CONSTRUCTION OF A HIGHLY DEPENDABLE OPERATING SYSTEM

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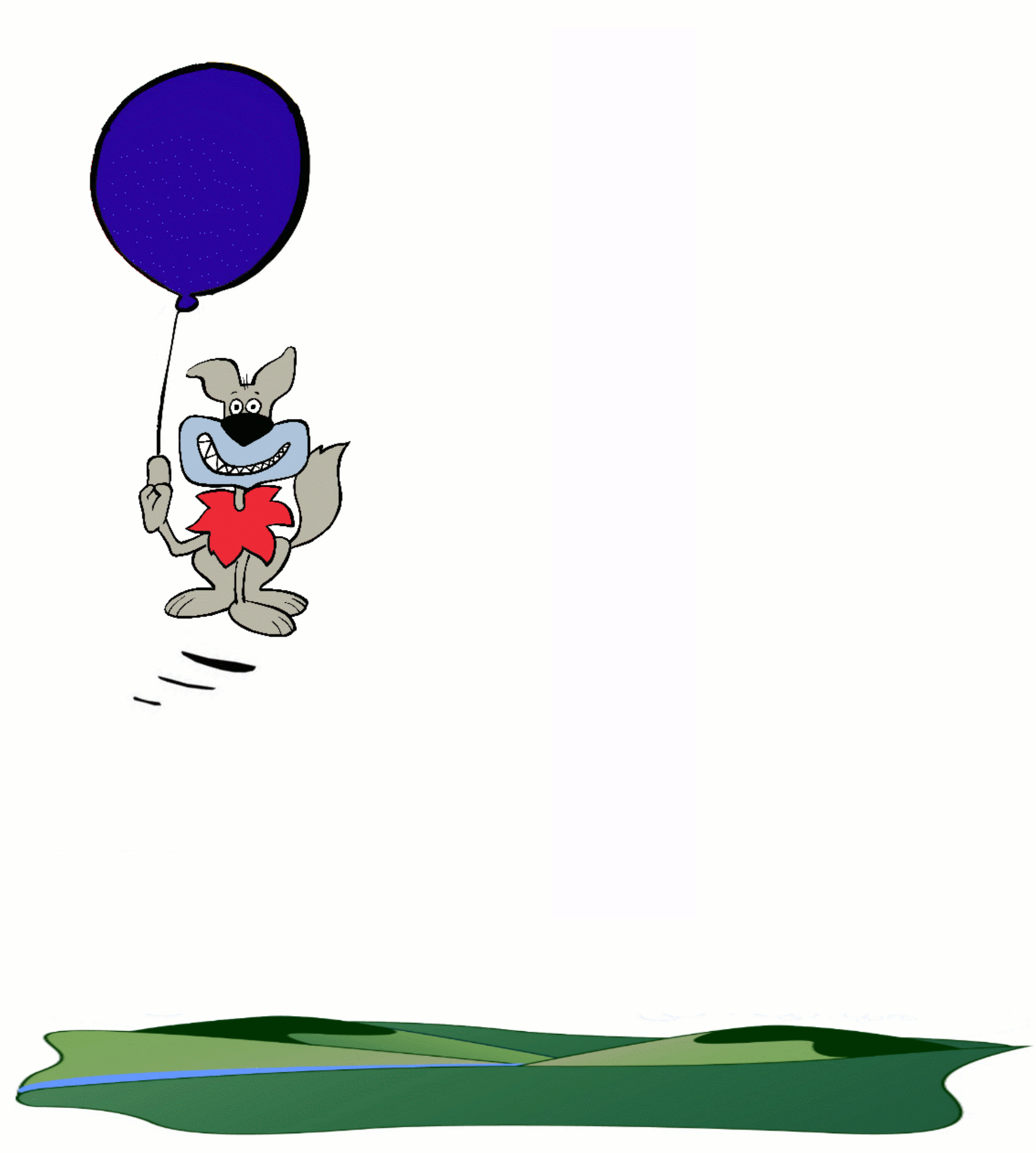
THE "BALLOON" OPERATING SYSTEM



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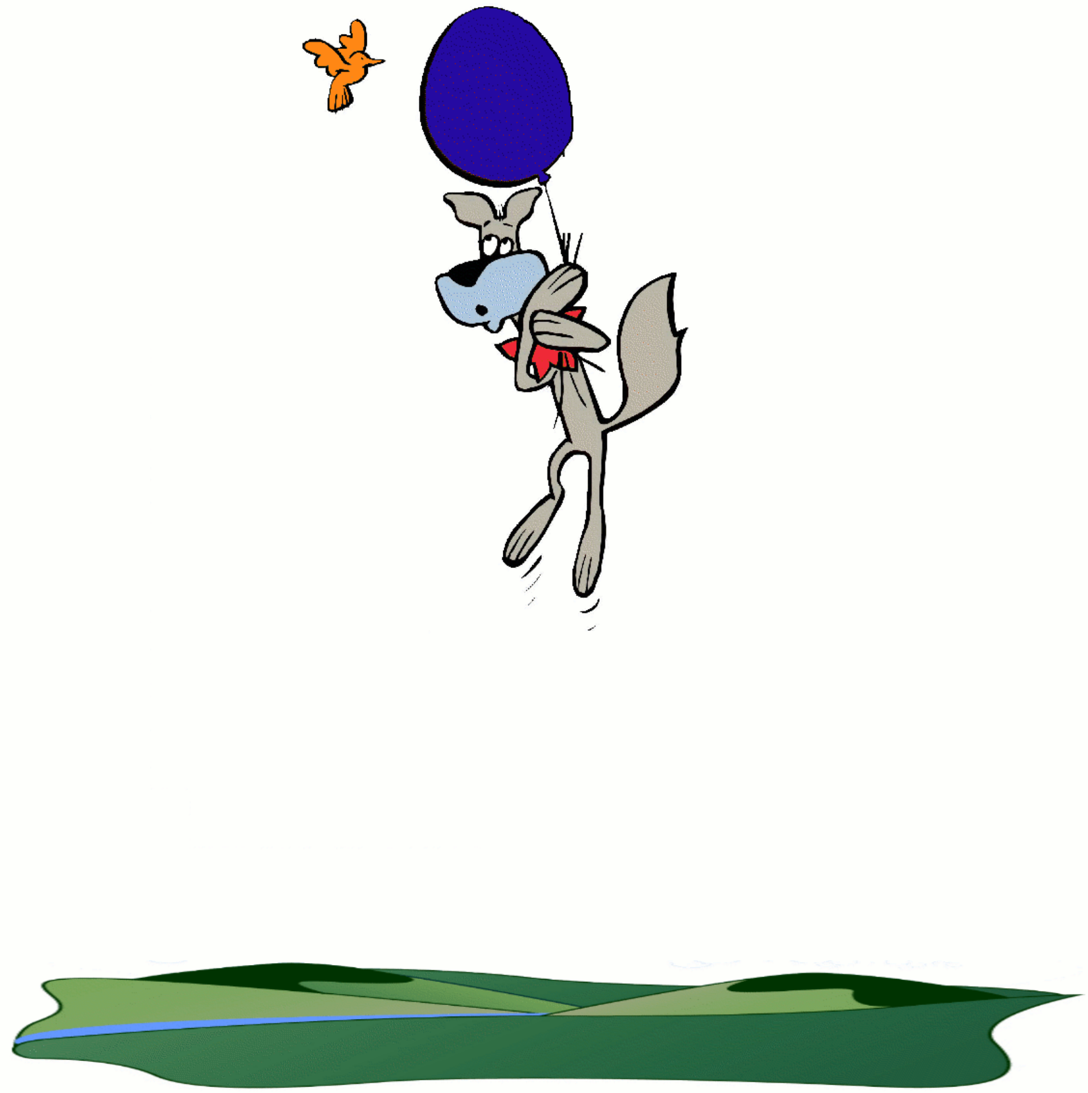

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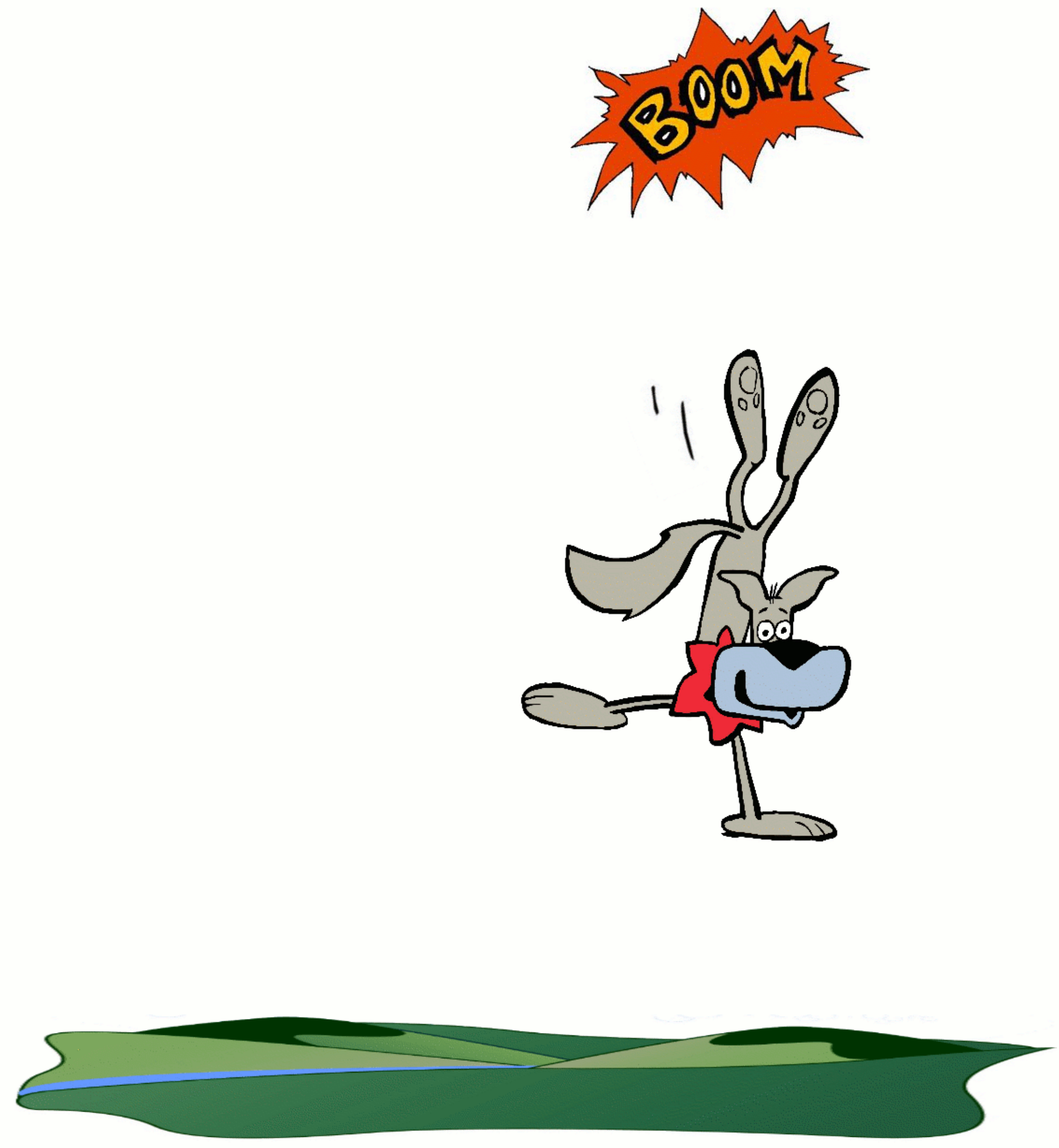
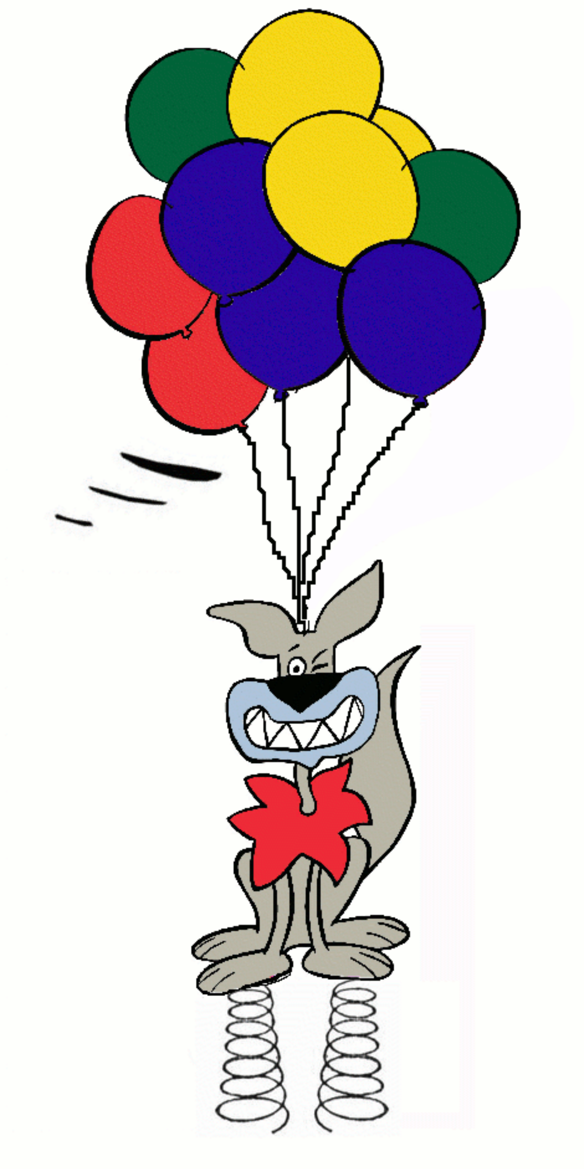


THE “BALLOON” OPERATING SYSTEM

IMPROVING OPERATING SYSTEM DEPENDABILITY

MINIX 3: a highly dependable OS

- Single failure no longer fatal
- Spring back after failure



TALK OUTLINE

- Welcome (done)
- Problem statement (next)
- Construction work
- Dependability features
- Performance statistics
- Discussion and conclusion

INTRODUCTION

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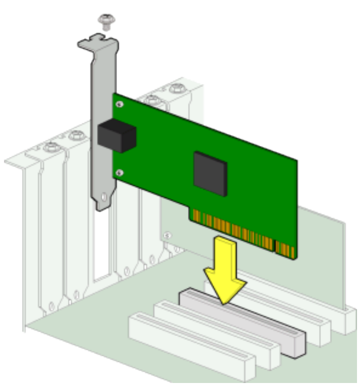
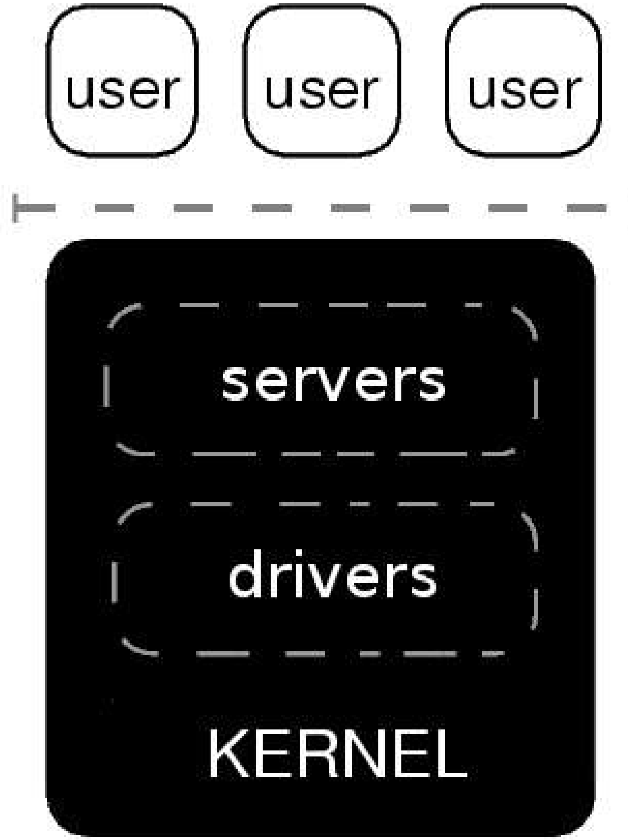
DRIVERS IN A MONOLITHIC OPERATING SYSTEM

- **Device drivers control hardware**





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DRIVERS IN A MONOLITHIC OPERATING SYSTEM

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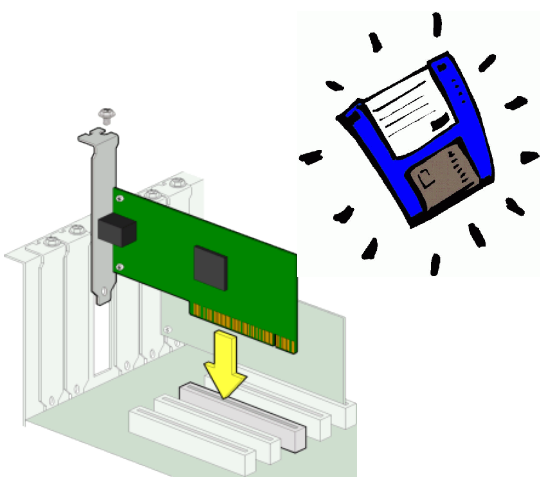

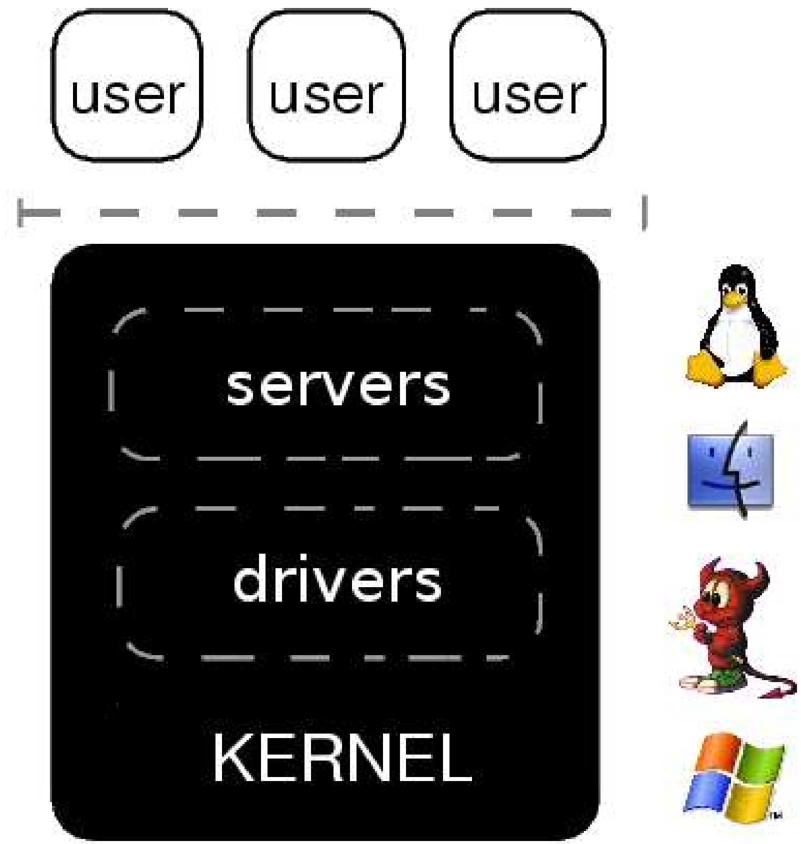

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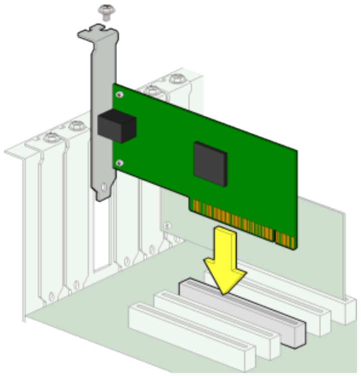
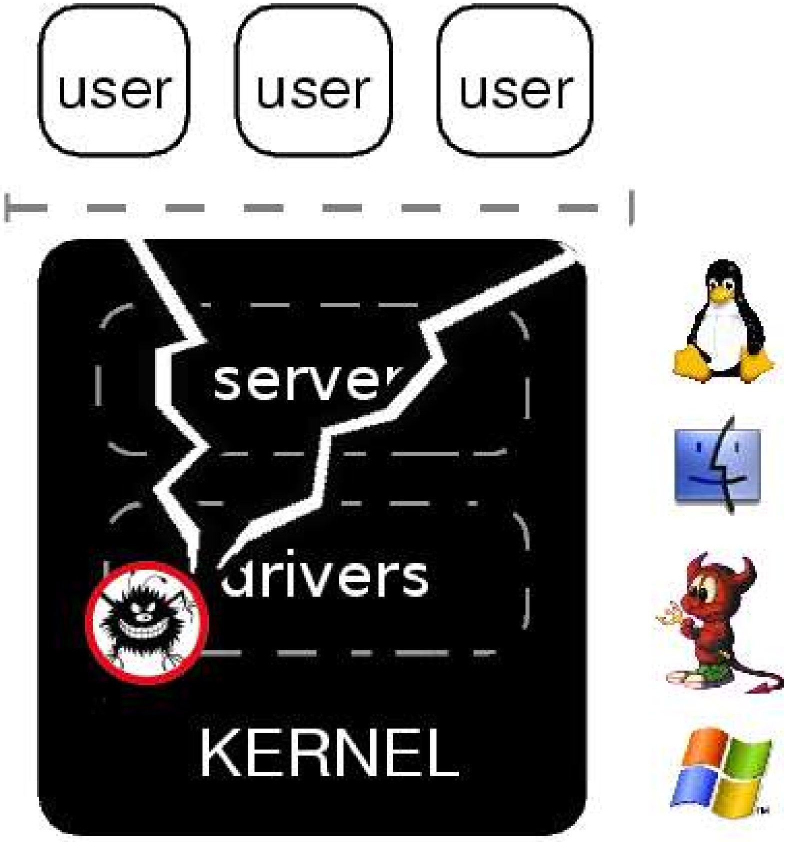
DRIVERS IN A MONOLITHIC OPERATING SYSTEM

- Device drivers control hardware
- Driver is run within the kernel
- Bugs can easily spread





INHERENT PROBLEMS OF MONOLITHIC DESIGNS

- **Fundamental design flaws in monolithic kernels**
  - All code runs at highest privilege level (breaches POLA)
  - No proper fault isolation (any bug can be fatal)
  - Huge amount of code *in* kernel (6-16 bugs per 1000 LOC)
  - Untrusted, 3rd party code in kernel (70% of code, more bugs)
  - Entangled code increases complexity (hard to maintain)

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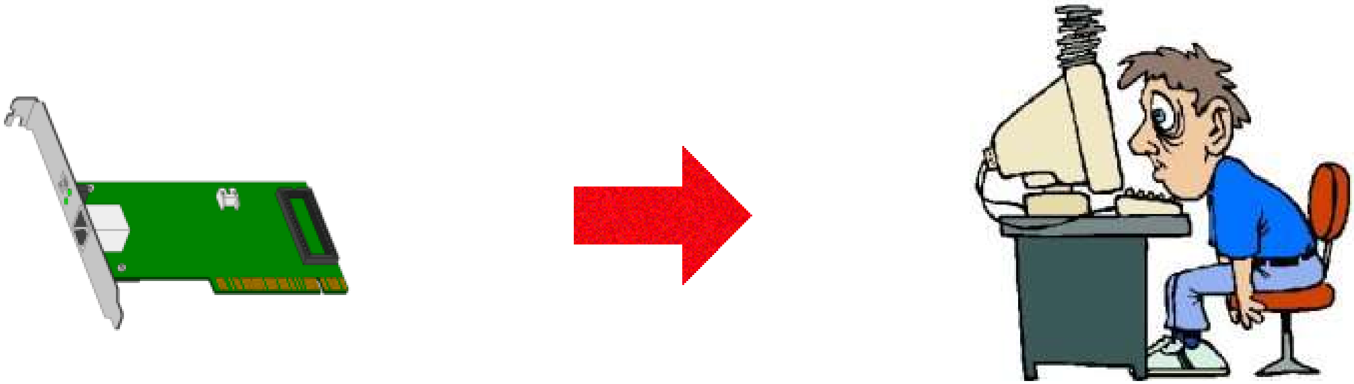
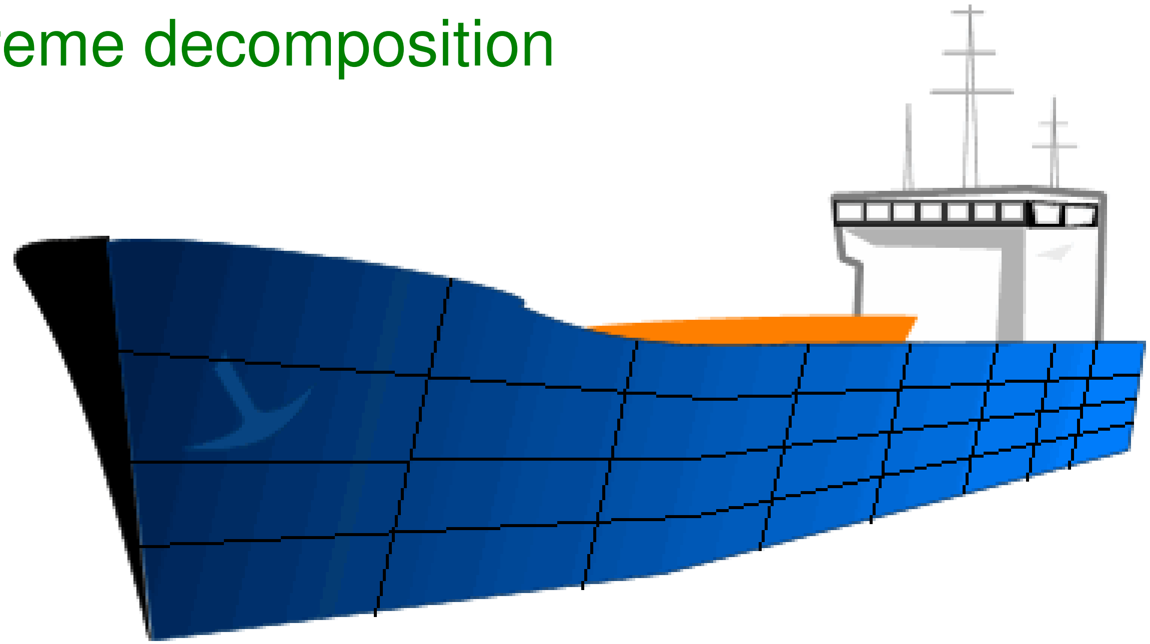


HOW ABOUT MODULAR DESIGNS?

- **Modularity is commonly used in other engineering disciplines**
  - Ship's hull is compartmentalized to improve 'dependability'
  - Aircraft carrier is build out of many, well-isolated parts
- **Use modularity to improve OS dependability**
  - We propose an extreme decomposition



CONSTRUCTION

UNDERLYING IDEA

“Perfection is not achieved when there is nothing left to add, but when there is nothing left to take away.”

-- Antoine de Saint-Exupéry

MINIX 3: A HIGHLY RELIABLE OPERATING SYSTEM

- **Microkernel design (< 4000 LOC)**
  - Low-level operations to support user-space OS
- **OS runs as set of isolated user-mode servers and drivers**
  - MMU protection and various other encapsulation properties
- **Mechanisms to detect and repair failures**
  - Privileged server can replace failed components

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DRIVER–KERNEL DEPENDENCIES

- **Finding dependencies**
  - Compile driver code in isolation to find missing symbols
  - In addition, all drivers attempt to perform I/O

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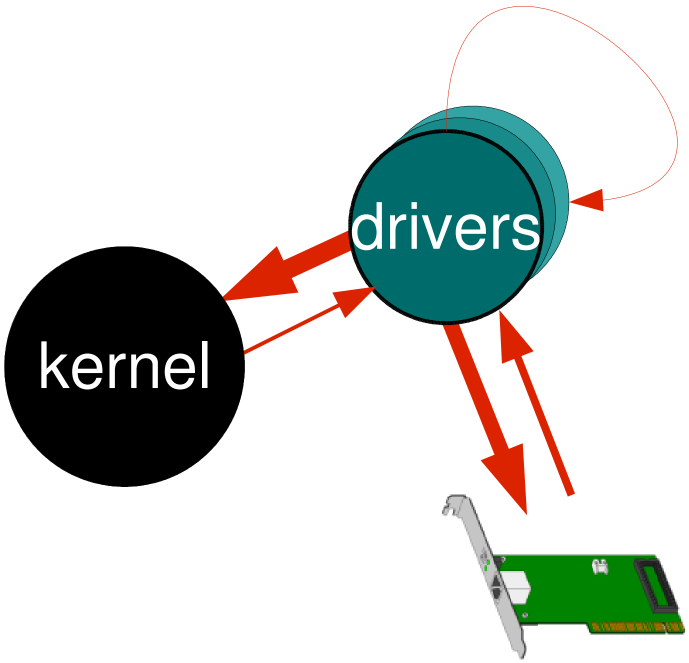
  - Compile driver code in isolation to find missing symbols
  - In addition, all drivers attempt to perform I/O
- **Who depends on what?**

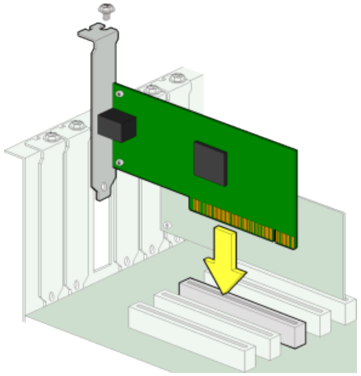


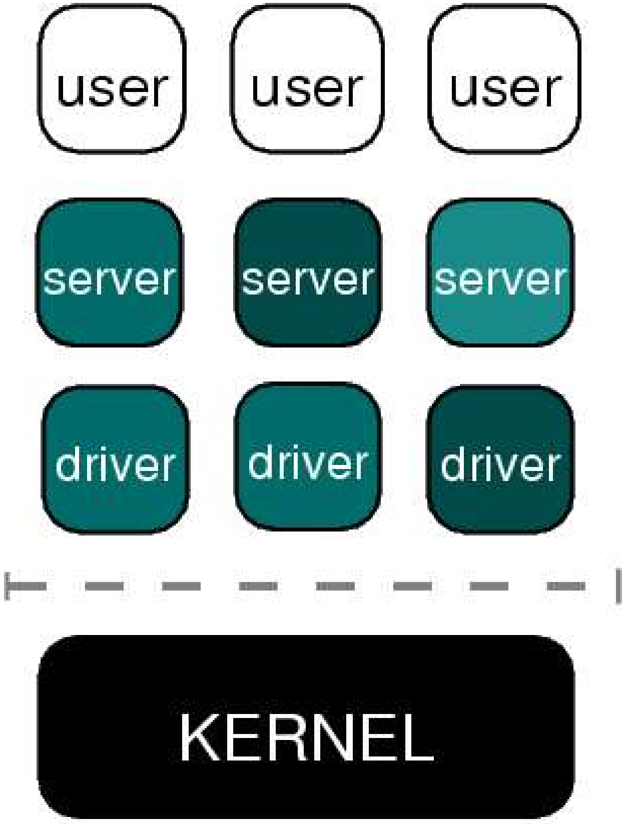
MOVING DRIVERS OUT OF THE KERNEL

- **Resolve dependencies one by one**
  - Add new system calls (SYS_DEVIO, etc.)
  - Disentangle interrupt handlers
  - Other improvements (new IPC, code cleanup, etc.)
- **Test modified driver in kernel space**
- **Finally, move to separate directory in user space**

ARCHITECTURE OF MINIX 3

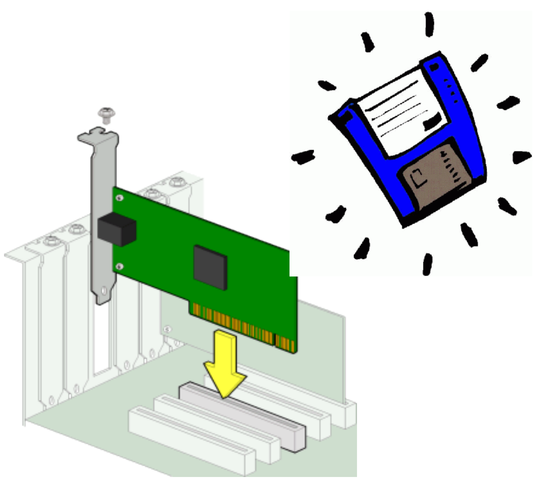
- **Device drivers are fully isolated in user space**

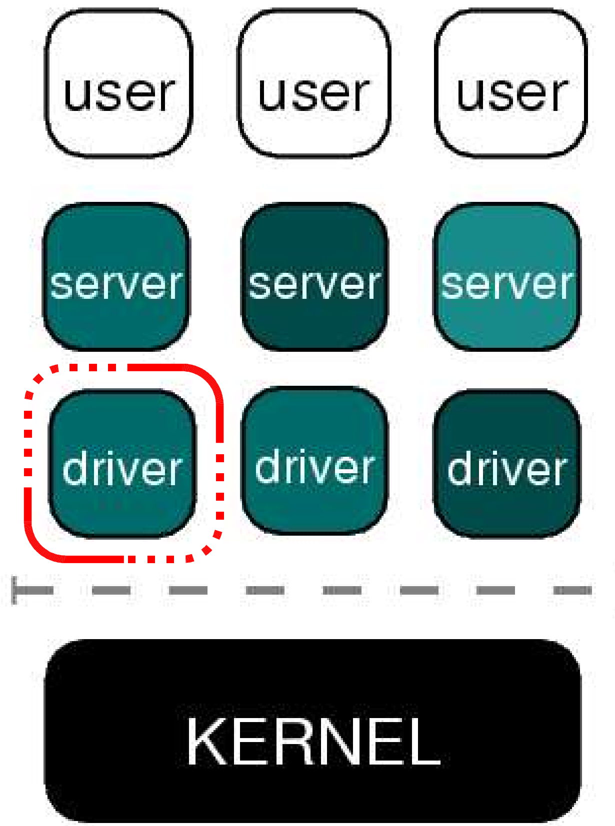




ARCHITECTURE OF MINIX 3

- Device drivers are fully isolated in user space
- Local failures cannot spread





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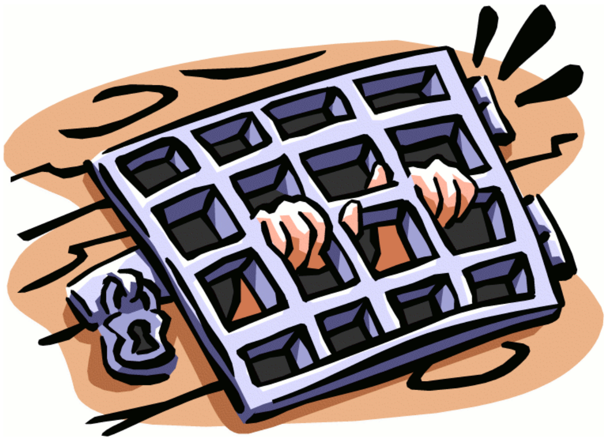
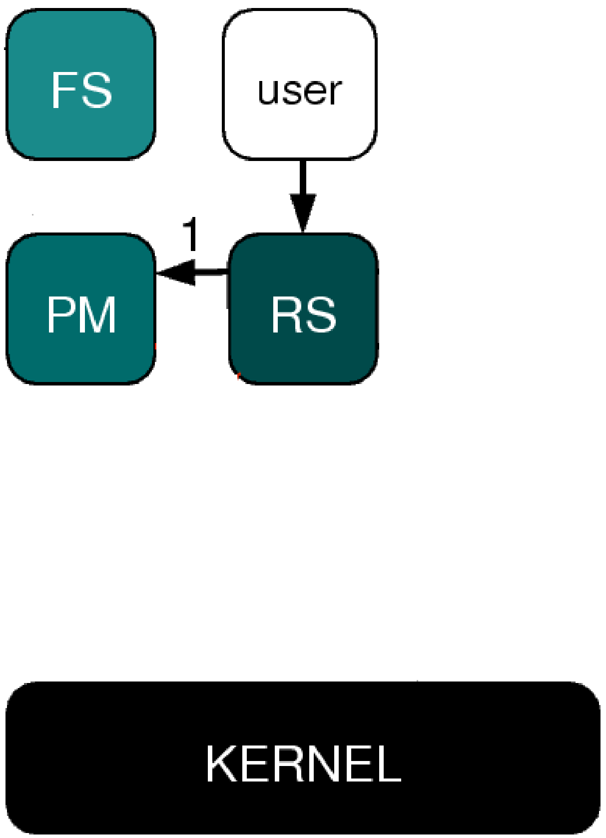
DEPENDABILITY

FAULT ISOLATION

- **All servers and drivers can fail independently**
- **Limit consequences of faults to enable recovery**
  - Servers and drivers fully compartmentalized in user space
  - Private address spaces protected by kernel and MMUs
  - Privileges of each process reduced according to POLA



DEVICE DRIVER MANAGEMENT



- **Starting a new driver**
  (1) Fork new process

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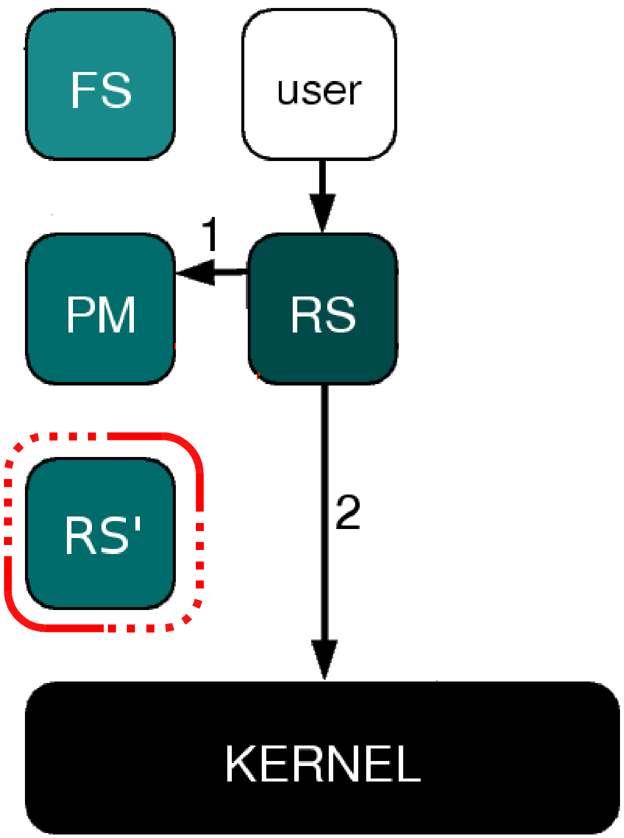
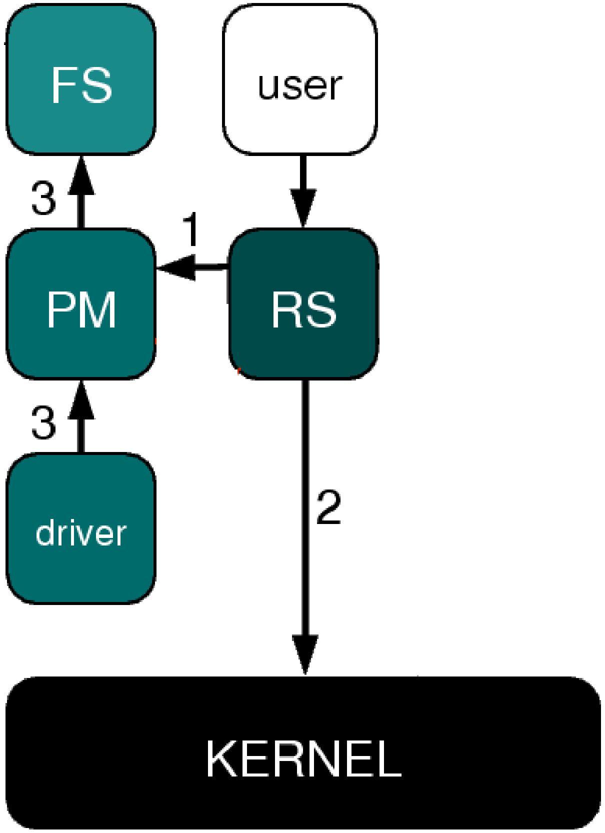


- **Starting a new driver**
  - (1) Fork new process
  - (2) Assign privileges

DEVICE DRIVER MANAGEMENT



- **Starting a new driver**

  (1) Fork new process

  (2) Assign privileges

  (3) Execute binary

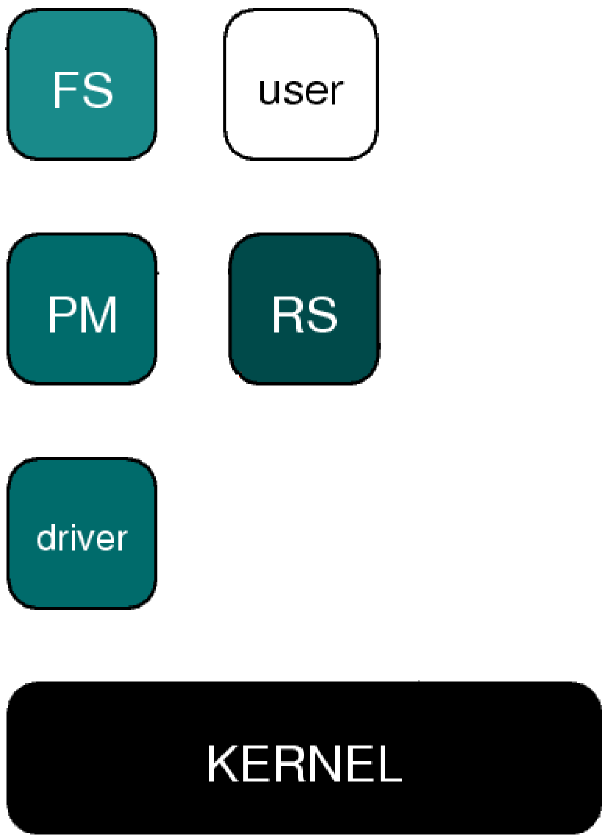
FAULT RESILIENCE

- **Our design tries to automatically *repair* defects**

  (1) Identify malfunctioning component

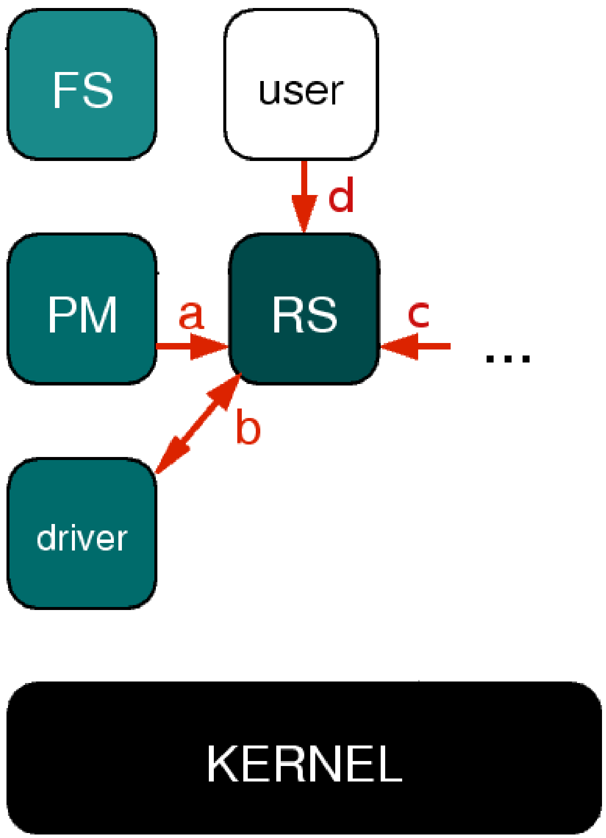
  (2) Execute associated recovery script

DETECTING DRIVER FAILURES



- **Human user observes**
  - System crash
  - Unresponsiveness
  - Weird behavior

DETECTING DRIVER FAILURES



- **OS monitors drivers**
  - (a) Exit notification
  - (b) Heartbeat message
  - (c) Component complains
  - (d) User requests update

RECOVERY PROCESS

- **Run recovery script**
  - Shell script that governs recovery steps taken
  - Full flexibility: write to log, send e-mail, restart component
- **Restart dead drivers**
  - Assumes restart enables recovery
- **Reintegrating the component**
  - Restarted component can retrieve lost state from data store
  - Dependent components are informed through data store

PERFORMANCE

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PERFORMANCE OF MINIX 3

- **Overhead of user-mode drivers (compared to MINIX 2)**
  - Run times for typical applications: 6% overhead
  - File system and disk I/O performance: 9% overhead
  - Disk throughput (with fast disk and DMA) up to 70 MB/s
  - Networking performance: Fast Ethernet at full speed
    - Initial experiments show gigabit ethernet is possible
- **System feels fast and responsive**
  - Time from multiboot monitor to login is under 5 sec.
  - The system can do a full build of itself in under 10 sec.

SOURCE CODE STATISTICS

- **Kernel (including kernel tasks): < 4000 LOC**
- **Most important servers and drivers: ~2500 LOC**
- **Minimal POSIX-conformant system: ~20,000 LOC**
  - Critical source code reduced by >2 orders of magnitude
  - Sources are small enough to read and understand

DEPENDABILITY EVALUATION

- **Fault-injection experiments are work in progress**
- **Measurements of the recovery overhead:**

DISCUSSION

USER VIEW OF MINIX 3

- **Using MINIX 3 is like using a normal multiuser UNIX system**
  - However, not as mature as FreeBSD or Linux
  - Only 18 months of development with small core of people
    - Nevertheless, over 400 UNIX applications available
    - In-house TCP/IP stack with BSD sockets
    - X Window System was ported
    - VFS infrastructure was also added
    - VM support is next big hurdle

GENERAL APPLICABILITY

- **Users demand highly dependable systems**
  - Trade-off between “X” / dependability is changing
    - “X” = performance, costs, etc.
- **We offer a *useful* alternative to commodity systems**
- **Our techniques can be applied to other systems**
  - Trend towards user-mode drivers on other systems
  - Guard drivers similarly to what we have done

CONCLUSIONS

- **We have constructed a highly dependable OS**
  - Number of fatal (kernel) bugs is reduced
  - Isolation in user space limits bug damage
  - Recovery from common failures is possible
- **Our approach is practical for real-world adoption**
  - Overhead negligible compared to hardware improvements
  - Reduction of critical code base improves manageability
  - Fault injection experiments prove viability of approach

MORE INFORMATION

- Jorrit N. Herder, Herbert Bos, Ben Gras, Philip Homburg, Andrew S. Tanenbaum,

  Reorganizing UNIX for Reliability,

  Proc. 11th Asia-Pacific Computer Systems Architecture Conference, Shanghai, China, Sep. 2006.

- Jorrit N. Herder, Herbert Bos, Ben Gras, Philip Homburg, Andrew S. Tanenbaum,

  Construction of a Highly Dependable Operating System,

  Proc. 6th European Dependable Computing Conference, Coimbra, Portugal, Oct. 2006 .

TIME FOR QUESTIONS

- **Try it yourself!**
  - MINIX 3 Live CD-ROM
  - Current version: see website
- **More information**
  - Web: www.minix3.org
  - News: comp.os.minix
  - E-mail: jnherder@cs.vu.nl
- **The MINIX 3 team:**
  - Jorrit Herder
  - Mischa Geldermans
  - Ben Gras
  - Philip Homburg
  - Herbert Bos
  - Andy Tanenbaum

ANSWERS