Operating Systems - Introduction

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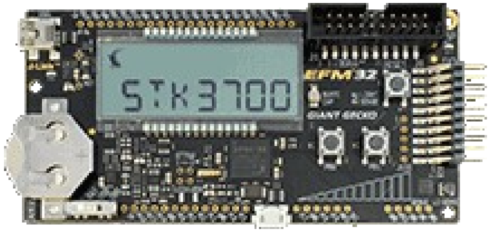
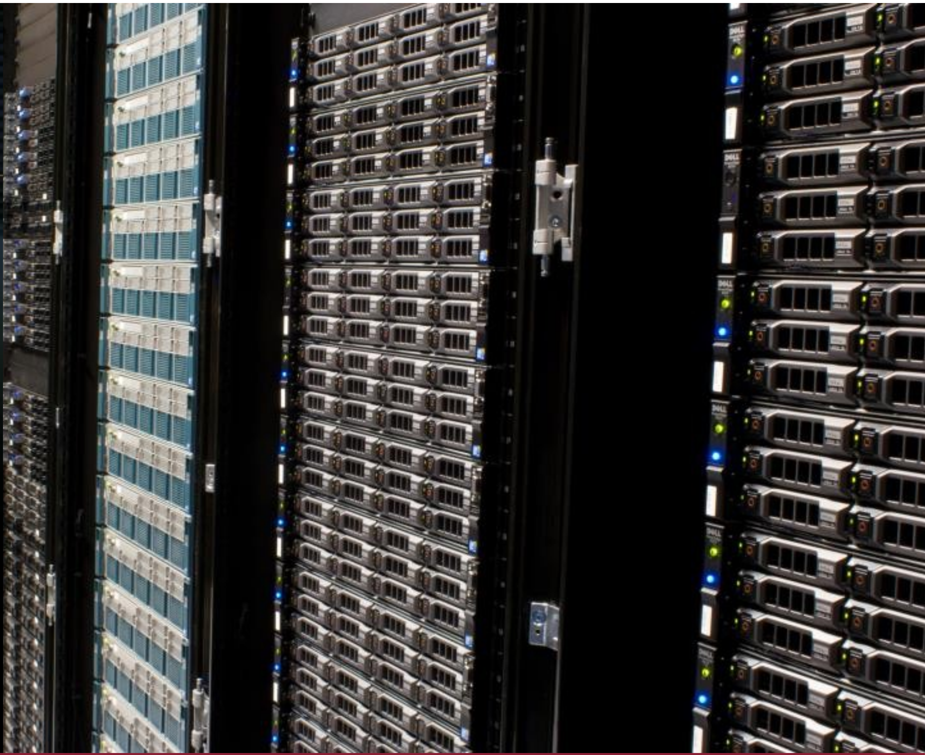
The slides of the latest lecture will be on the course page. (https://www.mit.bme.hu/eng/oktatas/targyak/vimiab00)

The lecturers and useful information

- Lecturer
  - András Millinghoffer
    - IE425, milli@mit.bme.hu
  - Interested in machine learning
  - Bioinformatics
- Course coordinator
  - Tamás Mészáros PhD.
    - IE437, meszaros@mit.bme.hu

- Official information on the web
  - https://www.mit.bme.hu/eng/oktatas/targyak/vimiab00
  - OR: mit.bme.hu -> english(🇬🇧) -> education -> Operating Systems (VIMIAB00)


STK3700
EFM32

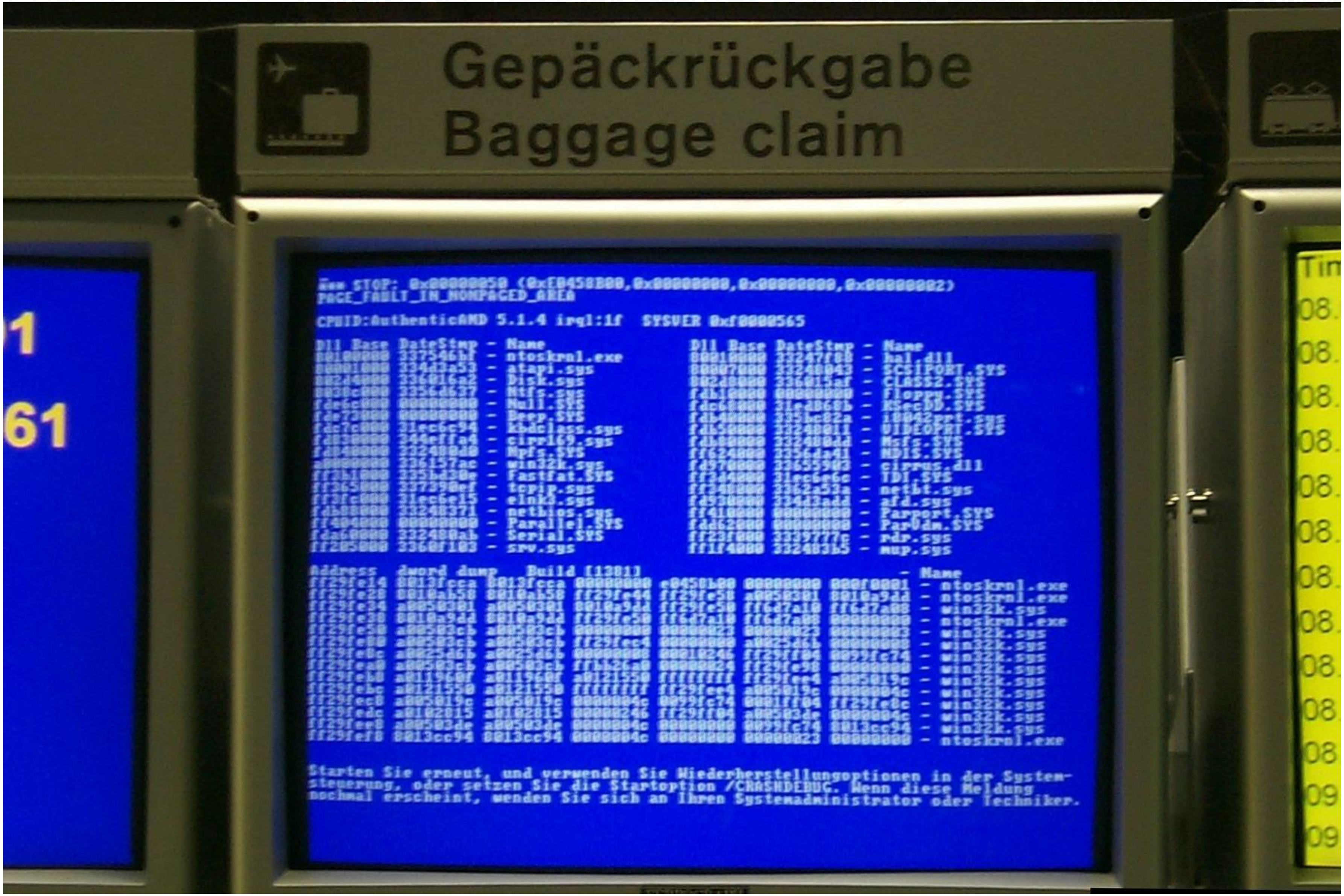


How complex is an OS?

Windows XP: 45 million LOC

MINIX core < 1400 LOC whole OS < 5000 LOC

Linux 3.1 **kernel**: 37 000 files, 14 million LOC – 4.17 23 million LOC



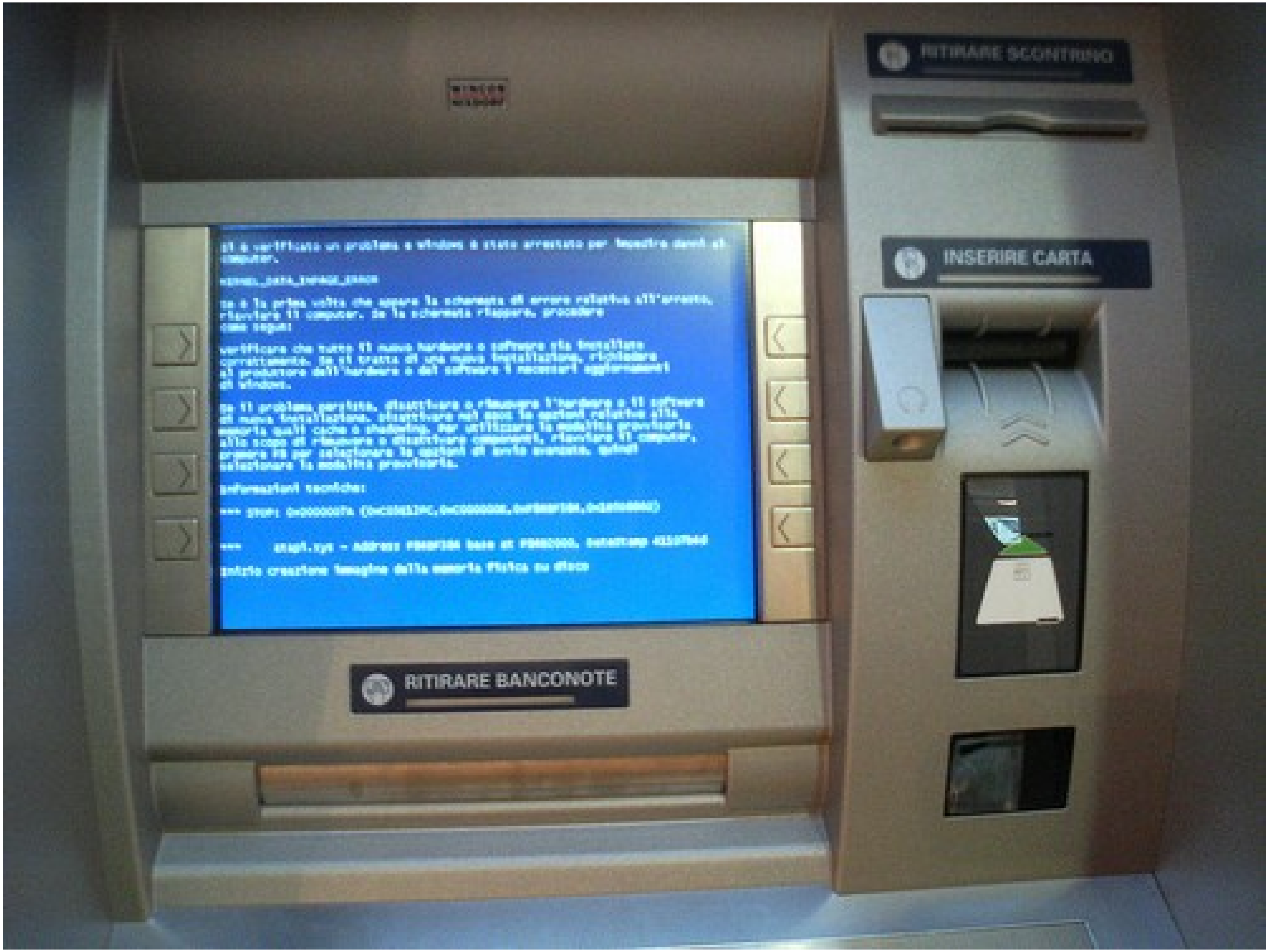
```
*** STOP: 0x00000050 (0xE0458B00,0x00000000,0x00000000,0x00000002)
PAGE_FAULT_IN_NONPAGED_AREA

CPUID:AuthenticAMD 5.1.4 irql:1f  SYSVER 0xf0000565

Dll Base DateStmp - Name                    Dll Base DateStmp - Name
80100000 337546bf - ntoskrnl.exe            80010000 33247f88 - hal.dll
80001000 334d3a53 - atapi.sys               80007000 33248043 - SCSIPORT.SYS
802d4000 336016a2 - Disk.sys                801d8000 336015af - CLASS2.SYS
8030c000 3356d637 - Ntfs.sys                fdb10000 00000000 - Floppy.SYS
fde6c000 00000000 - Null.SYS                fdc60000 31ed868b - KSecDD.SYS
fde73000 00000000 - Beep.SYS                fdb40000 335bc82a - i8042prt.SYS
fdc7c000 31ec6c94 - kbdclass.sys            fdb50000 33248011 - VIDEOPRT.SYS
fd830000 344effa4 - cirrl69.sys             fdb00000 332480dd - Msfs.SYS
fd840000 332480d0 - Npfs.SYS                ff624000 3356da41 - NDIS.SYS
a0000000 336157ac - win32k.sys              fd970000 33655903 - cirrus.dll
ff2b1000 335bd30e - Fastfat.SYS             ff344000 31ec6e6c - TDI.SYS
ff365000 337390ef - tcpip.sys               ff340000 3362a53a - netbt.sys
ff3fc000 31ec6e15 - elnk3.sys               fd930000 334d3add - afd.sys
fdb88000 33248371 - netbios.sys             ff410000 00000000 - Parport.SYS
ff404000 00000000 - Parallel.SYS            fdd62000 00000000 - ParVdm.SYS
fda60000 332480ab - Serial.SYS              ff23f000 3339777c - rdr.sys
ff205000 3360f103 - srv.sys                 ff1f4000 332483b5 - mup.sys

Address  dword dump   Build [1381]                                   - Name
ff29fe14 8013fcca 8013fcca 00000000 e0458b00 00000000 000f0001 - ntoskrnl.exe
ff29fe28 8010ab58 8010ab58 ff29fe44 ff29fe58 a0050301 8010a9dd - ntoskrnl.exe
ff29fe34 a0050301 a0050301 8010a9dd ff29fe50 ff6d7a10 ff6d7a08 - win32k.sys
ff29fe38 8010a9dd 8010a9dd ff29fe58 ff6d7a10 ff6d7a08 00000000 - ntoskrnl.exe
ff29fe50 a00503cb a00503cb 00000000 00000023 00000023 00000003 - win32k.sys
ff29fe80 a00503cb a00503cb ff29fec4 00000000 a0025d6b 00000000 - win32k.sys
ff29fe8c a0025d6b a0025d6b 00000008 00010246 ff29ff04 0099fc74 - win32k.sys
ff29fea0 a00503cb a00503cb ffbb26a0 00000024 ff29fe98 00000000 - win32k.sys
ff29feb0 a011960f a011960f a0121550 ffffffff ff29fee4 a005019c - win32k.sys
ff29febc a0121550 a0121550 ffffffff ff29fee4 a005019c 0000004c - win32k.sys
ff29fec8 a005019c a005019c 0000004c 0099fc74 0001ff04 ff29fe8c - win32k.sys
ff29fedc a0102815 a0102815 00000246 ff29ff04 a00503de 0000004c - win32k.sys
ff29fee8 a00503de a00503de 0000004c 00000000 0099fc74 8013cc94 - win32k.sys
ff29fef8 8013cc94 8013cc94 0000004c 00000000 00000023 00000000 - ntoskrnl.exe

Starten Sie erneut, und verwenden Sie Wiederherstellungoptionen in der System-
steuerung, oder setzen Sie die Startoption /CRASHDEBUG. Wenn diese Meldung
nochmal erscheint, wenden Sie sich an Ihren Systemadministrator oder Techniker.
```



```
Si è verificato un problema e Windows è stato arrestato per impedire danni al
computer.

KERNEL_DATA_INPAGE_ERROR

Se è la prima volta che appare la schermata di errore relativa all'arresto,
riavviare il computer. Se la schermata riappare, procedere
come segue:

Verificare che tutto il nuovo hardware o software sia installato
correttamente. Se si tratta di una nuova installazione, richiedere
al produttore dell'hardware o del software i necessari aggiornamenti
di Windows.

Se il problema persiste, disattivare o rimuovere l'hardware o il software
di nuova installazione. Disattivare nel BIOS le opzioni relative alla
memoria quali cache o shadowing. Per utilizzare la modalità provvisoria
allo scopo di rimuovere o disattivare componenti, riavviare il computer,
premere F8 per selezionare le opzioni di avvio avanzate, quindi
selezionare la modalità provvisoria.

Informazioni tecniche:

*** STOP: 0x0000007A ([illegible])

***     atapi.sys - Address [illegible] base at [illegible], DateStamp [illegible]

Inizio creazione immagine della memoria fisica su disco
```

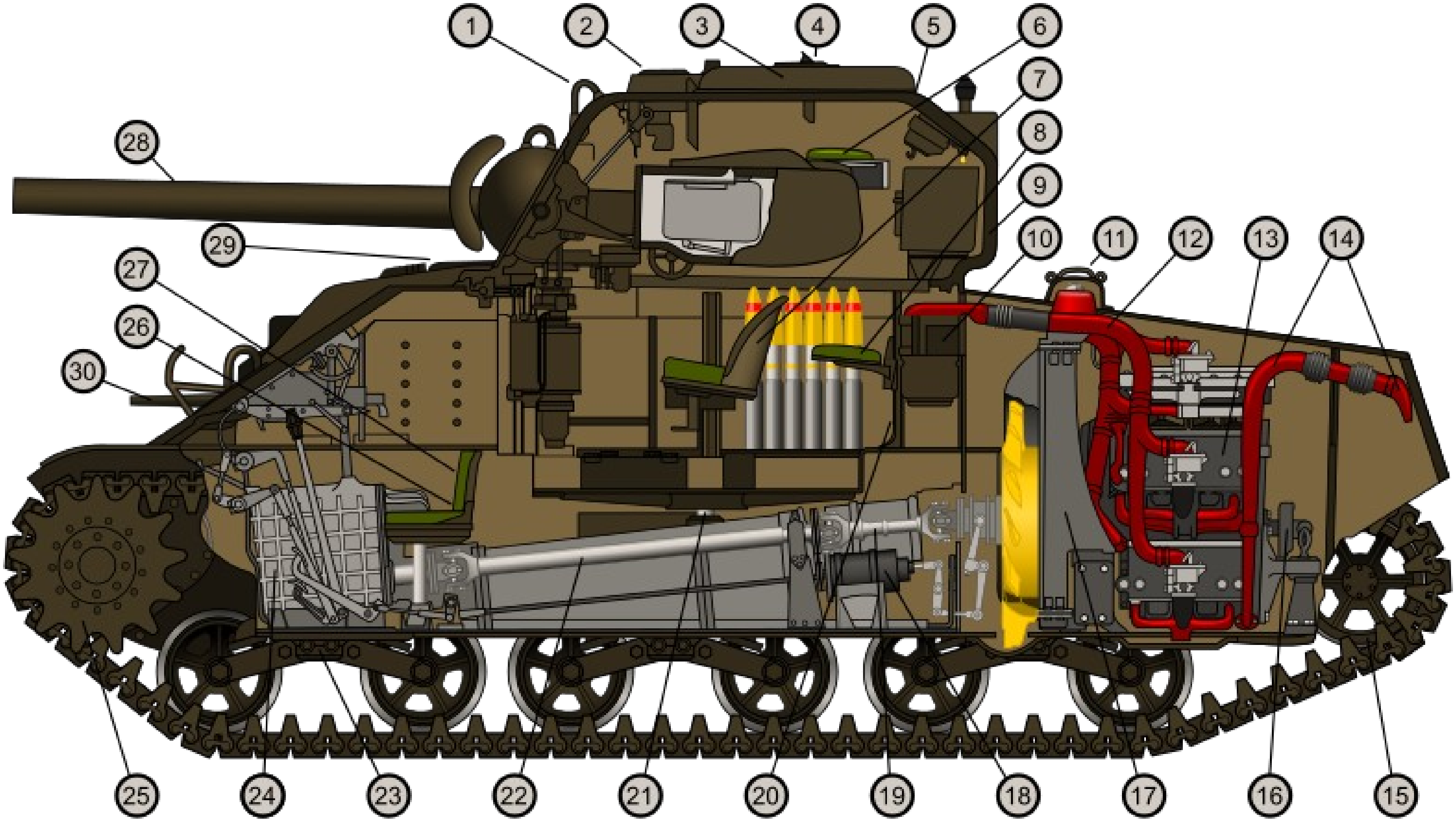
What’s the aim of the Operating System (OS)?

- Provides tools for the users
  - users: almost everyone: simple users, developers, system administrators
  - tasks: connections, information retrieval, computations, gaming, storage, … also: software development and system administration
  - tools: computer (PC, smartphone…), network, printer, disc, … but also the software tools of the OS.

- The OS is an ecosystem for the programs
  - It provides a „living” environment and resources
    - Provides standard interfaces for hardware devices
    - Provides computing capability
    - Provides integrated software tools and services like: security, development and administrative, etc. subsystems
  - Managing the shared resources
    - Controlling the running tasks
    - Parallel execution of the tasks
    - Provides communication channels between task to enhance cooperation

How well developed is an OS?

Source: Wikipédia



Source: Wikipédia

Goals of this course

- Learning the OS architecture and operation
  - Architecture (layered, monolithic, microkernel, etc.)
  - Running tasks (process, thread, scheduling, life-cycle, monitoring)
  - Virtual machine abstraction
  - Memory management (physical and virtual memory, paging and swapping)
  - Inter-process communication (FIFO, message queues, shared memory, RPC, socket)
  - Storage systems (files; local, network and distributed file systems)
  - Authentication, authorization and security
- Introducing these specific part in laboratory sessions
  - Windows administration
  - Linux basics: app and service installation, management
  - Embedded real-time operating system: FreeRTOS @ Silabs STK3700
- Encouraging the self-learning
  - This course isn't pure theoretical, this knowledge can be used in practice.

Structure of this course

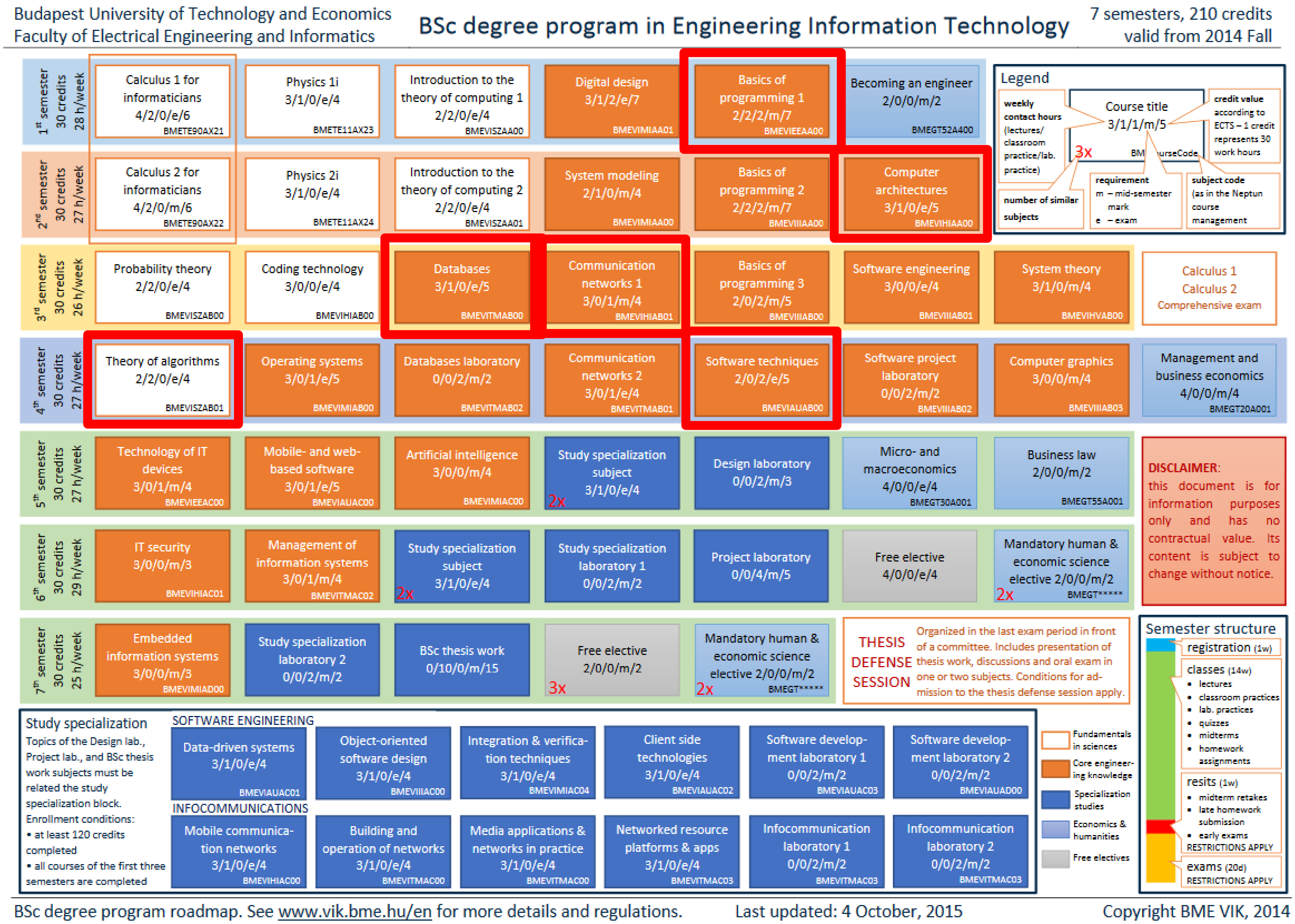
- Lecture (3 hours a week)
  - Every Monday from 10:15 (QBF08)
  - Every second Thursday, odd weeks from 14:15 (QBF08)
- Laboratories (min. 4 successful sessions)
  - Every second Thursday, even weeks from 14:15 (IL306)
  - min 8 hours, max 12 hours during the semester,
- Mid-term test (min. 40%)
  - Theoretical and practical questions, problem solving
- Exam (OK entry test and min. 40%)
  - Definitions, entry test (not present in midterm exam)
    - basic level of knowledge, mainly definitions
  - Yes-no questions (20 points)
    - general level knowledge
    - correct answers 1 point, wrong answers -0,5 point
  - Short answers (15 points)
    - general level knowledge
  - practical problem to solve (15 points)
    - can you choose and run algorithms?

- Home practice
  - Small tasks to solve in a virtual environment, test, demonstrations

Laboratories

- Laboratory session topics
  - Windows
  - Linux
  - Virtualization
- Dates To Be Determined
  - Requirements for laboratories
  - There will be an entry test
  - Rating
    - Not completed (failed entry test, failed to solve the tasks)
    - Completed (OK for entry test and for the tasks)
    - Completed plus (solved the extra tasks also which are marked with *)

Connection with other courses



Budapest University of Technology and Economics
Faculty of Electrical Engineering and Informatics

BSc degree program in Engineering Information Technology

7 semesters, 210 credits
valid from 2014 Fall

1st semester 30 credits 28 h/week	Calculus 1 for informaticians 4/2/0/e/6 BMETE90AX21	Physics 1i 3/1/0/e/4 BMETE11AX23	Introduction to the theory of computing 1 2/2/0/e/4 BMEVISZAA00	Digital design 3/1/2/e/7 BMEVIMIAA01	Basics of programming 1 2/2/2/m/7 BMEVIEEAA00	Becoming an engineer 2/0/0/m/2 BMEGT52A400		
2nd semester 30 credits 27 h/week	Calculus 2 for informaticians 4/2/0/m/6 BMETE90AX22	Physics 2i 3/1/0/e/4 BMETE11AX24	Introduction to the theory of computing 2 2/2/0/e/4 BMEVISZAA01	System modeling 2/1/0/m/4 BMEVIMIAA00	Basics of programming 2 2/2/2/m/7 BMEVIIIAA00	Computer architectures 3/1/0/e/5 BMEVIHIAA00		
3rd semester 30 credits 26 h/week	Probability theory 2/2/0/e/4 BMEVISZAB00	Coding technology 3/0/0/e/4 BMEVIHIAB00	Databases 3/1/0/e/5 BMEVITMAB00	Communication networks 1 3/0/1/m/4 BMEVIHIAB01	Basics of programming 3 2/0/2/m/5 BMEVIIIAB00	Software engineering 3/0/0/e/4 BMEVIIIAB01	System theory 3/1/0/m/4 BMEVIHVAB00	Calculus 1 Calculus 2 Comprehensive exam
4th semester 30 credits 27 h/week	Theory of algorithms 2/2/0/e/4 BMEVISZAB01	Operating systems 3/0/1/e/5 BMEVIMIAB00	Databases laboratory 0/0/2/m/2 BMEVITMAB02	Communication networks 2 3/0/1/e/4 BMEVITMAB01	Software techniques 2/0/2/e/5 BMEVIAUAB00	Software project laboratory 0/0/2/m/2 BMEVIIIAB02	Computer graphics 3/0/0/m/4 BMEVIIIAB03	Management and business economics 4/0/0/m/4 BMEGT20A001
5th semester 30 credits 27 h/week	Technology of IT devices 3/0/1/m/4 BMEVIEEAC00	Mobile- and web-based software 3/0/1/e/5 BMEVIAUAC00	Artificial intelligence 3/0/0/m/4 BMEVIMIAC00	Study specialization subject 3/1/0/e/4 2x	Design laboratory 0/0/2/m/3	Micro- and macroeconomics 4/0/0/e/4 BMEGT30A001	Business law 2/0/0/m/2 BMEGT55A001	
6th semester 30 credits 29 h/week	IT security 3/0/0/m/3 BMEVIHIAC01	Management of information systems 3/0/1/m/4 BMEVITMAC02	Study specialization subject 3/1/0/e/4 2x	Study specialization laboratory 1 0/0/2/m/2	Project laboratory 0/0/4/m/5	Free elective 4/0/0/e/4	Mandatory human & economic science elective 2/0/0/m/2 2x BMEGT*****	
7th semester 30 credits 25 h/week	Embedded information systems 3/0/0/m/3 BMEVIMIAD00	Study specialization laboratory 2 0/0/2/m/2	BSc thesis work 0/10/0/m/15	Free elective 2/0/0/m/2 3x	Mandatory human & economic science elective 2/0/0/m/2 2x BMEGT*****	THESIS DEFENSE SESSION Organized in the last exam period in front of a committee. Includes presentation of thesis work, discussions and oral exam in one or two subjects. Conditions for admission to the thesis defense session apply.		

Legend

Course title
3/1/1/m/5
3x BM urseCode

- weekly contact hours (lectures/ classroom practice/lab. practice)
- credit value according to ECTS – 1 credit represents 30 work hours
- number of similar subjects
- requirement m – mid-semester mark e – exam
- subject code (as in the Neptun course management

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Study specialization

Topics of the Design lab., Project lab., and BSc thesis work subjects must be related the study specialization block.
Enrollment conditions:
- at least 120 credits completed
- all courses of the first three semesters are completed

SOFTWARE ENGINEERING					
Data-driven systems 3/1/0/e/4 BMEVIAUAC01	Object-oriented software design 3/1/0/e/4 BMEVIIIAC00	Integration & verification techniques 3/1/0/e/4 BMEVIMIAC04	Client side technologies 3/1/0/e/4 BMEVIAUAC02	Software development laboratory 1 0/0/2/m/2 BMEVIAUAC03	Software development laboratory 2 0/0/2/m/2 BMEVIAUAD00
INFOCOMMUNICATIONS					
Mobile communication networks 3/1/0/e/4 BMEVIHIAC00	Building and operation of networks 3/1/0/e/4 BMEVITMAC00	Media applications & networks in practice 3/1/0/e/4 BMEVITMAC00	Networked resource platforms & apps 3/1/0/e/4 BMEVITMAC03	Infocommunication laboratory 1 0/0/2/m/2 BMEVITMAC03	Infocommunication laboratory 2 0/0/2/m/2 BMEVITMAC03

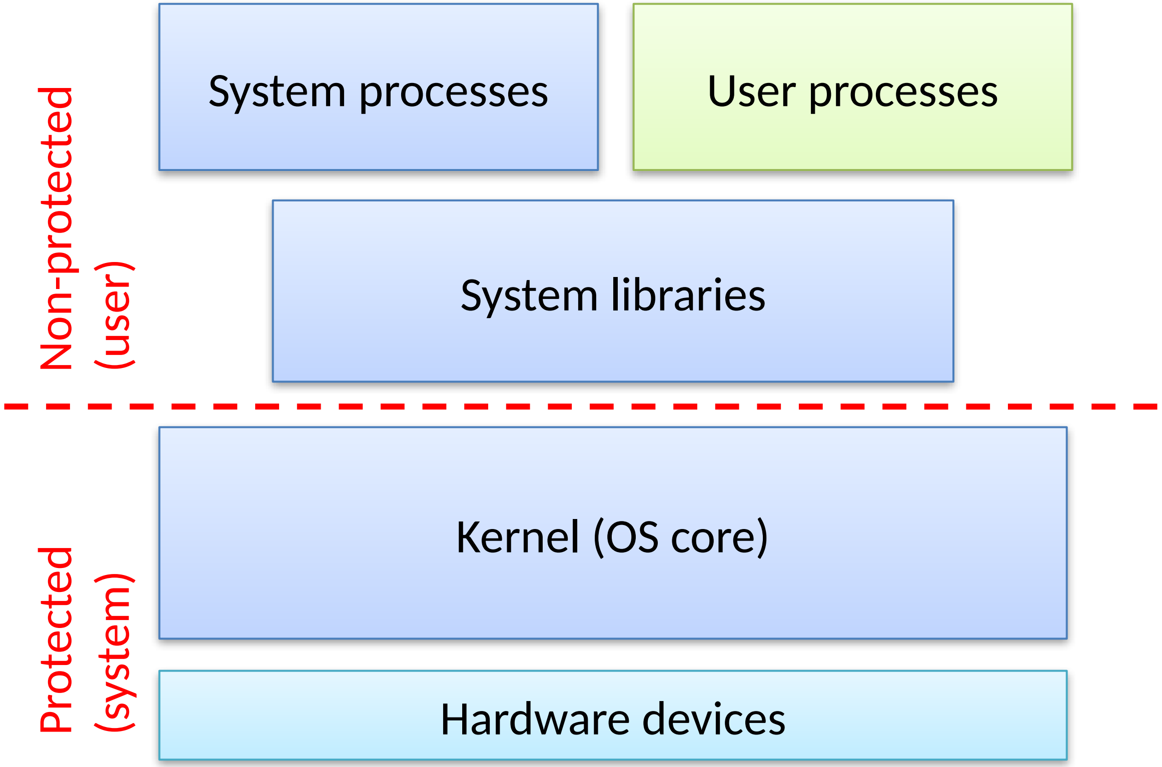
- □ Fundamentals in sciences
- 🟧 Core engineering knowledge
- 🟦 Specialization studies
- ▨ Economics & humanities
- ▢ Free electives

Semester structure

- registration (1w)
- classes (14w)
  - lectures
  - classroom practices
  - lab. practices
  - quizzes
  - midterms
  - homework assignments
- resits (1w)
  - midterm retakes
  - late homework submission
  - early exams
  - RESTRICTIONS APPLY
- exams (20d)
  - RESTRICTIONS APPLY

BSc degree program roadmap. See www.vik.bme.hu/en for more details and regulations. Last updated: 4 October, 2015 Copyright BME VIK, 2014

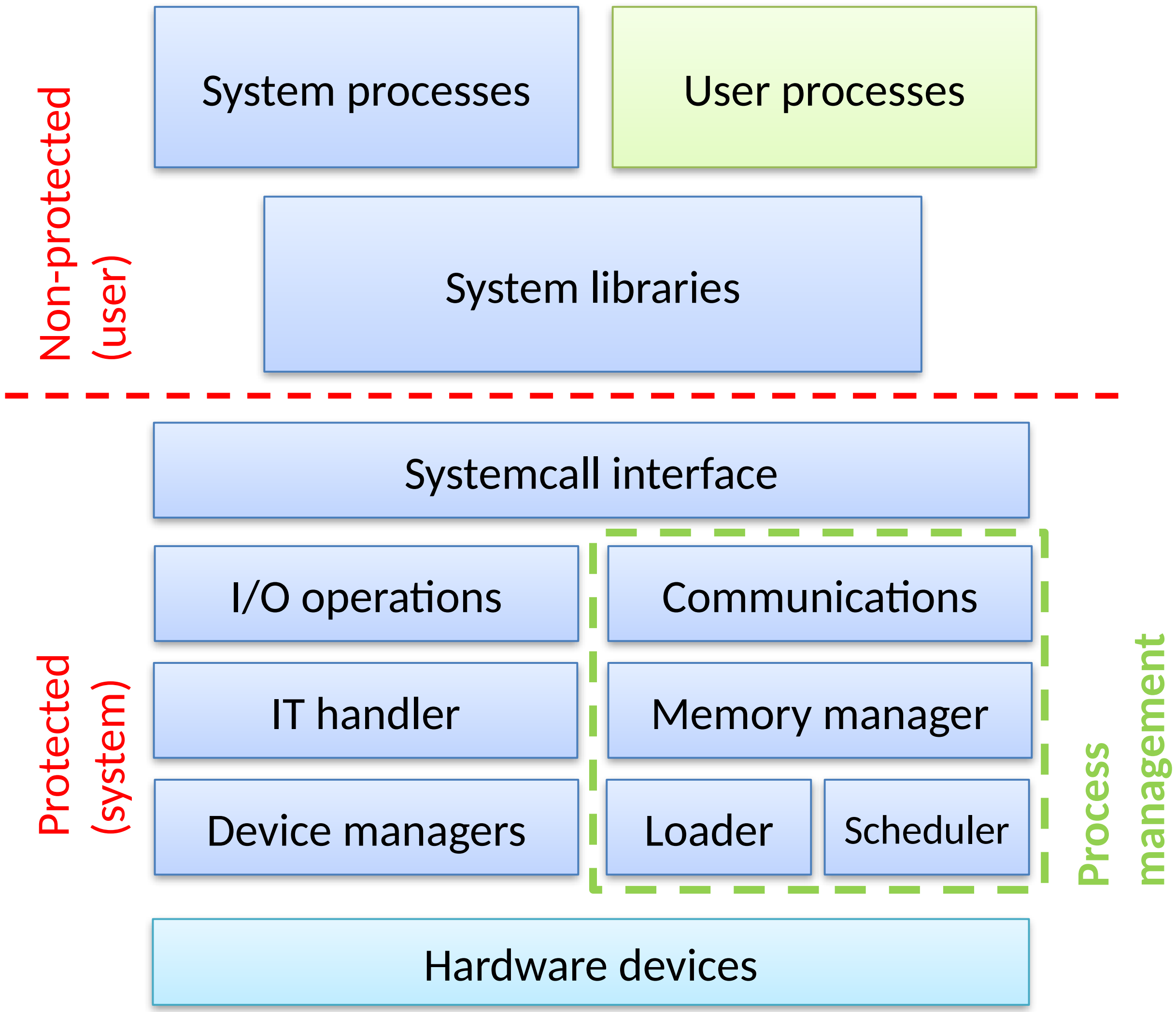
The main blocks of the OS



Kernel: the core (base) of the OS

- Serving user (and system) processes
  - Life cycle monitoring (creation, operation, termination)
  - Providing resources: computational and storage
  - Managing events
  - Providing access to the hardware devices
- Hardware management
  - Managing the accessible physical resources
  - Managing simultaneous queries, separation, solving conflicts
  - Initializing devices
  - Managing and forwarding HW based events
  - Providing a „standard” interface to access these resources
- Controlling reliability, performance and security
  - Protection of the resources from erroneous or noxious usage
  - Separation and protection of the user data
  - Providing common security services

The main blocks of the OS and the kernel



How many lines a kernel?

- Unix kernel
  - Linux 3.1: 37 000 file, 14 million Lines of Code (~half of it is device management)
  - MINIX basic kernel < 1400 LoC, full version: 5000 LoC
- 3D visualization of the Linux kernel
  - http://www.pabr.org/kernel3d/kernel3d.html
  - http://blog.mit.bme.hu/meszaros/node/164
- Further reading, videos
  - http://www.jukie.net/bart/blog/linux-kernel-walkthroughs
  - http://en.wikiversity.org/wiki/Reading_the_Linux_Kernel_Sources

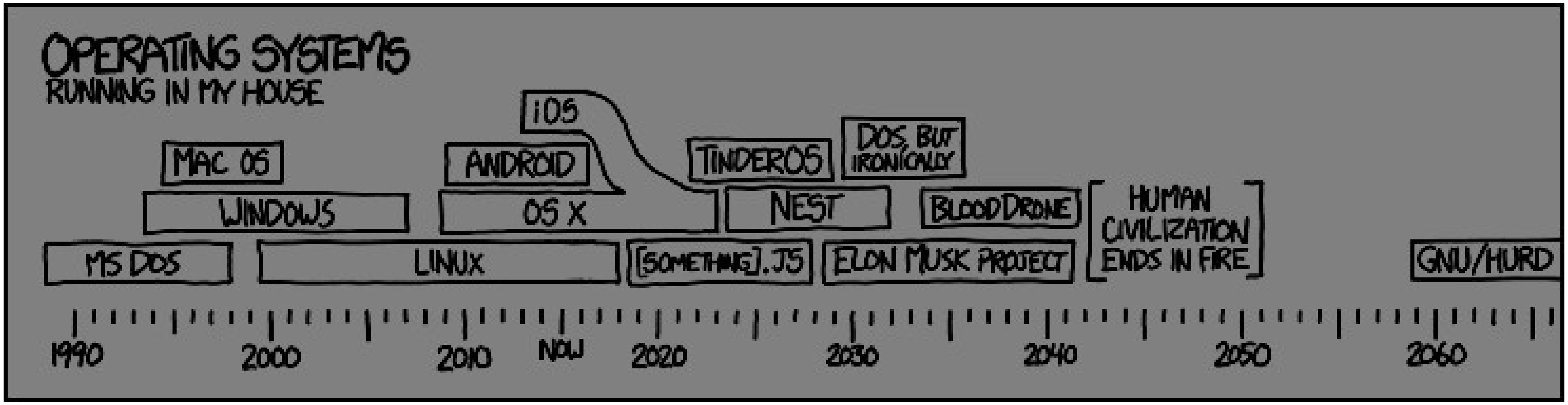
Definition of the OS

- There are many possible definitions
  - Everything that’s in the box, when buying an „OS”
  - Sum of the software which makes possible the running of user tasks
  - The program which are allocate the hardware resources
  - The only program which are always running
  - ….

Do not learn these

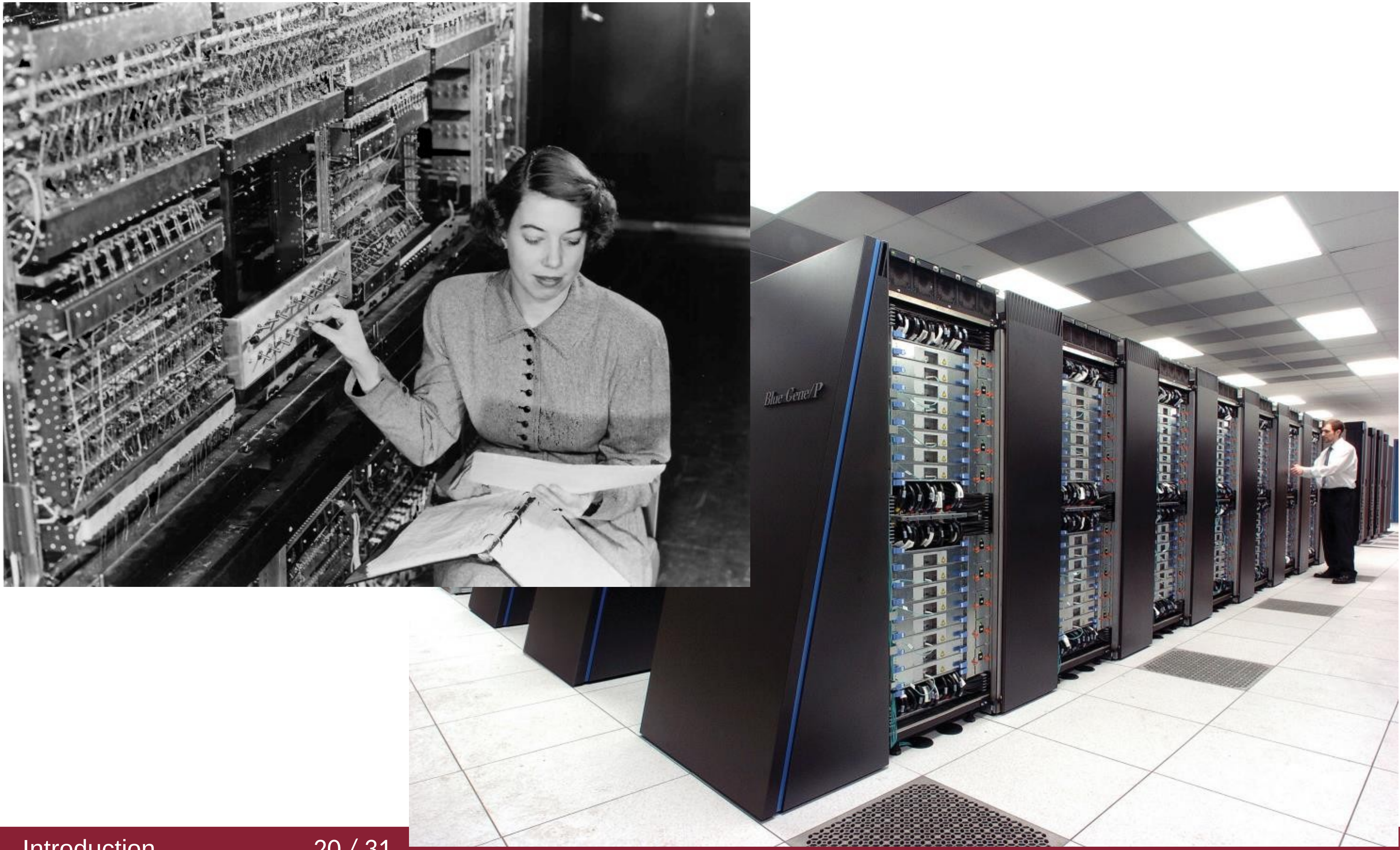
- The OS is the sum of the programs which are managing the hardware of the computer and makes possible to run user tasks.

Operating Systems: past, present and future



Source: xkcd

Historical overview

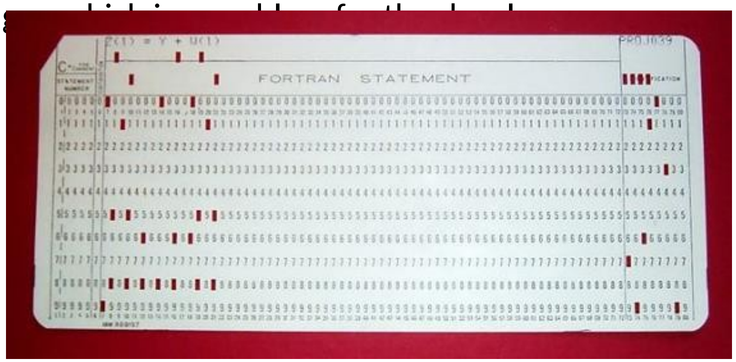


Historical overview

- Related with hardware evolution
  - Appearing new techologies, HW types and services
  - The computing capability is multiplies by 10 every 5 years (slowing)
  - The price/MIPS ratio is multiplied 10 times in 3.5-4 years
- >60 years of experience
  - Hundreds of HW platforms
  - HW, SW combined developement
- Open source codes, many books
- Colorful developement
  - From smartphones to grid servers
  - From engineering/mathematical tasks to today’s entertainment devices

Milestones of the OS evolution

- Batch computing – Big room computers
  - The OS is running one task at once
  - The tasks are incoming from punched card, or later magnetic tapes in **batches**.
  - The OS was a device manager and loader
- Multiprogrammed OS (OS/360) – IC, memory, disc
  - The memory is split to sections in order to load more than one process at once
  - If one of processes are waiting for an I/O task, the other one can be run on the processor
  - The running sequence is less predictable and the response time is long
- Time sharing OS (MULTICS) – HW level protection
  - The processor time is shared equally between users
  - Predictable system and better response times
  - Written in a higher level programming language (PL/I)
- Personal computer OS – LSI circuits, microprocessors,
- x86
  - Evolution of user interfaces
  - More and more tasks (games, media applications, etc.)
- Embedded OS – Integrated functionality, complex, cheap IC-s
  - Performing real-time tasks in a resource constrained environment

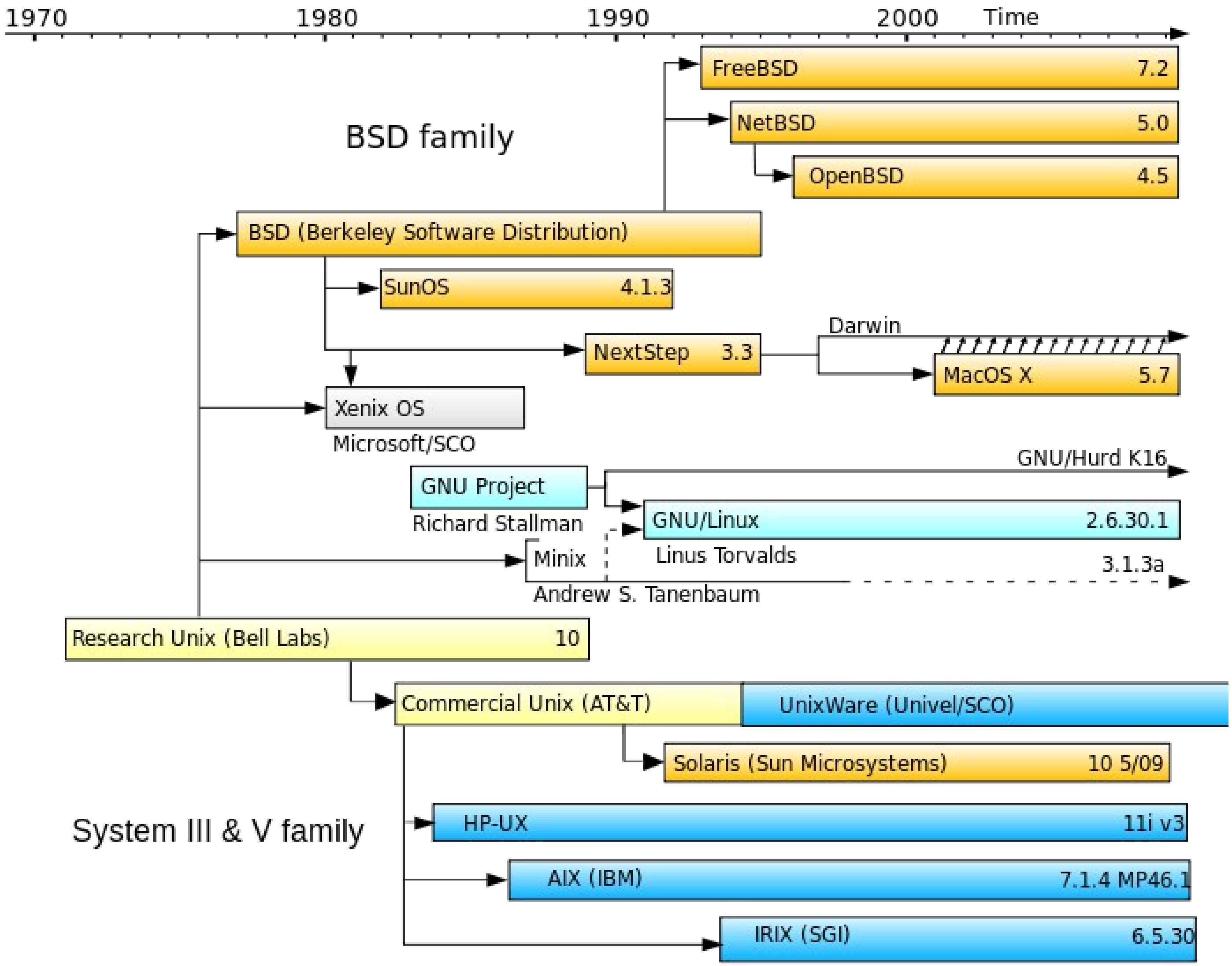


Creation of UNIX

- 1969 AT&T Bell Lab
  - Ken Thompson and Dennis Ritchie
  - Space travel game
  - Slow OS vs. fast game
  - Ken writes a small OS kernel (UNIX)
  - Ritchie writes a programming language: C, then UNIX in C code
  - MULTICS -> UNICS

digital pdp11

The main branches of the UNIX family



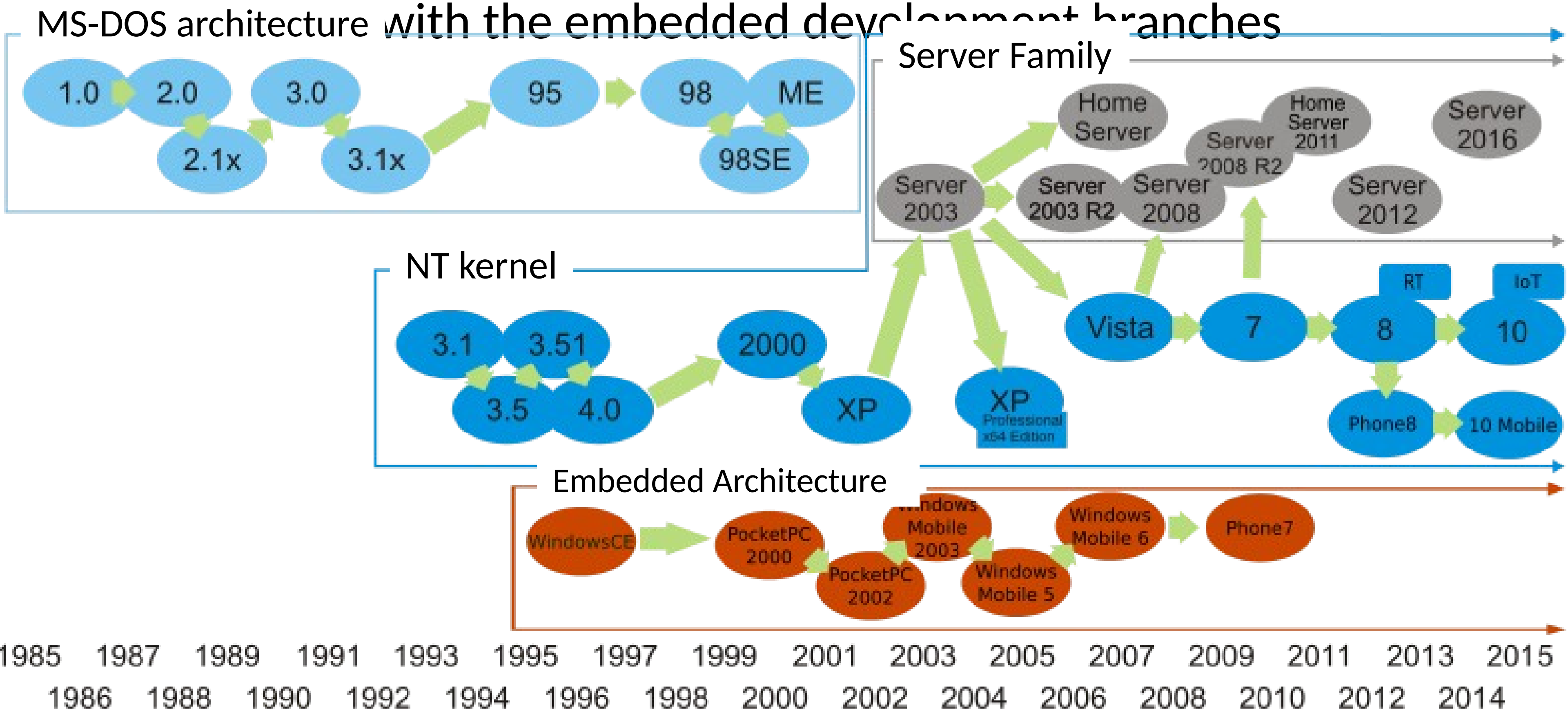
UNIX (≠Linux) distributions (incomplete list)

- Up to date catalog: http://distrowatch.com/
- On servers
  - RedHat Enterprise Linux and clones (CentOS, Scientific Linux)
  - SUSE Linux Enterprise Server / openSUSE (Novell)
  - Debian
  - Ubuntu Server
  - OpenBSD and siblings (FreeBSD, NetBSD, …)
  - Oracle (Sun) Solaris and other versions (OpenSolaris)
- On clients
  - Ubuntu (Kubuntu, Edubuntu, Mythbuntu, …)
  - Linux Mint
  - Arch Linux
  - Fedora (RHEL „sandbox”)
  - SUSE Linux Enterprise Desktop / openSUSE (Novell)
- In embedded systems
  - Android-based systems (phones, tablets, TV-s, TV boxes, etc.)
  - Tizen, OpenWrt, Embedded Debian, Arch Linux for ARM, etc.
  - OpenElec.tv (only for further reading)

The personal computer (PC) era - War without control

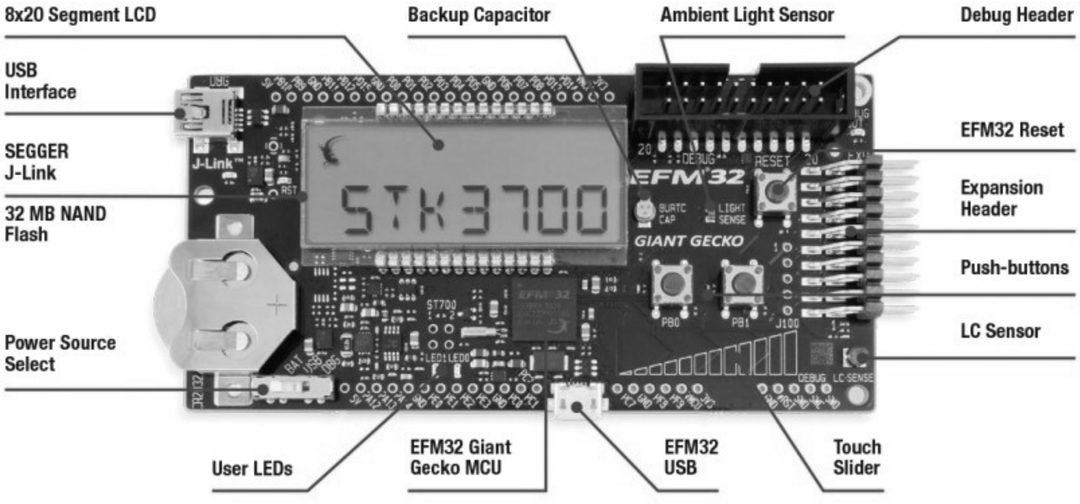
Evolution of Windows

- Graphical User Interface (GUI) for MS-DOS and for the Apple
- Multimedia applications (Win 3.1)
- Refurbished kernel design (Windows NT) <- IBM OS/2, DEC VMS with the embedded development branches



Embedded OS

- Specific task oriented systems, embedded in the environment
  - Many applications: vehicles, industrial and medical equipments, TV-s, smartphones
  - Typical requirements: real-time, deterministic, and safety critical operation
  - Multiple HW architectures, broad range of performance
- Examples
  - VxWorks (real-time, commercial)
    - Besides the OS, it provides a development and simulation environment
    - Mars Pathfinder (1997) (classic example of the errors based on priority inversion)
  - FreeRTOS (real-time, open-source, discussed on Lab.)
    - It is able to maintain hard real-time requirements
    - Complex services
  - MicroC/OS (real-time, open-source)
    - Available on many platforms, complex services
  - RT-Linux (real-time, open-source)
    - Real-time kernel extension for Linux (two kernels)
    - Applications are running in kernel mode
  - Etc
    - VRTX, eCOS, QNX, Windows CE, …



Classification of the operating systems

- Based on the user tasks’ nature and purpose
  - Client: GUI-s and client programs are emphasized
  - Server: providing server features (web, mail, database, etc.)
  - Embedded: making smarter industrial or household equipments
  - Others: GRID systems, Storage systems
- Based on the OS (and kernel) properties
  - User interface: GUI or terminal
  - Kernel structure: monolithic, microkernel, exokernel, multikernel (will be discussed later)
  - Kernel operation: real-time, non real-time
  - CPU support: x86, ARM, etc, and multi-architecture, SMP, multiprocessor (100+)
  - License: closed or open-source (GPL, BSD licenses)
  - Communication: network and distributed (supports and provides such services)

- Def.: real-time system
  - The response time to a query (specific) will be less than a given time period
    - Hard real-time: with the probability of 1
    - (soft) real-time: with high probability

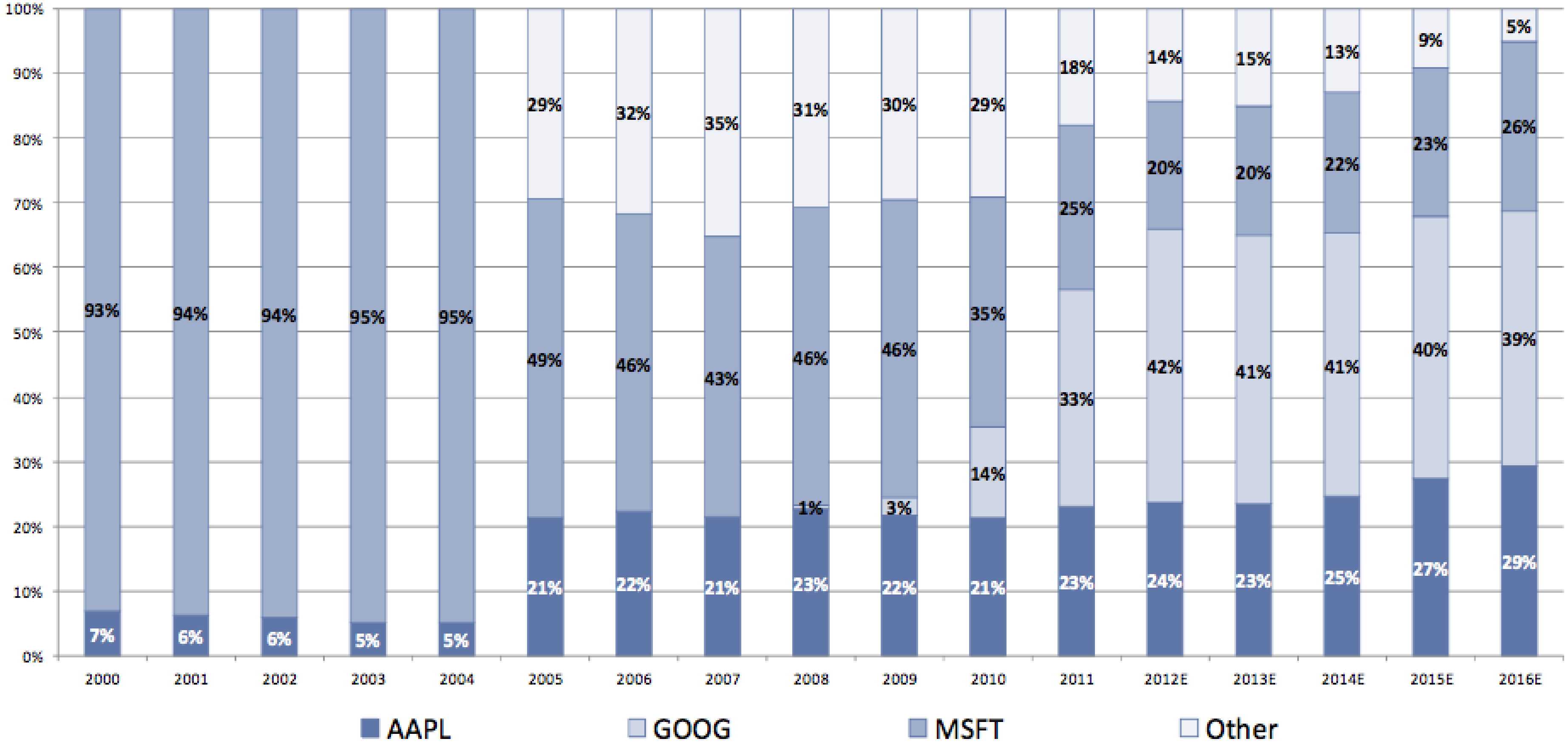
Market share of the OS-s

- On clients
  - The smartphones and tablets are changing the OS market dramatically
  - PC: Windows 92%, Mac OSX 6,4%, Linux 1,6%
    (few years ago: Windows 94%, Max 5%, Linux 1%)
  - PC+phones+tablets: Windows 20%, OSX/iOS (UNIX) 24%, Android (UNIX) 42%
  - See next slide!
  - Up to date charts:
    - *http://en.wikipedia.org/wiki/Usage_share_of_operating_systems*
- *On servers*
  - *Unix 68%, Windows 32%*

Market share of the OS-s

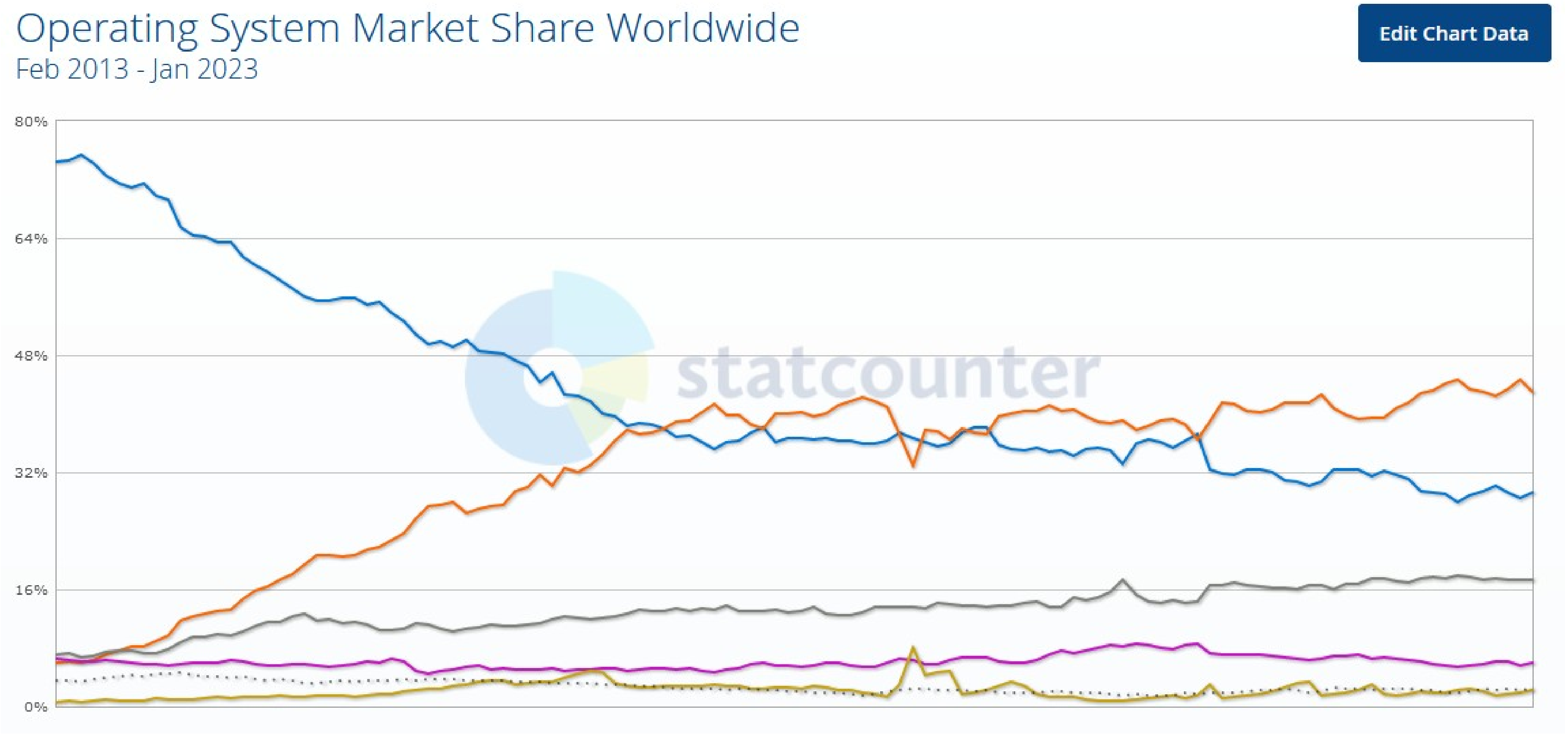
Exhibit 1: Vendor share of consumer compute, 2000-2016E

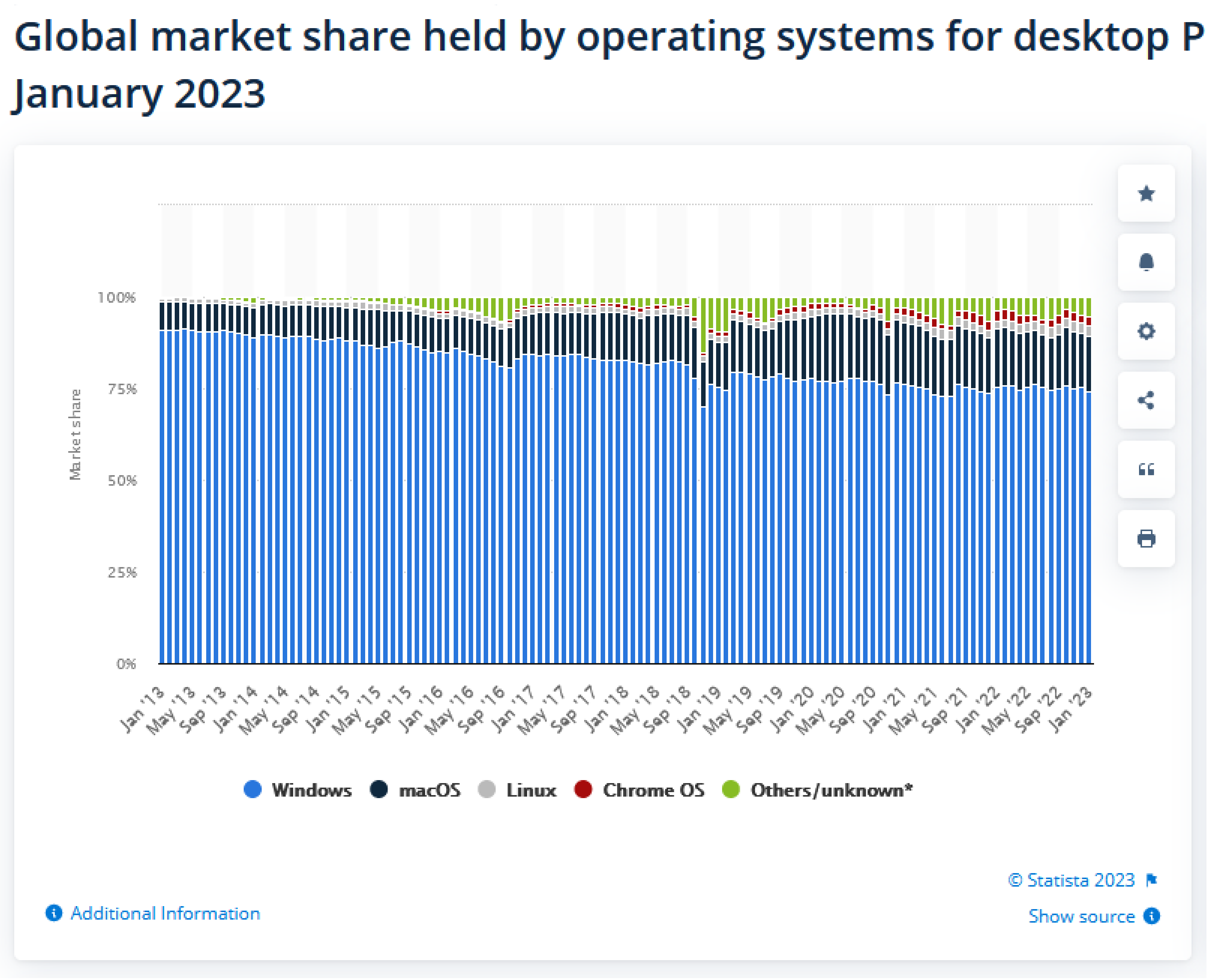
Shift from single-vendor dominance (MSFT) to multiple vendors (AAPL, GOOG, MSFT, Other)



Source: IDC, Goldman Sachs Research.

Market share of the OS-s





Global market share held by operating systems for desktop P January 2023

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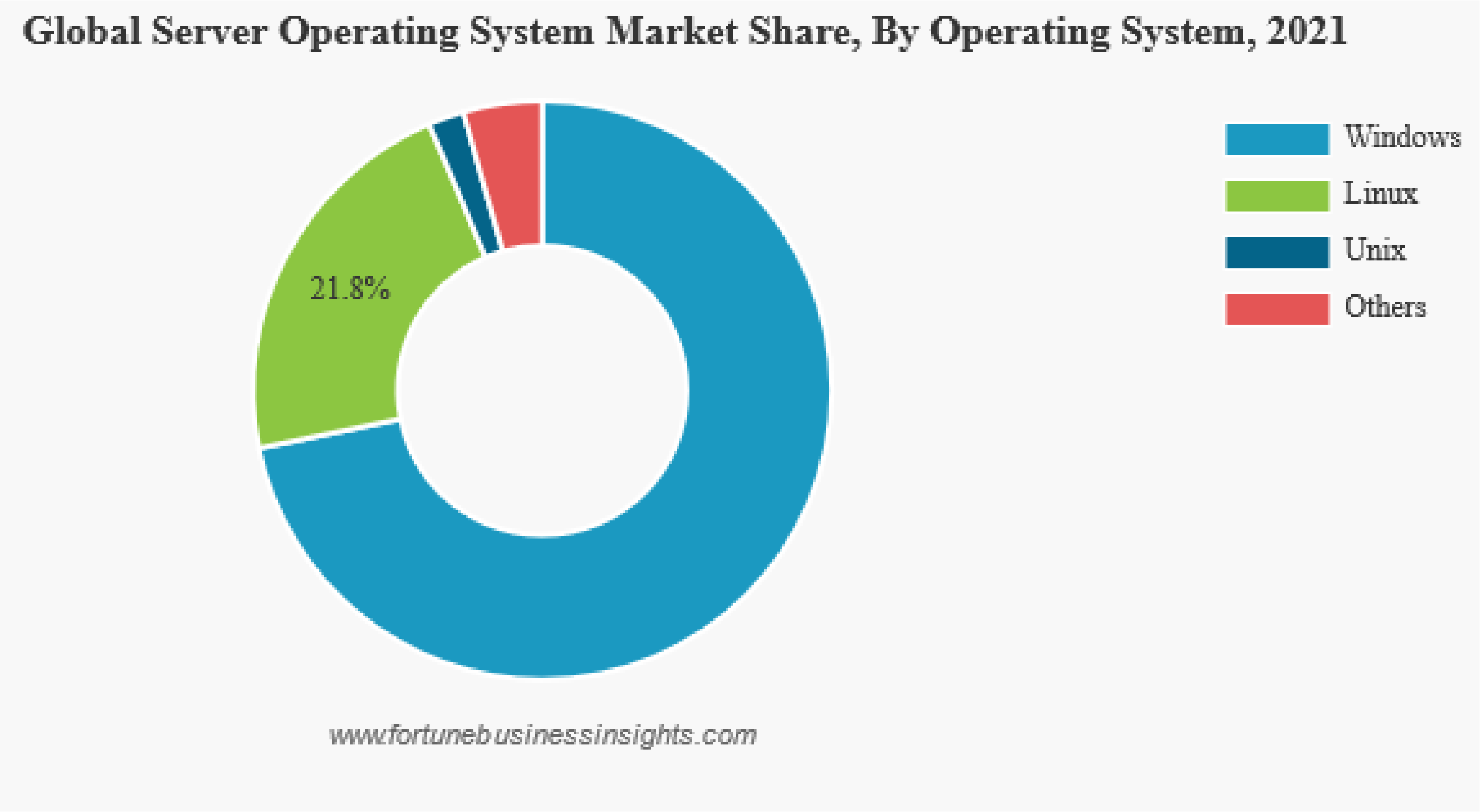

What makes order in the chaos of OS-s?

- Wide range of HW-s and SW-s
  - The nightmare of application developers
- The open-systems approach
  - Interoperability
  - Portability
  - User „portability”
- Implementing open-systems: standardization
  - Standard (de jure): specified by a formal association and approved in a formal way
  - Standardization of interfaces and protocols
  - Testing of conformity: checking implementations and applications
- Associations: ISO/IEC, IEEE, W3C, ANSI, Open Group, etc.
- OS standards (examples)
  - IEEE POSIX standard family
  - Linux Standards Base (LSB)
  - AT&T SVID (pl. SVR4) and BSD
  - Open Group: X/Open, Unix95, Unix98, …

Trends

- Better and cheaper HW-s
  - More processor cores, less power consumption
  - Heterogeneous architectures (multi type cores, OpenCL, FPGA threads)
  - Changing throughputs (SSD, fast flash IC-s)
- OS development trends
  - Multicore kernels (**multikernel**)
    - distributed system of **OSNode**s
  - Reducing the kernel overhead (**exokernel**)
    - the kernel makes a longer data route between the processor and devices
    - minimizing the kernel tasks, and some parts of the kernel runs on user level
  - The kernels are usually built around the processor
    - **universal memory:** the fast flash disks can become primary memories
    - CPU address base instead of [device ID + block] addressing
    - The memory is tied to multiple processor cores
    - The architecture is more and more built around the memory
  - New type of file systems
    - Extremely distributed – e.g. Google, object repository

Summary

- The OS is complex ecosystem
  - It’s purpose to manage HW devices and perform user tasks
  - Also provides many additional services
  - Wide range of usages on wide range of HWs
- The basic ideas are simple
  - Purpose oriented, secure, compatible, cooperative, open, easily programmable
- Colorful systems
  - From a few thousand LoC to multi-million LoC systems
  - Different services and user interfaces
  - The standardization is important (open interfaces and protocols)
- During this semester
  - An introduction will be provided to the different details of this ecosystem
  - Further knowledge can be obtained by trying some of the tasks in a virtualized environment (without risks)