*Proseminar 18.059*

# *Entwurf von HW/SW-Systemen*

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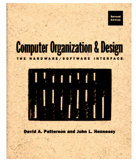
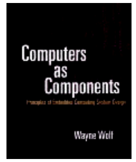
tech-www.informatik.uni-hamburg.de/lehre/ss2002/hwsw-entwurf



## *Literatur:*




D.A.Patterson & J.L.Hennessy:
computer organization & design, the hardware/software interface
Morgan Kaufmann, 1998 (2nd Ed.), 1-55860-491-X

W. Wolf, Computers as components,
Morgan Kaufmann, 2001, 1.55860-693-9

S. Furber: ARM system-on-chip architecture
Addison Wesley, 0-201-67519-6

Skripte T1/T2/T3/T4
GNU Dokumentation: gcc.gnu.org bzw. www.redhat.com/embedded
Datenbücher, z.B. developer.intel.com, www.amd.com, www.motorola.com
Palm OS Emulator, ...



## *Themen, Termine*

| | | |
|---|---|---|
| | 04.04 | Vorbesprechung, Vergabe der Referate |
| 1 | 11.04 | Performance / Benchmarking |
| 2 | 18.04 | Mikroprozessoren |
| 3 | 25.04 | ARM-Architektur |
| 4 | 02.05 | HW/SW-Interface, Beispiel embedded Java |
| 5 | 09.05 | Crosscompiler, Software für embedded systems |
| 6 | 16.05 | System on a Chip Trends |
| 7 | 23.05 | (fällt aus) |
| 8 | 30.05 | Systemsimulation: Palm OS Emulator / xcopilot |
| 9 | 13.06 | Emulation: FPGA, Excalibur |
| 10 | 20.06 | Medien- und Signalprozessoren |
| 11 | 27.06 | Chipkarten, Smart Cards |
| 12 | 04.07 | Mikrosysteme, Beispiel smart dust |
| 13 | 13.07 | (Reservetermin) |



## *Proseminar: mehrere Lernziele*

Inhalt / Thema des Proseminars (33%)

- Mikroprozessoren und -Trends
- Systementwurf - SW für eingebettete Systeme

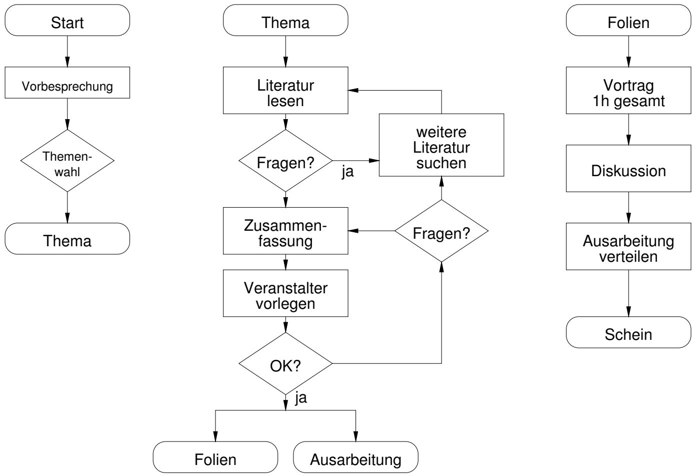
Thema erarbeiten: (33%)

- Literatur lesen und verstehen (englisch!)
- weitere Literatur suchen und sichten
- umfangreiches Thema zusammenfassen
- Folien und Ausarbeitung erstellen
- dabei selbständiges Arbeiten, evtl. Gruppenarbeit

Vortrag: (33%)

- Vortrag halten, Lampenfieber überwinden
- Diskussion

# *Proseminar-Algorithmus*






# *Vorführungen, Beamer:*

Beamer für Powerpoint & Co:

- im Prinzip möglich
- B201, F334: fest installiert, sonst im RZ anmelden
- rechtzeitig (zwei Wochen vorher) beim Betreuer anfragen
- lohnt für Animationen, Programmdemos, Medienwiedergabe

- ca. 30 Min fürs Aufbauen und Fehlerteufel einplanen
- eigenes Notebook mitbringen

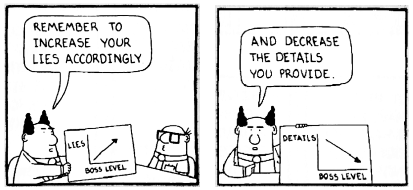
- PC und Macintosh unterstützt
- Beamer verfügen über (mono) Lautsprecher

- Ausarbeitung in jedem Fall notwendig



# *Vortrag:*

- Tafel und Kreide
- Overhead-Folien
- Powerpoint & Co




Faustregeln:

- 2 .. 3 Minuten pro Folie
  => etwa 20 .. 30 Folien / Stunde Vortrag
- grosse Schrift (>20pt), Querformat
- nicht nur Schlagworte ("Powerpoint-Syndrom")
- sondern möglichst viele Diagramme / Abbildungen
- Backup-Folien bereithalten: Details zu erwarteten Fragen

20 pt
15 pt
12 pt
10 pt
8 pt



# *Ausarbeitung:*

wissenschaftliches Schreiben üben:

- als Text ausformulieren
- mit Gliederung und Literaturhinweisen
- Unfang ca. 4-8 Seiten
- möglichst schon beim Vortrag verteilen
- portable Dateiformate:

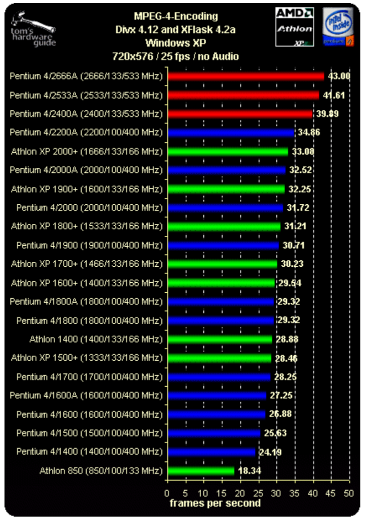
  HTML, PDF, Postscript (Druckertreiber: Apple Laserwriter II)
  aber: keine "write-only" Formate wie Word
- einfache Folienkopien nur im (begründeten) Notfall
- Literaturliste der FB18-Bibliothek:
  "Studieren Lernen Arbeiten"

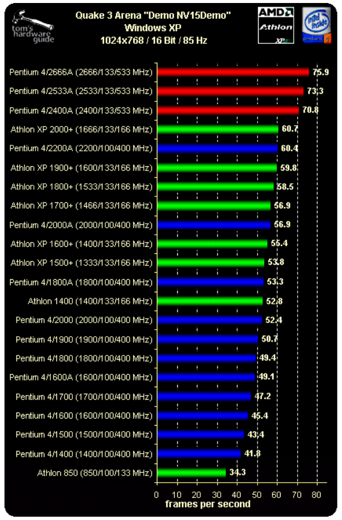
# *Mikroprozessoren:*

- riesige Vielfalt von Prozessoren
- zumehmend Spezial-µPs
- Universalprozessoren
  - so schnell wie möglich:
    PC, Workstations — Pentium, Athlon, ...
    Server — Alpha, S/390 G6, Itanium, ...
  - so schnell wie nötig:
    eingebettete Systeme — ARM, MIPS, 68k, ...
    low power — ..., Crusoe, ...
- Medienverarbeitung (DVD, MP3) — MMX, TriMedia, MAJC, ...
- Signalprozessoren (Modem, Handy) — DSP56K, ...
- 4/8/16-bit Microcontroller — 8051, PIC, 68332, ...



# *Benchmarks: DivX / Quake*






# *Mikroprozessoren: Performance 03/2001*

| SPEC CPU2000 Benchmarks (baseline): | SPECint | SPECfp |
|---|---|---|
| AMD Athlon 1.2 GHz | 443 | 387 |
| Intel Pentium-III 1.0 GHz (VC820) | 407 | 284 |
| Intel Pentium-IV 1.5 GHz (VC850) | 524 | 549 |
| Compaq Alphaserver 833 MHz | 518 | 590 |
| HP 9000 j6000 | 417 | 433 |
| Sun Blade 900 MHz | 438 | 482 |

- keine offiziellen Werte für PowerPC
- alle anderen RISC weit abgeschlagen

- Programme beanspruchen L1/L2-Cache + Hauptspeicher
- gleicher Speicher: sehr ähnliche Werte

(www.spec.org/osg/cpu2000, Stand 03/2001)



# *Mikroprozessoren: x86-Evolution ...*

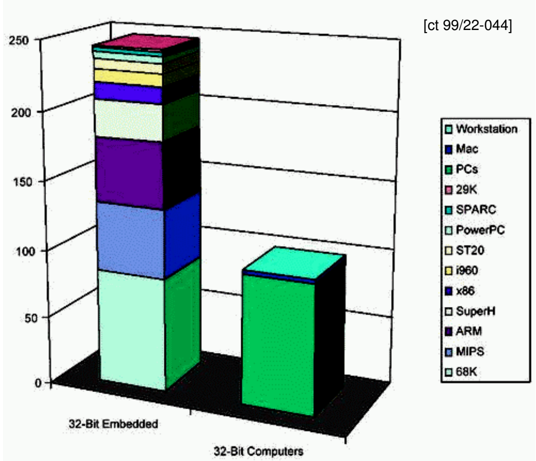
| Intel Processor | Date of Product Intro-duction | Perform-ance in MIPs[1] | Max. CPU Frequency at Intro-duction | No. of Transis-tors on the Die | Main CPU Register Size[2] | Extern. Data Bus Size[2] | Max. Extern. Addr. Space | Caches in CPU Pack-age[3] |
|---|---|---|---|---|---|---|---|---|
| 8086 | 1978 | 0.8 | 8 MHz | 29 K | 16 | 16 | 1 MB | None |
| Intel 286 | 1982 | 2.7 | 12.5 MHz | 134 K | 16 | 16 | 16 MB | Note 3 |
| Intel386™ DX | 1985 | 6.0 | 20 MHz | 275 K | 32 | 32 | 4 GB | Note 3 |
| Intel486™ DX | 1989 | 20 | 25 MHz | 1.2 M | 32 | 32 | 4 GB | 8KB L1 |
| Pentium® | 1993 | 100 | 60 MHz | 3.1 M | 32 | 64 | 4 GB | 16KB L1 |
| Pentium® Pro | 1995 | 440 | 200 MHz | 5.5 M | 32 | 64 | 64 GB | 16KB L1; 256KB or 512KB L2 |
| Pentium II® | 1997 | 466 | 266 | 7 M | 32 | 64 | 64 GB | 32KB L1; 256KB or 512KB L2 |
| Pentium® III | 1999 | 1000 | 500 | 8.2 M | 32 GP 128 SIMD-FP | 64 | 64 GB | 32KB L1; 512KB L2 |

(Intel Pentium-III databook)

## Mikroprozessoren: "embedded systems"



## Mikroprozessoren: 32-bit Markt '99




- pro Jahr (1999): 250 Mio. 32-bit µPs, plus ca. 100M in PCs
- zusätzlich ca. 5 Mrd. 4/8/16-bit Microcontroller



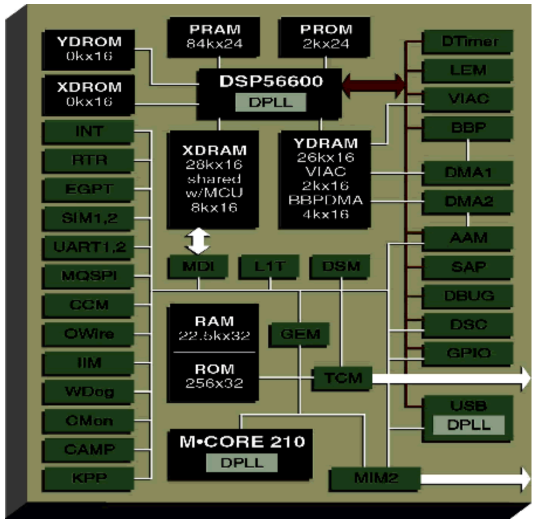
## Prozessoren in "embedded systems"

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Prozessor | 4 .. 32 bit | 8 bit | - | 16 .. 32 bit | 16 bit | 32 bit | 32 bit | 8 .. 64 bit | ..32 bit |
| Speicher | 1K .. 1M | < 8K | < 1K | 1 .. 64M | ? | < 128 M | 8 .. 64M | 1 K .. 10 M | < 64 M |
| ASICs | 1 uC | 1 uC | 1 ASIC | 1 uP ASIP | DSPs | 1 uP, 3 DSP | 1 uP, DSP | ~ 100 uC, uP, DSP | uP, ASIP |
| Netzwerk | cardIO | - | RS232 | diverse | GSM | MIDI | V.90 | CAN,... | I2C,... |
| Echtzeit | nein | nein | soft | soft | hard | soft | hard | hard | hard |
| Safety | keine | mittel | keine | gering | gering | gering | gering | hoch | hoch |

=> riesiges Spektrum: 4 bit .. 64 bit Prozessoren, DSPs, digitale/analoge ASICs, ...
=> Sensoren/Aktoren: Tasten, Displays, Druck, Temperatur, Antennen, CCD, ...
=> Echtzeit-, Sicherheits-, Zuverlässigkeitsanforderungen



## System on a Chip: Motorola DSP56690

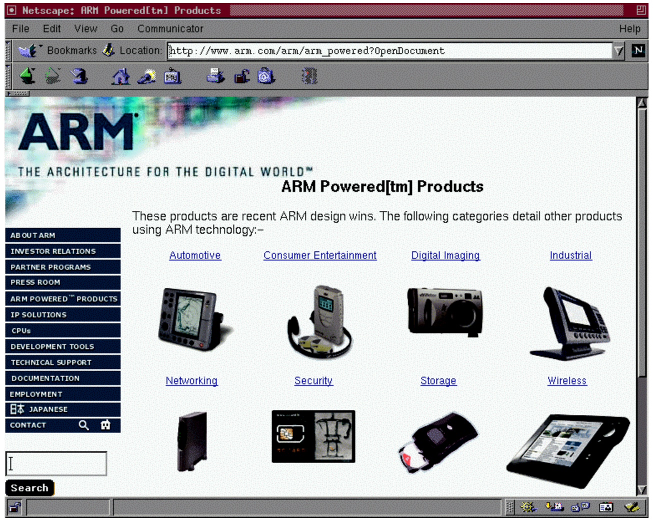



single-chip:

- 16-bit DSP
- 32-bit M*CORE
- RAM
- ROM
- diverse I/O

- low-power

## *ARM: aktuelle Produkte im März 2001*





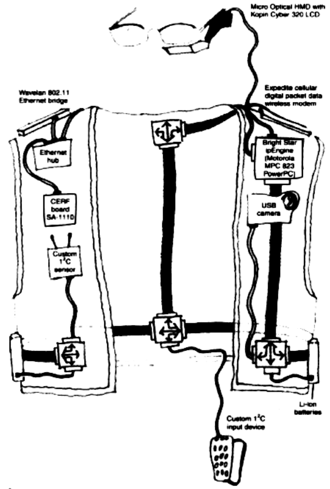

## *ARM*

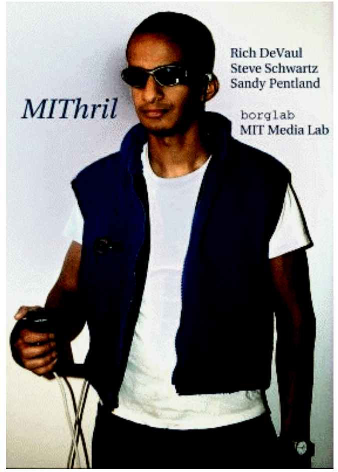
- Marktführer für 32-bit Mikroprozessoren / Mikrocontroller
- derzeit ca. 60% Marktanteil: vor MIPS (30%) und anderen
- einzige relavante europäische Prozessorfirma
  www.arm.com

| | |
|---|---|
| • "fabless" | keine eigenen Fabriken |
| • "IP" | Lizensierung der Prozessoren als "intellectual property" |
| • "cores" | fertige Designs für Integration in Chips |
| • "ARM" | 32-bit RISC, besonders einfacher Befehlssatz |
| • "Thumb" | kompakter Befehlssatz für minimale Codegröße |
| • "Jazelle" | neuartiger Java-Befehlssatz |
| • "AMBA" | einfaches aber effizientes on-chip Bussystem |



## *Wearable Computers: MIThril*

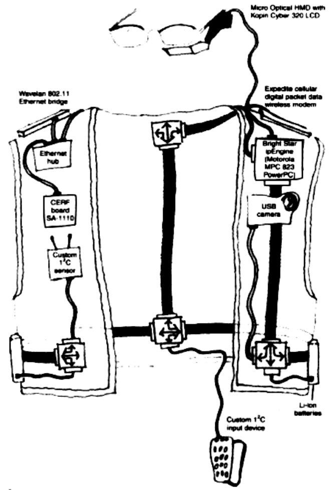





(IEEE Micro 06/2001, www.media.mit.edu/wearables/mithril)



## *MIThril: Komponenten*



StrongARM CPU, 206 MHz
mit Chipsatz (Intel SA1110/1111)
128 MByte DRAM
2 MB Flash, 1 GB Microdrive
TMS 320VC33 DSP

Schnittstellen:
"MicroOptical" Displaybrille
Mikrophon, Lautsprecher
2 Kameras, 256x256 Pixel
IrDA, Netzwerk, Modem, I2C
Tastatur in die Weste integriert
oder separat

(IEEE Micro 06/2001, www.media.mit.edu/wearables/mithril)

## Systementwurf

gutes Gesamtsystem erfordert:

- leistungsfähige Hardware und Software
- konkurrenzfähige Preise
- rechtzeitige Fertigstellung ("time to market")

- HW: zunehmend 32-bit Prozessoren plus ASICs
- SW: GUI, Echtzeit, Vernetzung, Sicherheit, ...

=> wichtige Aufgabe für die Informatik

- Entwurfsmethoden für eingebettete Systeme
- HW/SW-Codesign

- "system on a chip" Entwurfsmethoden
- Systemsimulation / Emulation



## Systementwurf: Entwurfsvorgehen

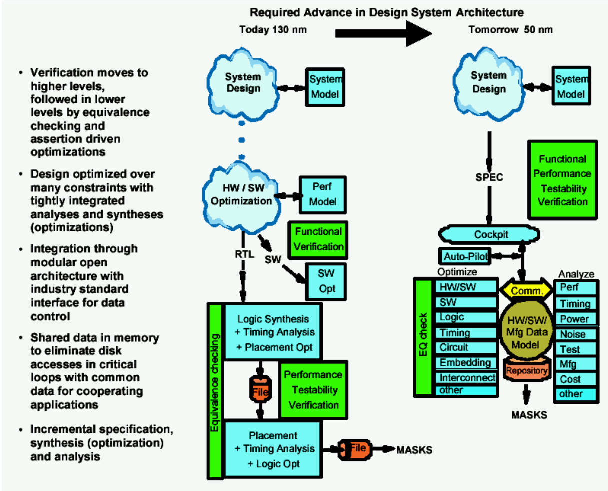



*Figure 16 Required Evolution of Design System Architecture.*



## Systementwurf: "Total Design Cost"

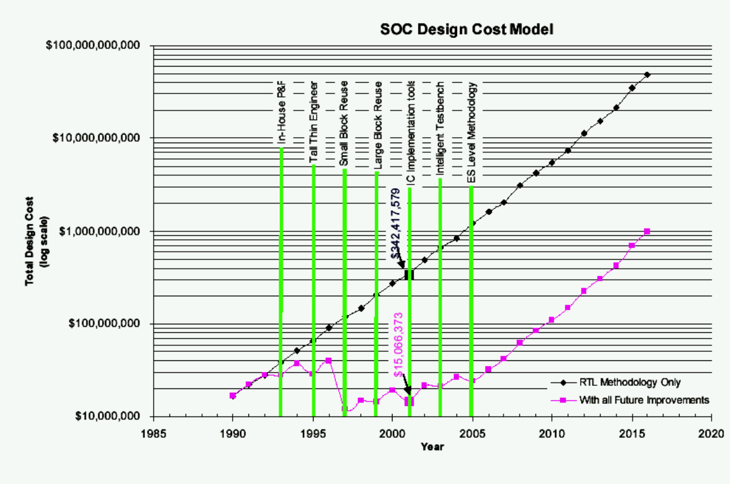
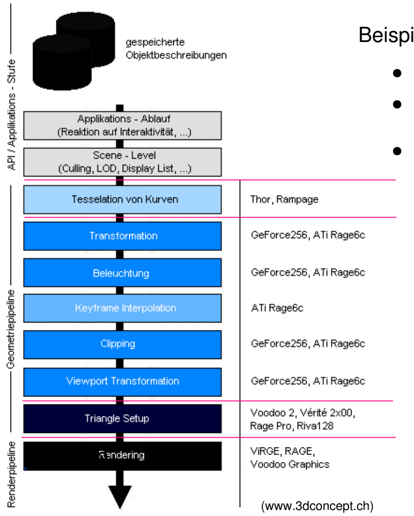



*Figure 15 Impact of Design Technology on System Implementation Cost.*

(ITRS Roadamp 2001)



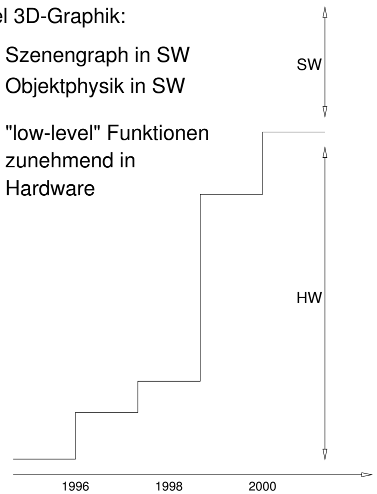
## Systementwurf: Hardware vs. Software




Beispiel 3D-Graphik:

- Szenengraph in SW
- Objektphysik in SW

- "low-level" Funktionen zunehmend in Hardware



## *Systementwurf: Cross-Compiler*

Softwareentwicklung für "eingebettete Systeme":

- Zielsystem "zu klein" für Entwicklungsumgebung
- keine geeignete Peripherie

=> Entwicklung auf PC / Workstation

- gewohnte Umgebung mit GUI, Editor, Compiler, Tools, ...
- Coderstellung mit Cross-Compiler

- Simulation eines Systemmodells
- Emulation mit FPGA-Prototypen
- schließlich Test an echten Prototypen



## *Systementwurf: Co-Simulation*

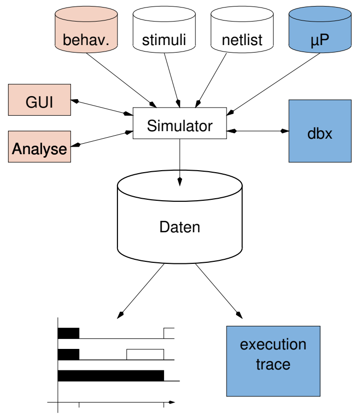
System-Simulation mit Prozessormodellen:

- Verhaltensmodelle
- Strukturmodelle
- Modelle der Systemumgebung
- Prozessormodelle mit Speicher

- statische und prozedurale Stimuli
- embedded Software
- interaktiv oder batch-mode

- Analyse direkt oder post-mortem
- inklusive Software-Debugger

- für komplexe Aufgaben erforderlich
- extreme Datenmengen






## *Softwareentwicklung: Beispiel POSE*


Geräte "zu klein" für Compiler&Tools
externe Softwareentwicklung

- Cross-Compiler
- System-Simulation
- Emulation, inkl. GUI und OS
- Remote-Debugging

http://www.palmos.com/dev/tech/tools/emulator/



## *Systementwurf: Emulation*


=> FPGA-basierte Prototypen: "Emulatoren"

- erlaubt Test von HW und SW, z.B. Booten von Windows
- typische Taktraten 1 .. 30 MHz
- voller Test aller Funktionen (außer Echtzeit)

## *Moore's Law*

- Planarprozeß ist massiv parallel
- Kosten fast unabhängig von der Anzahl einzelner Elemente

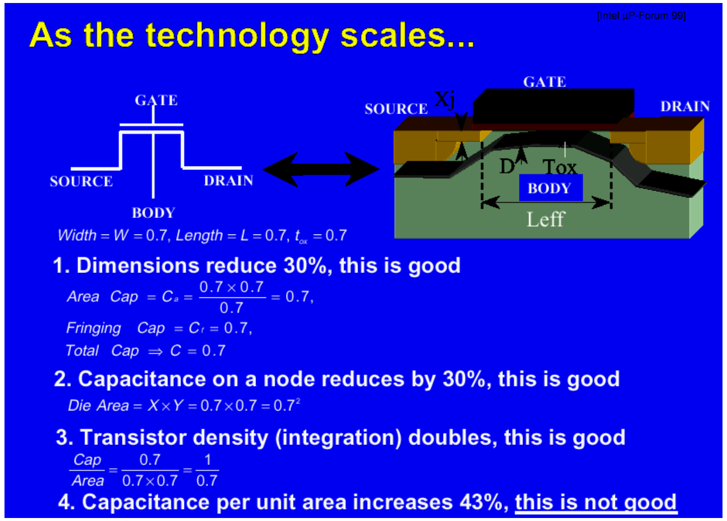
=> Moore's Law: exponentieller Anstieg des Integrationsgrades

- mehr Funktionen bei gleichen Kosten (gleiche Chipfläche)
- oder gleiche Funktion bei geringeren Kosten
- rein wirtschaftlich bedingt
- solange, bis Kapitalkosten für neue Technologie zu hoch

| Verbesserungen durch: | (relativer Anteil) |
|---|---|
| • feinere Lithographie | (50%) |
| • verbesserte Transistoren / Strukturen | (25%) |
| • bessere Rechnerarchitektur | (25%) |



## *Moore's Law: Transistor-Skalierung*






## *Moore's Law: Lithographie, Hochintegration*

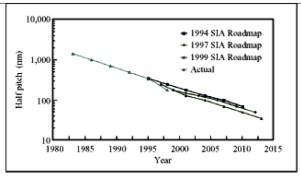



**Figure 1**

Historical and future trends of lithographic resolution capability. Here, half pitch is the minimum size of lithographic features on a chip. (SIA—Semiconductor Industry Association.)

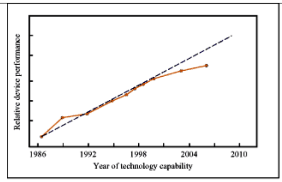



**Figure 2**

Comparison of performance for devices produced in successive technology generations vs. the year in which each technology generation first reached capability for volume production. Circles and the yellow curve represent historical and expected future behavior. The straight line represents an exponential growth rate as predicted from Moore's law. Circuit effects such as loading are not considered in this measurement of relative performance.

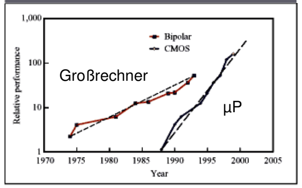



**Figure 6**

Historical and future server performance trends using bipolar and CMOS circuits. The straight lines represent the time-averaged exponential improvement in the performance of the technology.

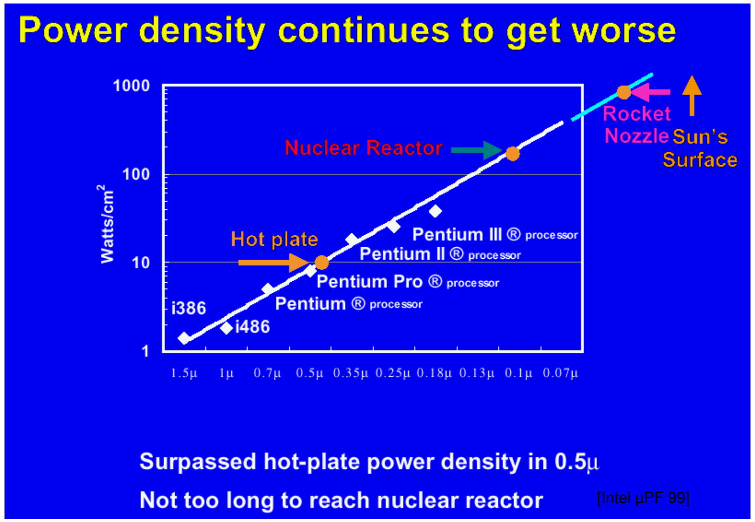
- exponentielles Wachstum
- seit 1970, bis > 2015

- seit 1996 CMOS besser als ECL
- zunehmend Abwärmeproblem

(IBM JR&D 44-3, 2000)



## *Moore's Law: Leistungsverbrauch*



## *Smart Dust*

Berkeley "Smart Dust" Projekt:

- Integration kompletter Rechensysteme auf 1 mm³

- vollständiger Digitalrechner (CPU, RAM, ROM, I/O)
- inklusive Betriebssystem (Tiny OS)
- inklusive autonome Vernetzung

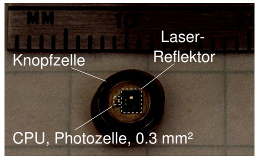
- inklusive Sensoren (z.B. Photodioden, Magnetfeld, Gyro.)
- inklusive Kommunikation (Funk oder optisch, s.u.)
- inklusive Stromversorgung (Photodioden, Batterie, Vibration, µGeneratoren)

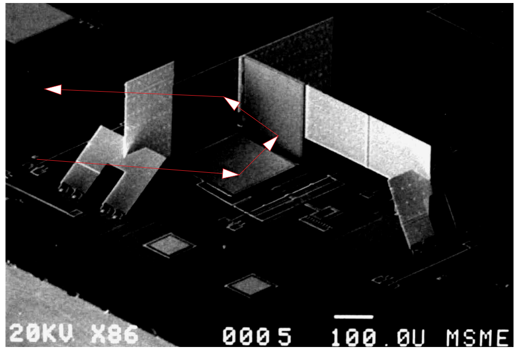
- Tausende vollständig autonome Mikrorechner
- "Ausstreuen" in der Umgebung
- minimale Kosten, riesiges Anwendungsspektrum

(Berkeley Sensor & Actuator Center, eecs.berkeley.edu)



## *Smart Dust: Corner Cube Reflektor*



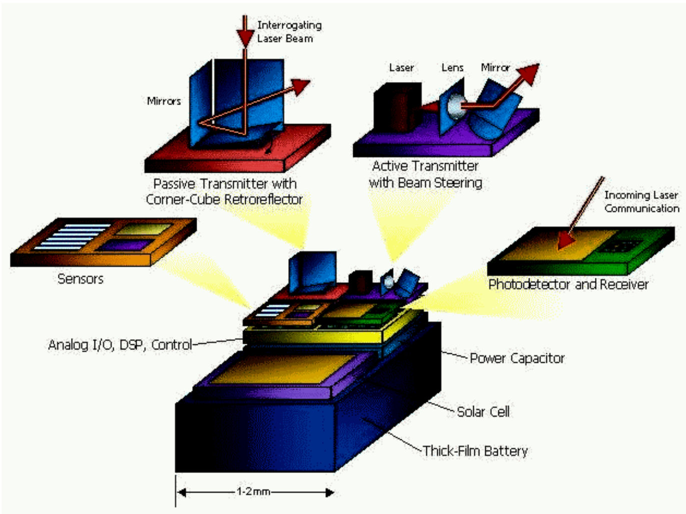

CCR- Retroreflektor: ("Katzenauge")

- 2 starre Spiegel (Gold auf Si), Aufstellen "per Hand"
- untere Spiegelfläche beweglich (elektrostatisch, ca. 30V)
- gezielte Modulation von eingestahltem (Laser-) Licht
- Reichweiten >100m demonstriert

(robotics.eecs.berkeley.edu/~pister/SmartDust/)

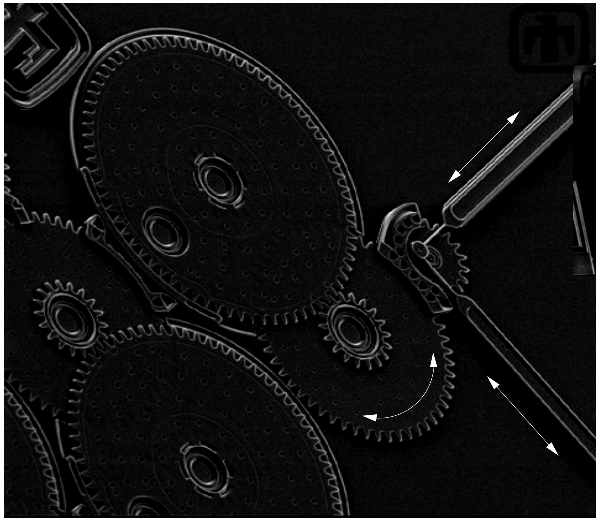


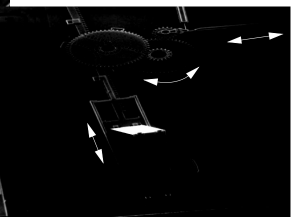
## *Smart Dust: Konzept für das Gesamtsystem*






## *MEMS: Mikrogetriebe*





5-Layer PolySi Prozess:
Batch-Fertigung aller
Strukturen inklusive Lager
keine zusätzliche Montage
bis 300.000 rpm

## Smart Dust: in the year 2010 . . .

In 2010 radios will cost $0.10. They will be short range (1-100m), low power (10nJ/bit), and low bit rate (1-100kbps). They will be truly single-chip radios, requiring no external components at [all]. MEMS devices will be used liberally for filters and tuneable oscillators.

In 2010 scanning 3 color laser projection systems will be no larger than a grain of rice, and cost under a dollar. They will be in augmented reality displays that appear to others as regular glasses. They will be in laser pointers, turning any wall into an electronic whiteboard. They will be in large arrays on walls, forming a truly staggering 3D display with brightness, contrast, and viewing angle unparalleled by any technology available or predicted today.

In 2010 everything you own that is worth more than a few dollars will know that it's yours, and you'll be able to find it whenever you want it. Stealing cars, furniture, stereos, or other valuables will be unusual, because any of your valuables that leave your house will check in on their way out the door, and scream like a troll's magic purse if removed without permission (they may scream at 2.4 GHz rather than in audio).

(robotics.eecs.berkeley.edu/~pister/SmartDust/2010.txt)



## Smart Dust: . . . 2010 . . .

... In 2010 a speck of dust on each of your fingernails will continuously transmit fingertip motion to your computer. Your computer will understand when you type, point, click, gesture, sculpt, or play air guitar.

In 2010 infants will not die of SIDs, or suffocate, or drown, without an alert being sent to the parents. How will society change when your neighbors pool calls your cell phone to tell you that Johnny is drowning and you're the closest adult that could be located?

In 2010 hunting SCUD TELs in Iraq or T-72s in Yugoslavia will consist of firing up a web browser and proving your authorization.

In 2010 everything of any value that you own will have it's own set of sensors, letting you know when your tire pressure is low, the bridge ahead is out (or unsafe), your milk is going bad, or your water heater is about to die.

In 2010 MEMS sensors will be everywhere, and sensing virtually everything. Scavenging power from sunlight, vibration, thermal gradients, and background RF, sensors motes will be immortal, completely self contained, single chip computers with sensing, communication, and power supply built in. Entirely solid state, and with no natural decay processes, they may well survive the human race. Descendants of dolphins may mine them from arctic ice and marvel at the extinct technology.



## Smart Dust: . . . limits . . .

Acquiring a digital data sample from many sensors requires on the order of 1 nJ. Threshold detection at discrete time periods will require substantially less energy in most cases. Higher performance sensors will require more energy per sample, but the nJ/sample number is applicable to, for example: whisper-to-chainsaw acoustic, sub-degree accuracy temperature, milli- to kilo- gravity acceleration sensing (Which also provides tilt and vibration information), magnetic field to 0.1% of earth's field, barometric pressure to 5m, wind flow to 1 m/s, relative humidity to 2%, ambient light level and spectrum.

Transmitting a bit of data over 10-100 meters by RF today takes approximately 100nJ with Bluetooth, Wavelan, and other local area RF networks. Transmitting a kilometer takes at 10 to 100 microJoules. These numbers are not likely to fall much, since they are often pushed up close to the fundamental physical limits. Another order of magnitude may be available by sacrificing immunity to unintentional jamming from nearby transmitters. If the dynamic range of the radio receivers is reduced, substantial improvements inpower can be realized.

Collimated line-of-site optical communication systems will transmit 10m with an energy cost of 10pJ/bit, more than 10,000 times lower than existing radio technology. We have demonstrated 1nJ/bit in the lab already. This incredible gain over RF is due entirely to an antenna gain of roughly 7 orders of magnitude when going from an isotropic radiator to a 1 mrad divergence beam.

32 bit computation currently costs around 1nJ/instruction on power-optimized microprocessors. Engineering limits in the next 5 years or so are approximately 1pJ/instruction for dedicated hardware.



## Smart Dust: . . . limits

Good batteries provide roughly 1 J/mm^3 . Solar cells provide approximately 100uW/mm^2 in full sunlight, more than 100nW/mm^2 in average room lighting. Vibrational energy availabe in an office setting is in the nW/mm^3 range. RF power in a simple antenna is generally not useful, unless there is a cell phone in use in the room, or a dedicated RF power source, in which case microWatts can easily be generated. Conversion is difficult, but feasible.

Assuming a simple task of sampling a sensor, performing some relatively simple processing (threshold, FIR/IIR filtering, statistical analysis, or FFT), listening for incoming messages, and transmitting a simple outgoing message, the energy cost will be a few nanoJoules.

Combining this with the power source information, a cubic millimeter battery will provide enough power to perform such a simple task once a second for 10 years. A cubic millimeter vibrational energy rectifyer will operate at that rate forever.
Indoors a square millimeter solar cell will provide enough power to perform 100 tasks/second, or in full sunlight 100,000 tasks/second.

For indoor optical line of sight communication, a cubic millimeter battery will provide enough energy to transmit 50 billion bits (roughly half a dozen full-length movies).