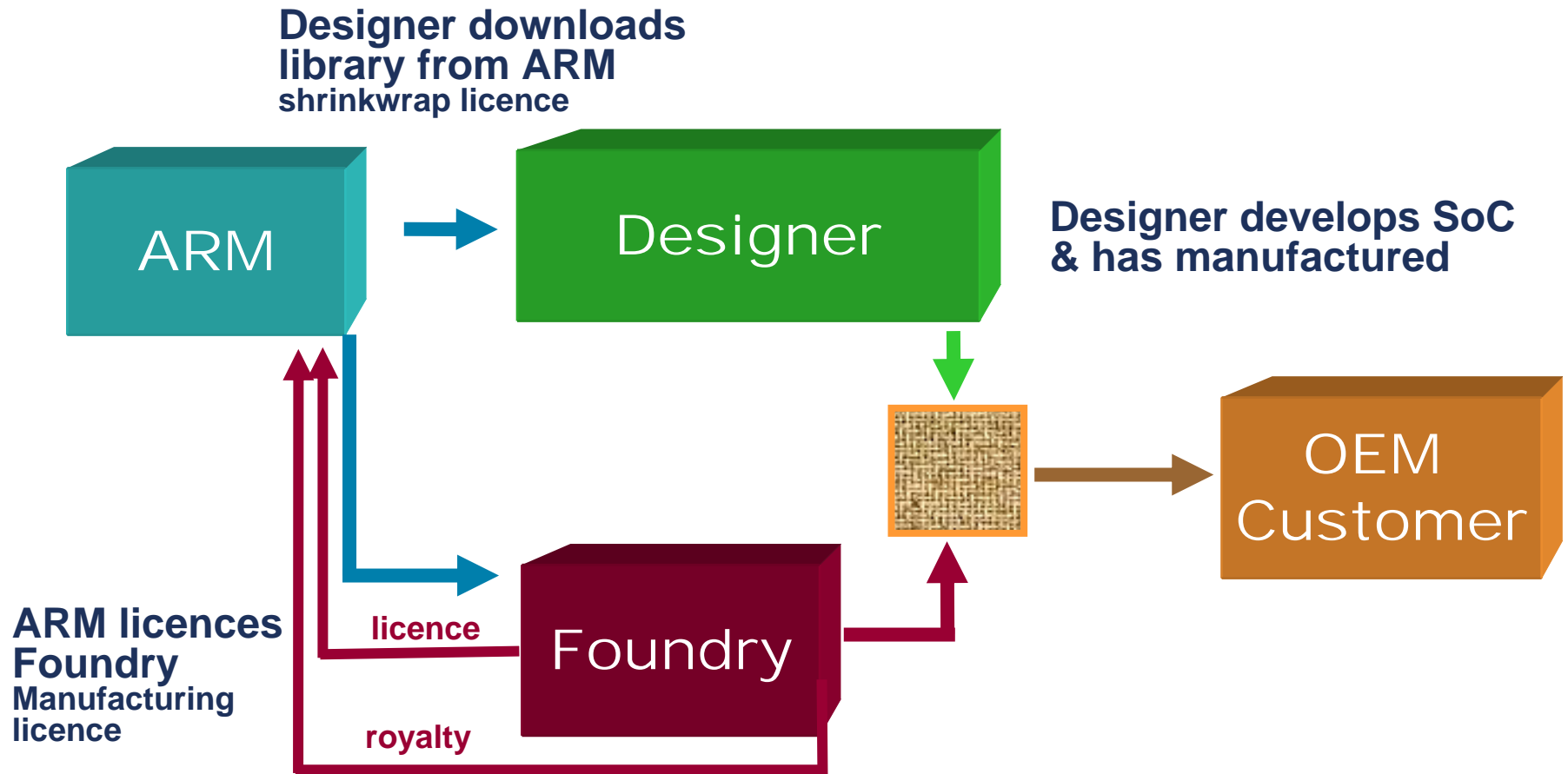
Core Foundry Business Model



Licence fee covers proportion of development costs

Royalty shares reward success.

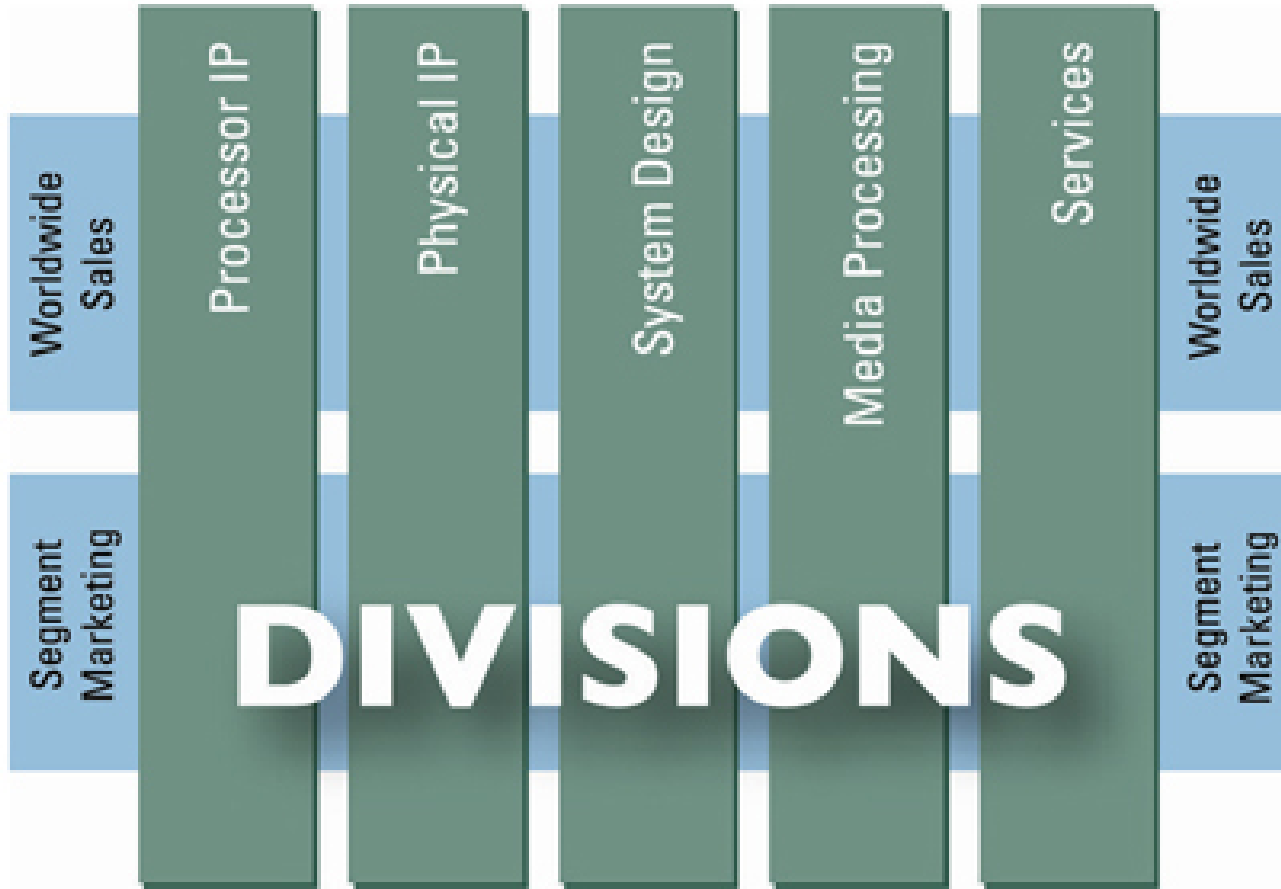
Physical IP Foundry Business Model



Licence fee covers proportion of development costs

Royalty share rewards success.

Organisation (always fluid ...)



Specialist Divisions to provide best in class Products

Corporate customer interfaces for high levels of customer satisfaction.

On organization

- ‘Organization’ (and re-organization) troubled the Roman Army
- It still troubles business today
- It is never better than an approximation to what is needed
 - And there is never a uniquely best solution
- It is inevitably complex

- However, it has a very simple goal: *make it easy for customers to buy stuff from you!*

- Customers **must** be protected from organizational complexity
 - They should see one simple, uniform, efficient, long-lasting interface
 - C.f. one-stop shopping, one click ordering, etc
 - Ignore this at your peril!

Ongoing challenges

(Back to the future, part II)

Business development

■ Internal

- Integrating acquisitions and achieving revenue synergies
- Optimising the organisation structure and evolving the culture
- Producing complete, on-time solutions to Customer problems
- Increasing cost of testing
- Hiring ARM-shaped people

■ External

- Fast moving industry
- Competitors eroding price and targeting niche markets
- Increasing ARM's presence outside Wireless
- Not competing directly with partners
- Compliance with new legislation like the Sarbanes-Oxley act
- Accidental patent infringement
- Consolidation reducing licensing opportunities

- *What will be the next breakthrough innovation?*

IP Protection

- Patents

- 20-year duration
- Based on importance, filed in US; US, UK and Japan or 17 countries

- Confidentiality, Trademarks

- Contract Sections

Definitions, License, Delivery, Fees, Support and Maintenance, Confidentiality, IP Warranties and Indemnity, Warranties, Limitation of Liability, Term and Termination, Effect of Termination, General

- Constrained to ARM compliant cores

- Watermarking

- Dealing with infringement

- Security at Design Centres

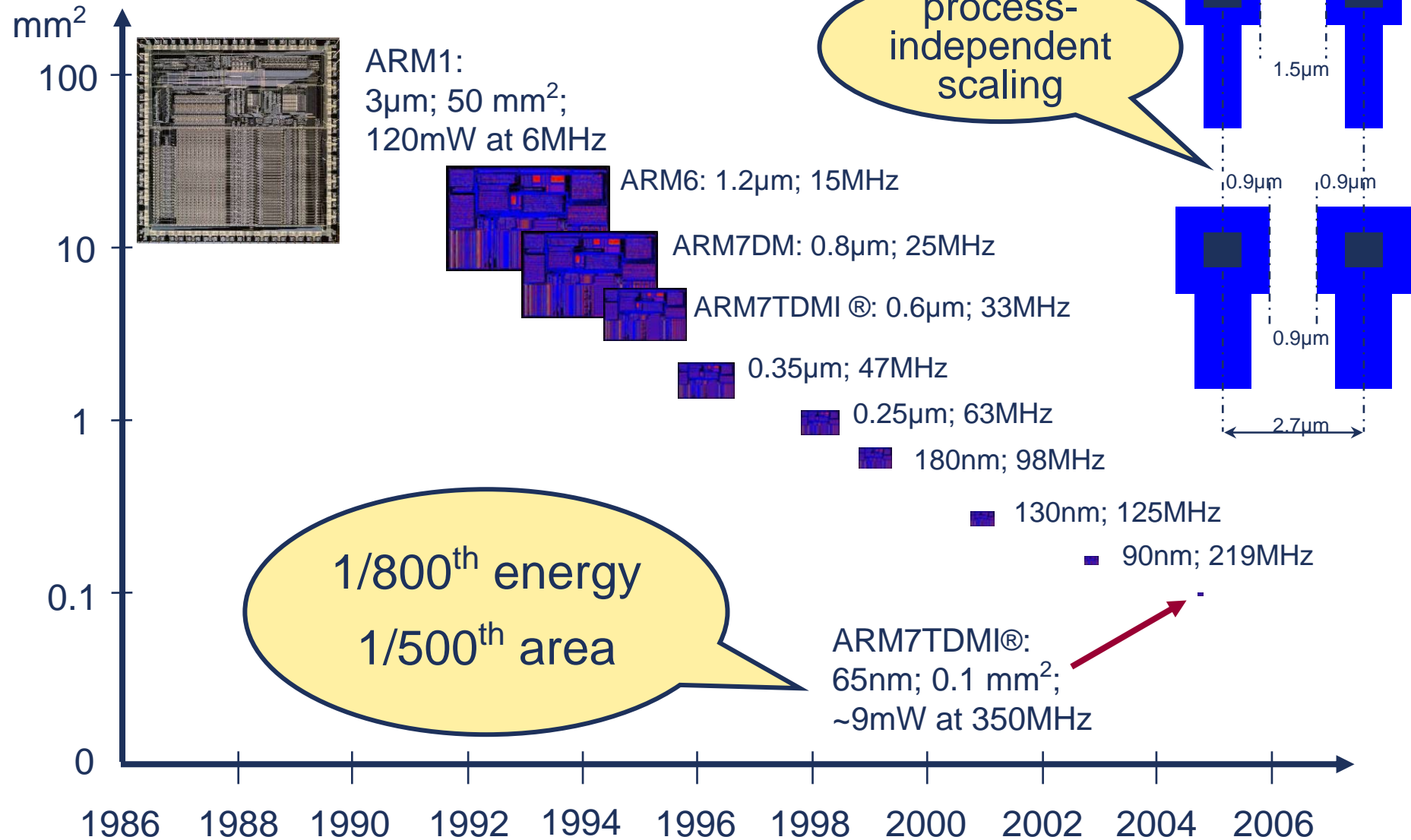
Facts and Figures

- People: 1728 (at end of 2007)
- Patents: 700 (900 pending), representing 627 inventions (early 2006)
- Offices: 31 (early 2008)
- Partners: ~200 (early 2008)
- Connected Community: several hundred
- 2008 Cumulative ARM compliant cores shipped: > 10Bn
- 2007 Cores in Mobile ~2Bn, ~1Bn non-Mobile
- 2007 Revenue: £260M, \$514M
(32% PD licence, 34% PD royalty, 17% PIPD, 17% Tools and services)
- 2007 Operating Margin: >30%
- 2007 EPS: 2.7p

Some reflections on changing scale

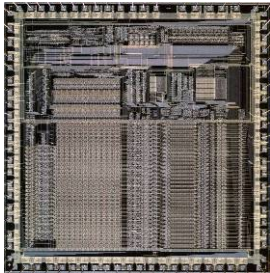
(It's all a bit *Alice in Wonderland*)

Scaling the ARM (a)way

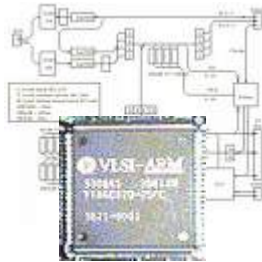


But faster and faster ...

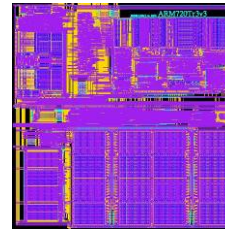
The 80s and 90s:



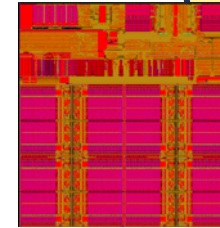
1985 – ARM1
50mm²;
4MHz; 3μm



1988 – ARM3
12MHz; 1.2μm



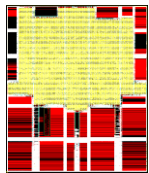
1994 – ARM710
33MHz; 0.6μm



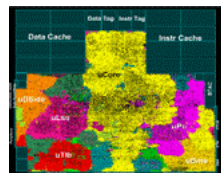
1999 – ARM920T
140MHz; 0.25μm

600x
performance,
4.5mm² core

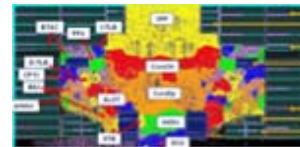
The new millennium:



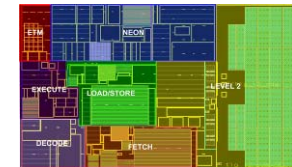
2001 – ARM926EJ-S
200MHz; 180nm
200 DMIPS



2004 – ARM1176JZ-S
400MHz; 130nm
480 DMIPS



2005 – ARM MPCore (2 way)
620MHz; 90nm
1,488 DMIPS



2006 – ARM Cortex A8
1GHz; 65nm
2,000 DMIPS

APM 1991: 9 Attendees



APM 2004: 350 Attendees



DevCon 2006: 2200 attendees!





Thousands of Physical IP Users