TECHNISCHE UNIVERSITÄT DRESDEN

Department of Computer Science Institute of System Architecture, Operating Systems Group

SECURITY ARCHITECTURES

CARSTEN WEINHOLD

MOTIVATION

- Common observations:
  - Complex software has security bugs
  - Users are plagued by malware
  - User PCs become bots, crypto miners, …
  - Critical data gets stolen / held for ransom
  - Targeted attacks at high-value users: Industry, governments, dissidents, NGOs, ...
- Snowdon told us how bad it really is!

MOTIVATION

- It's all the same for mobile devices
  - Malware in Android Store: lots of it …
  - Hacked Xcode: hundreds of iOS apps compromised
- Security-critical bugs:
  - Drivers [1,2], USB stacks [7], boot loaders
  - Messaging apps [8], web browser, media service, …
- „Jailbreaking" / „rooting" = attack on security:
  - Requires physical access ...
  - ... or visit special website [9]

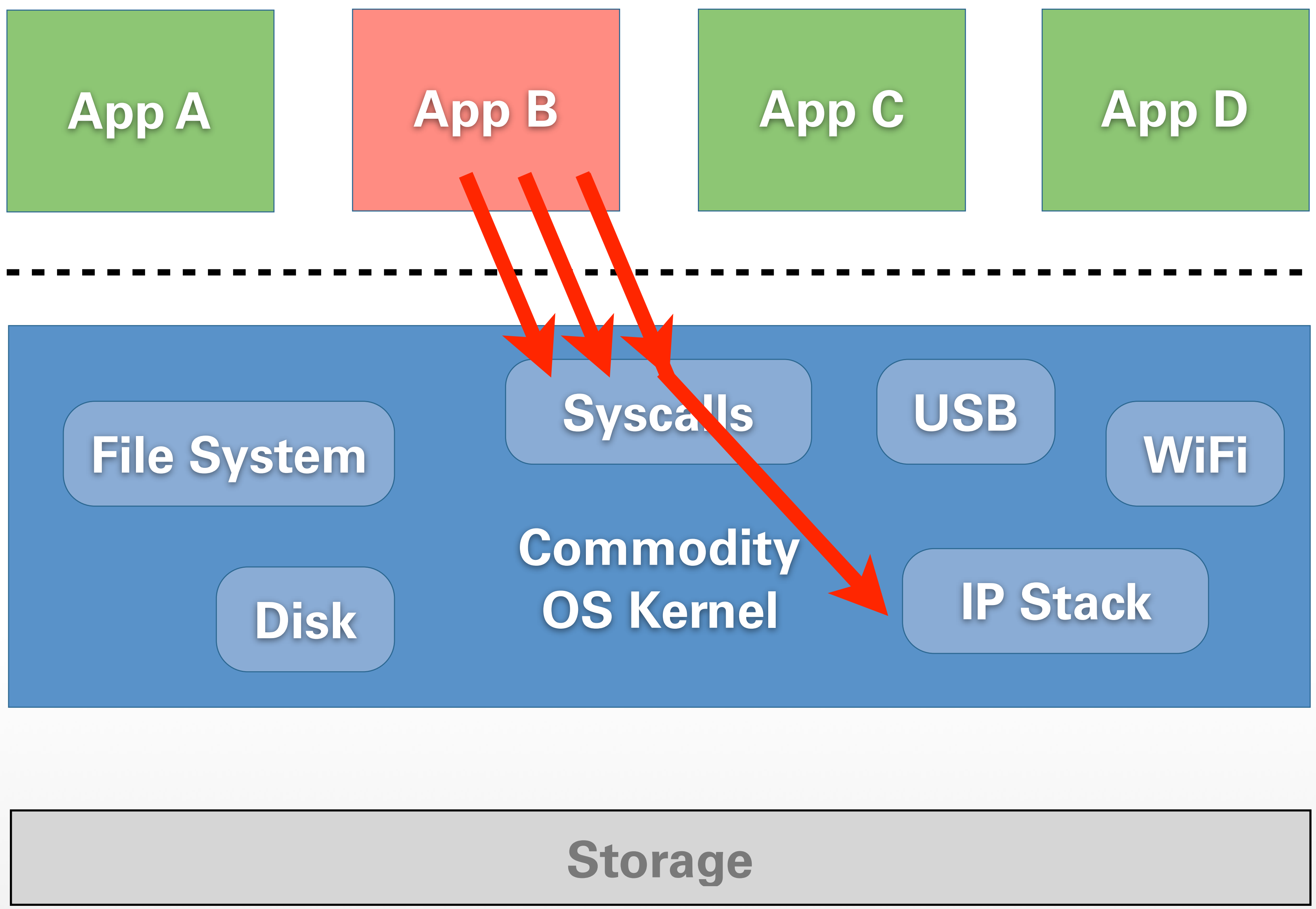
MELTDOWN & SPECTRE

CLASSICAL ARCHITECTURES

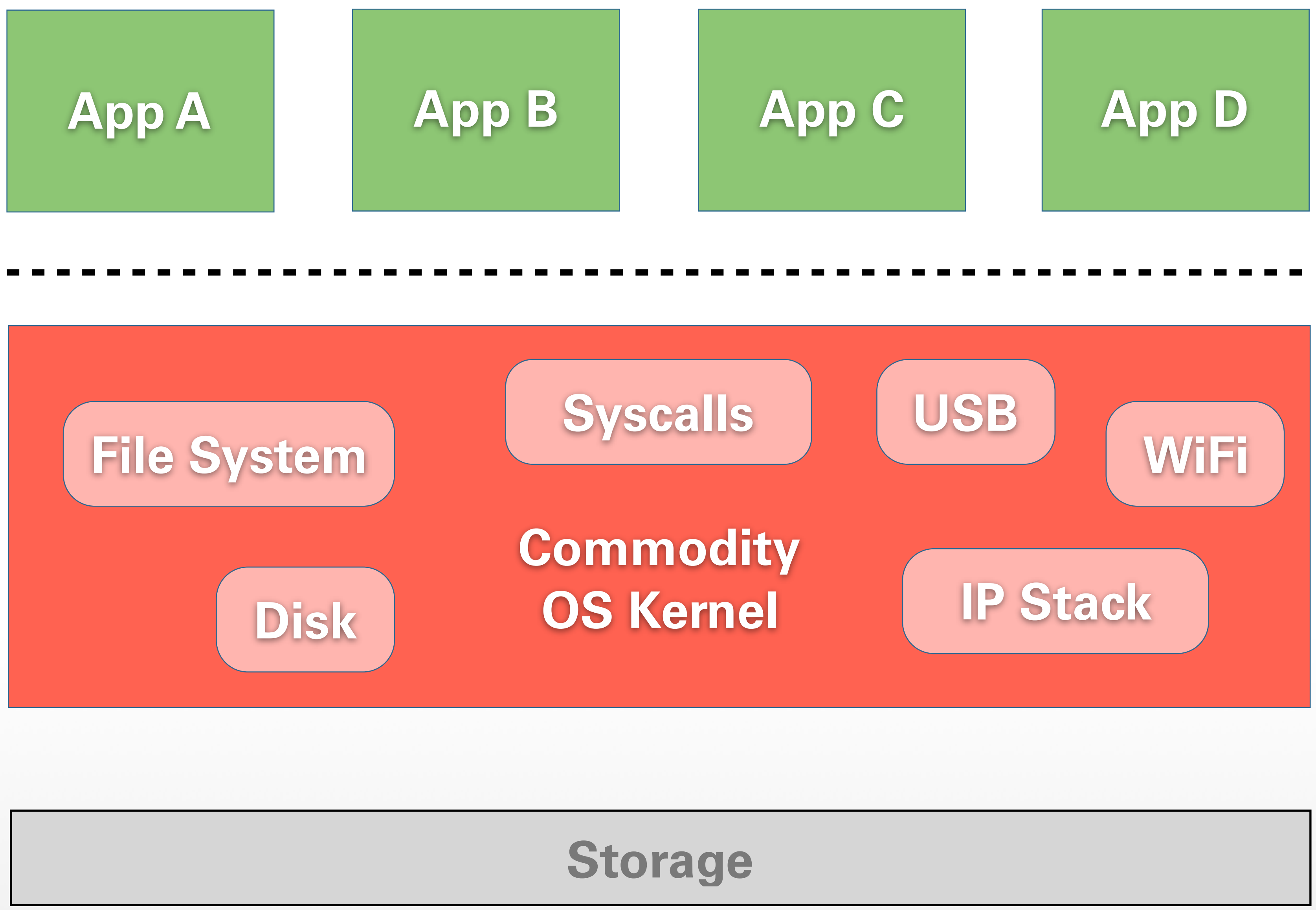
ISOLATION

- Isolation in commodity OSes based on user accounts:
  - Same privileges for all apps
  - No isolation within applications
  - Permissive interfaces (e.g., ptrace to manipulate other address spaces)

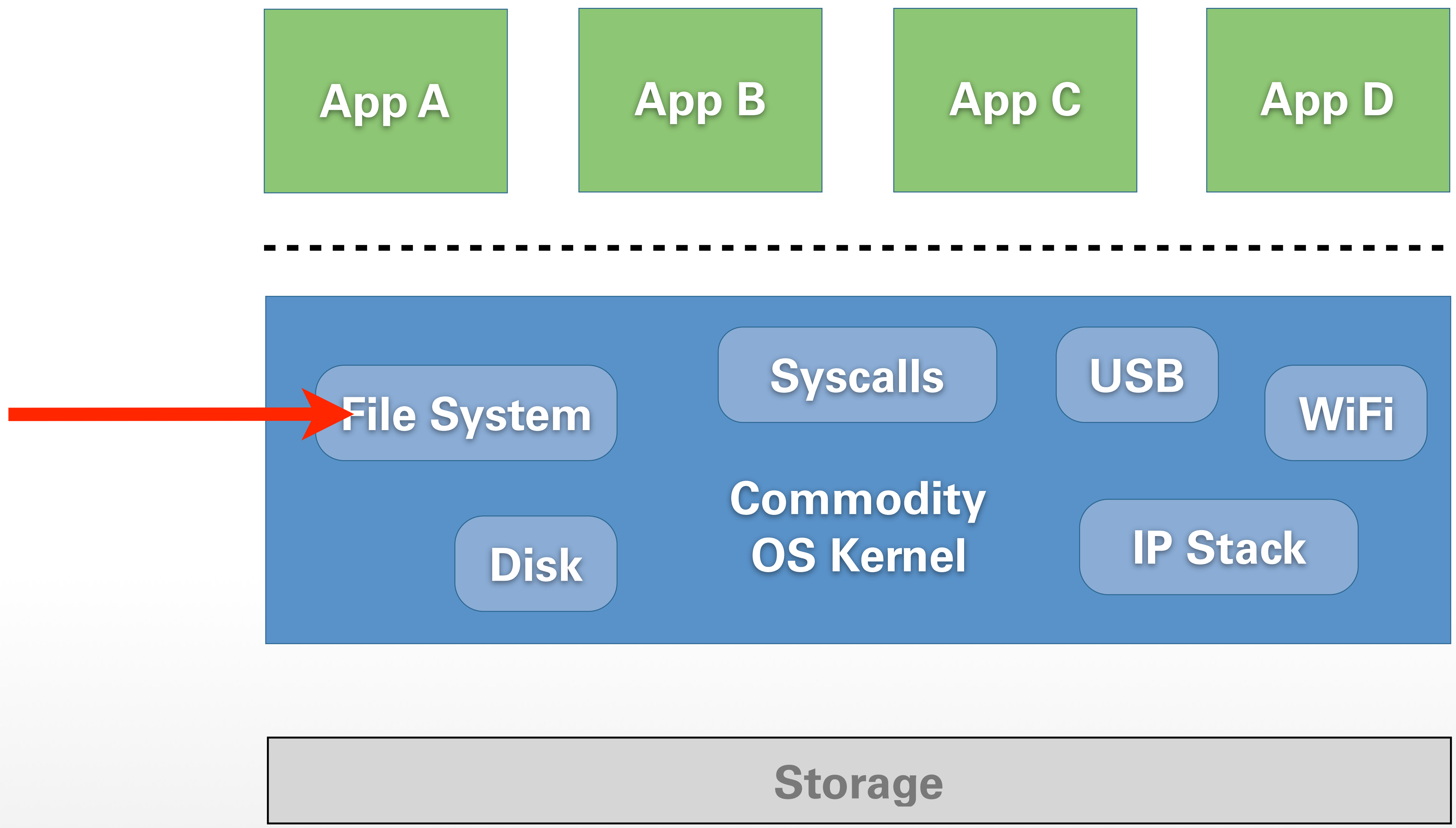
KERNEL ATTACK VECTOR



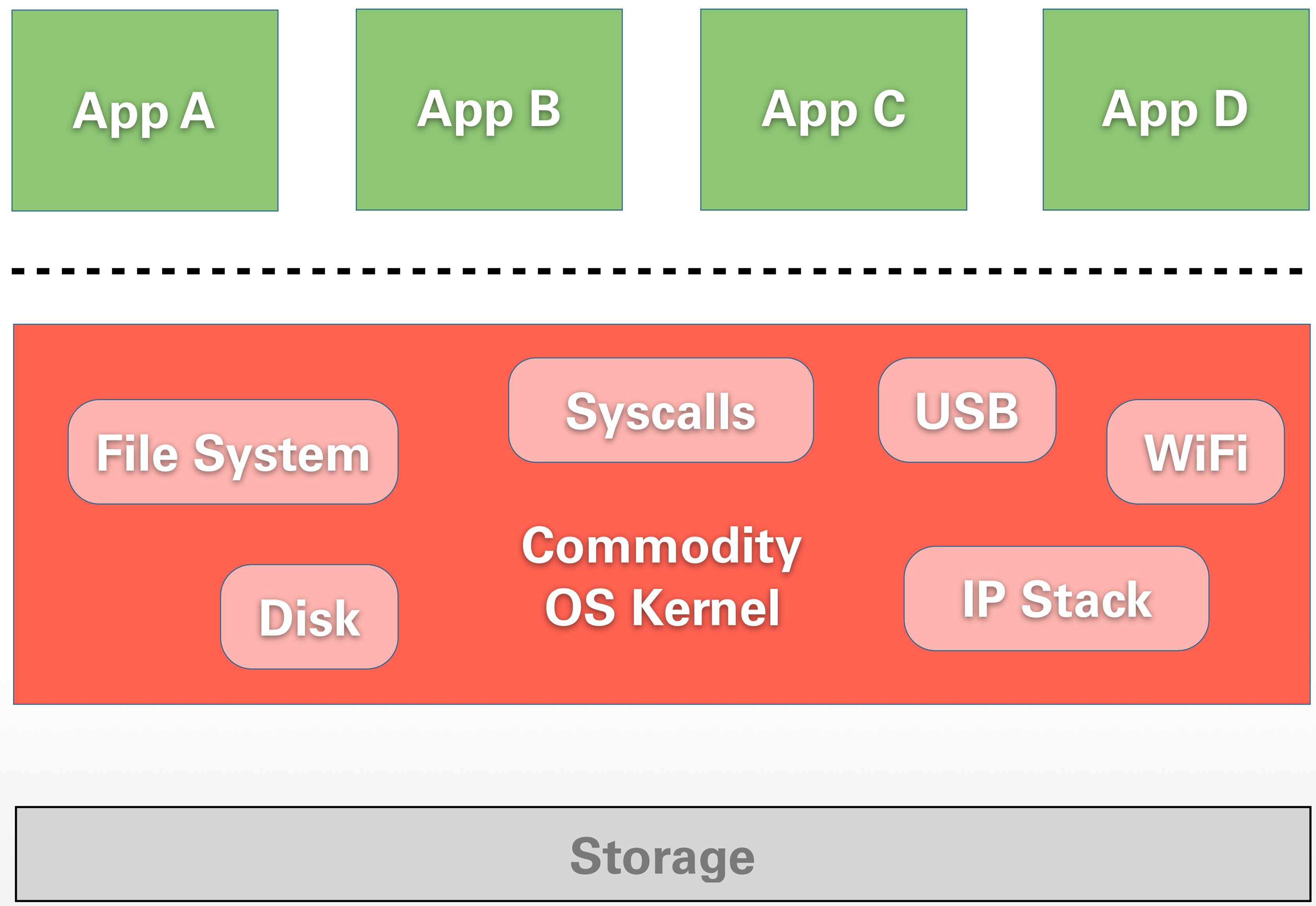
KERNEL ATTACK VECTOR



KERNEL ATTACK VECTOR



KERNEL ATTACK VECTOR

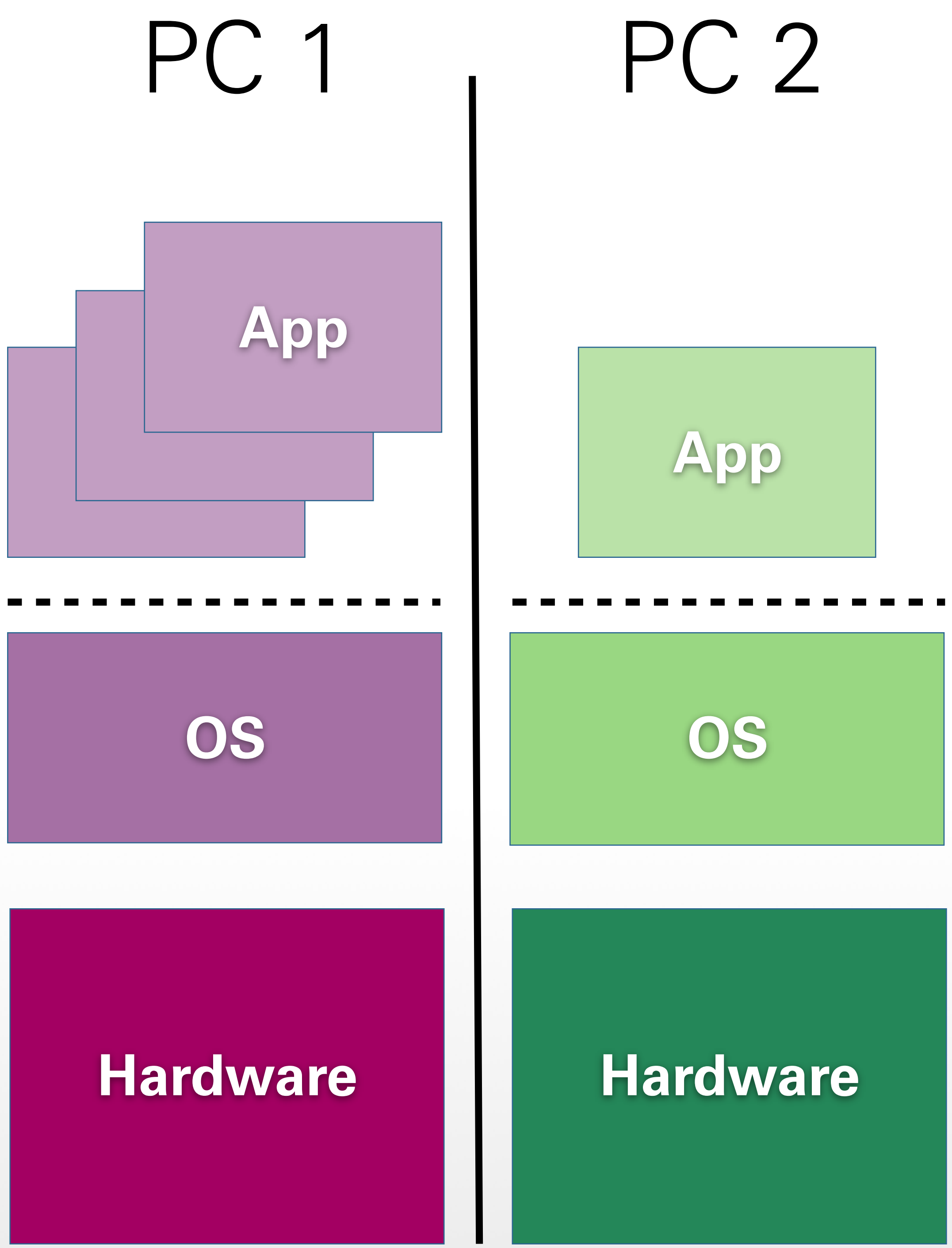


ISOLATION

- Isolation in commodity OSes based on user accounts:
  - Same privileges for all apps
  - No isolation within applications
  - Permissive interfaces (e.g., ptrace to manipulate other address spaces)
- Efforts to restrict privileges:
  - SELinux, AppArmor, Seatbelt, ...

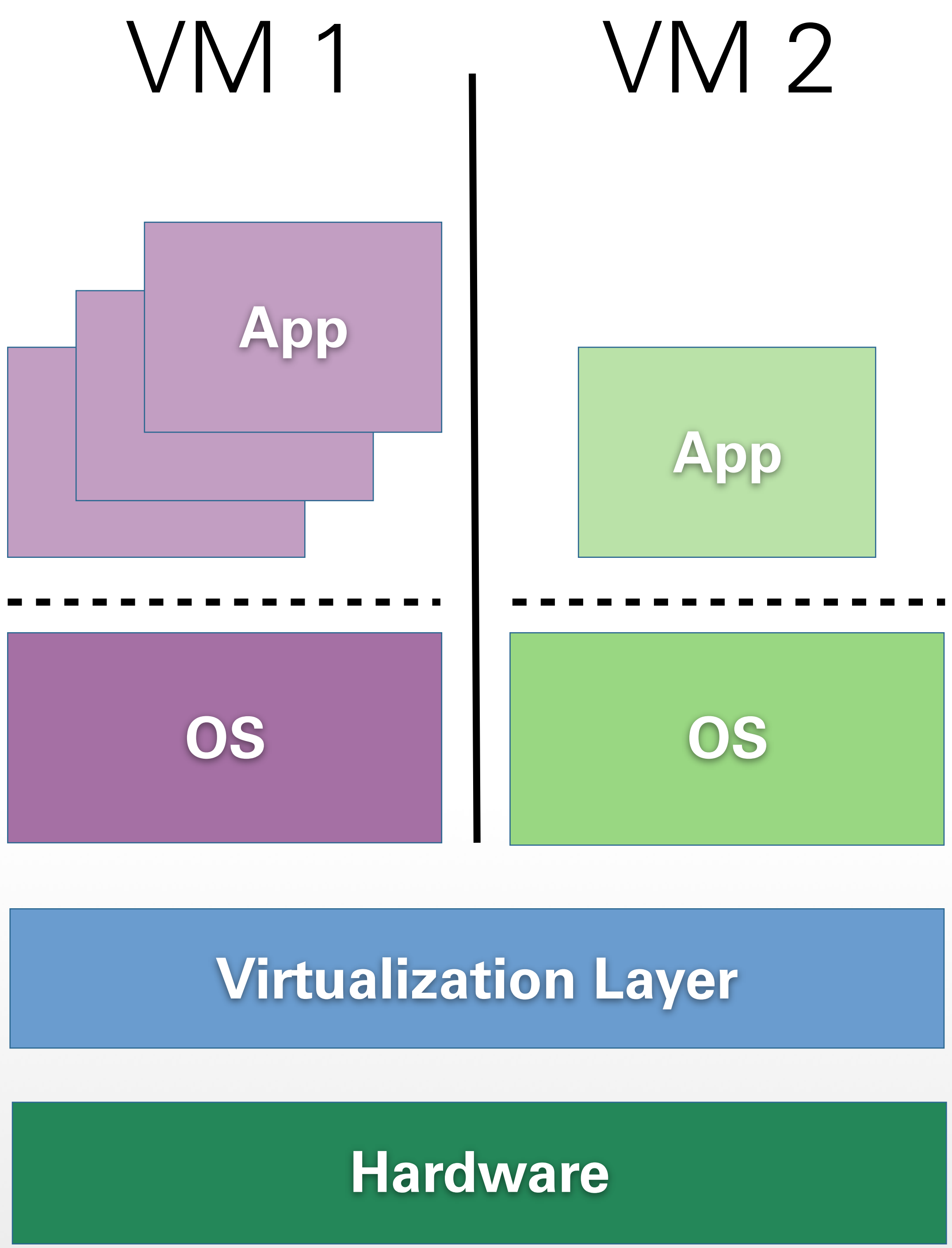
HW ISOLATION

- Separate computers
- Applications and data physically isolated
- Effective, but ...
  - High costs
  - Needs more space
  - Inconvenient
  - Exposure to network may pose threat



VM ISOLATION

- Multiple VMs, OSes
- Isolation enforced by virtualization layer
- Saves space, energy, maintenance effort
- But still ...
  - Switching between VMs is inconvenient
  - Even more code



ARE WE SECURE?

- Huge code bases remain
- Applications still the same
- Many targets to attack:
  - Applications, libraries, commodity OSes
  - Virus scanner, firewall, ...
  - Virtualization layer
- High overhead for many VMs

SECURITY ARCHITECTURES

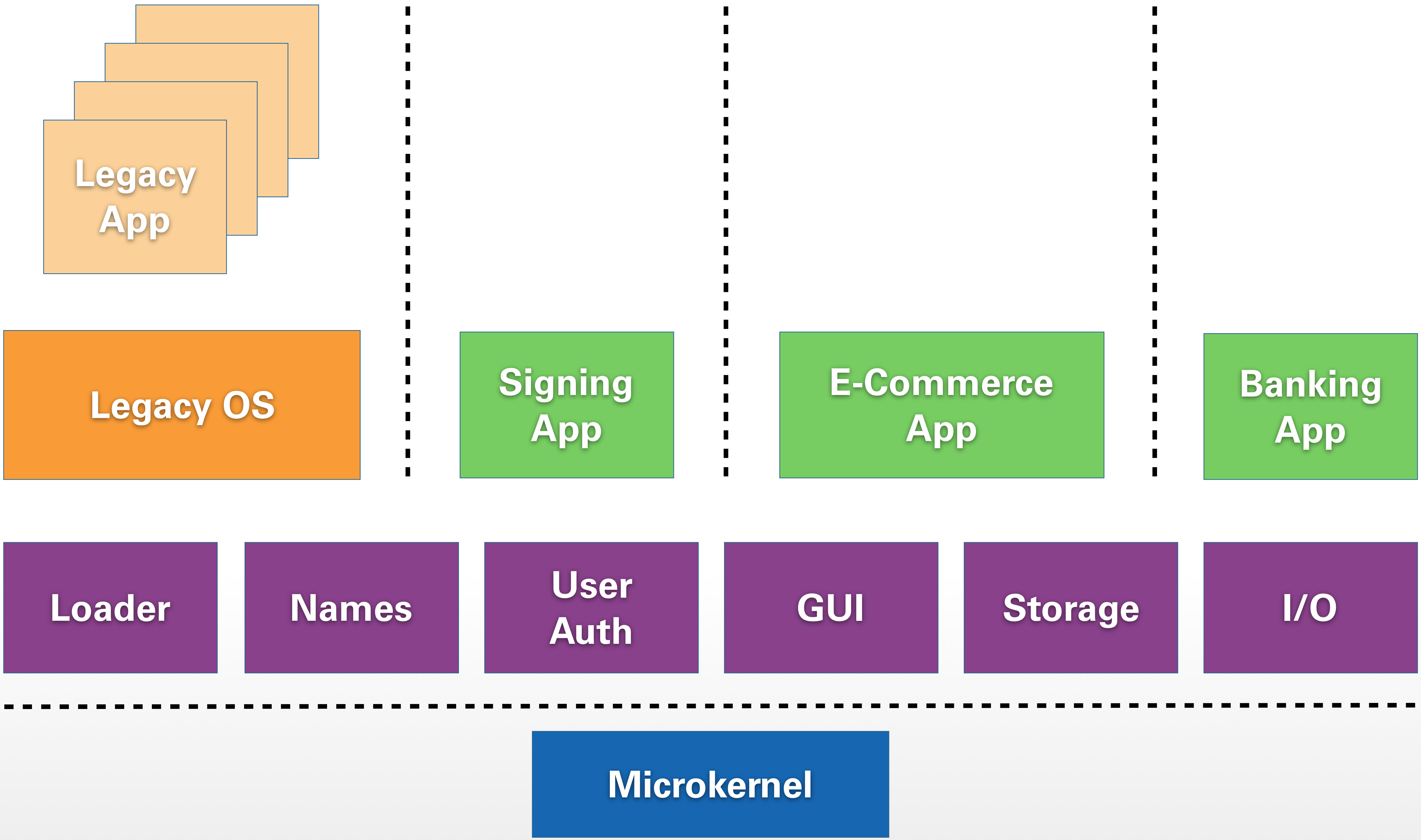
SECURITY GOALS

- Protect the user's data
- Secure applications that process data
- Acknowledge different kinds of trust:
  - Application **A** trusted to handle its own data, but not the files of application **B**
  - OS trusted to *store* data, but not to *see* it
- Identify and secure **TCB:** the **T**rusted **C**omputing **B**ase

APPROACH

- To improve security: Reduce size of TCB = smaller attack surface
- First (incomplete) idea:
  - Remove huge legacy OS from TCB
  - Port application to microkernel-based multi-server OS
  - Remove unneeded libc backends, etc.
  - Possible approaches discussed in lecture on „Legacy Reuse“

NIZZA ARCHITECTURE



NIZZA ARCHITECTURE

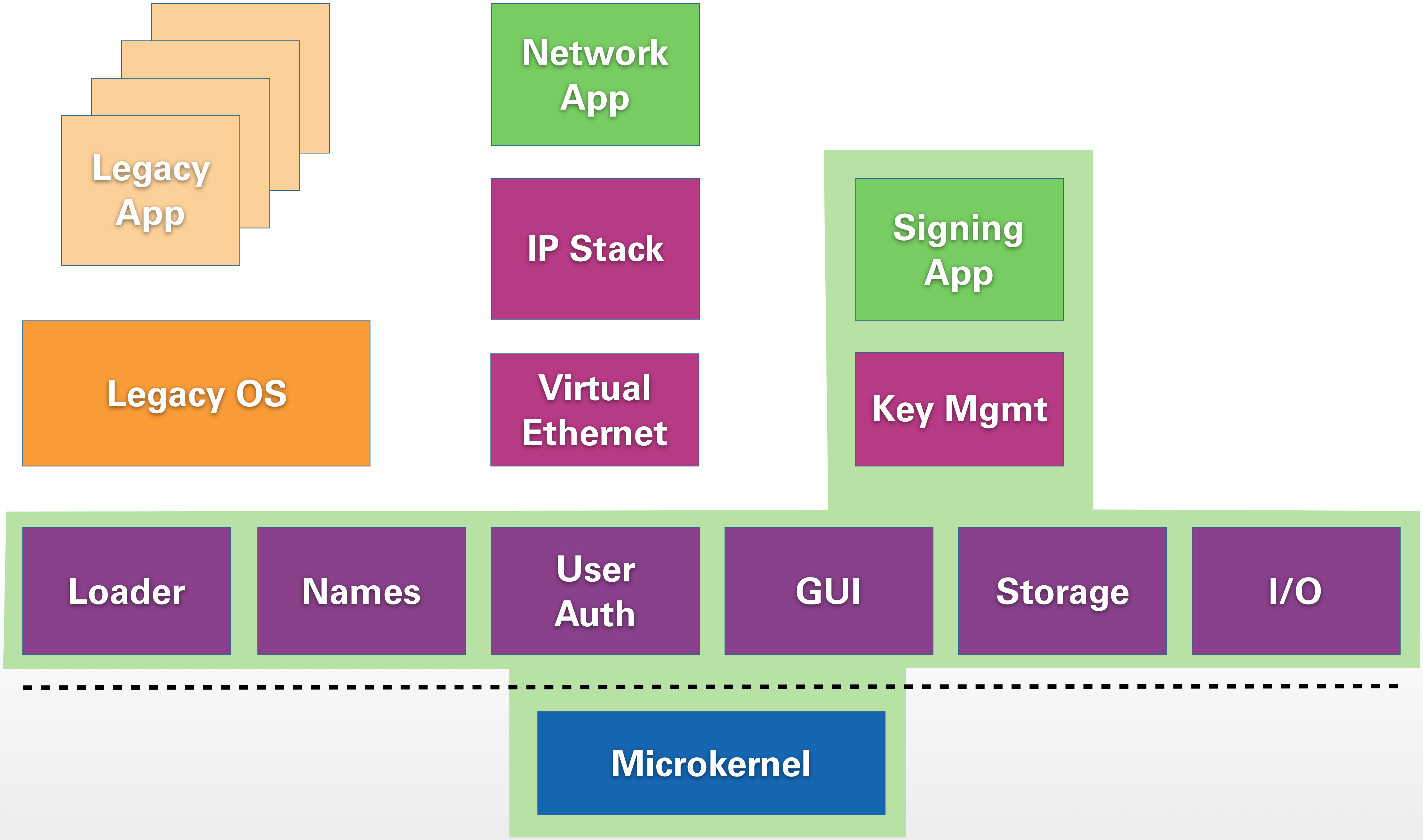
Nizza architecture: fundamental concepts:

- Strong isolation
- Application-specific TCBs
- Legacy reuse
- Trusted wrappers
- Trusted computing

APP-SPECIFIC TCB

- Reflects **Principle of Least Privilege**
- TCB of an application includes only components its security relies upon
- TCB does not include unrelated applications, services, libraries

APP-SPECIFIC TCB



APP-SPECIFIC TCB

- Reflects **Principle of Least Privilege**
- TCB of an application includes only components its security relies upon
- TCB does not include unrelated applications, services, libraries
- Mechanisms:
  - Address spaces, IPC control for isolation
  - Well-defined interfaces

TECHNISCHE UNIVERSITÄT DRESDEN

SPLITTING COMPONENTS

SPLIT APPS

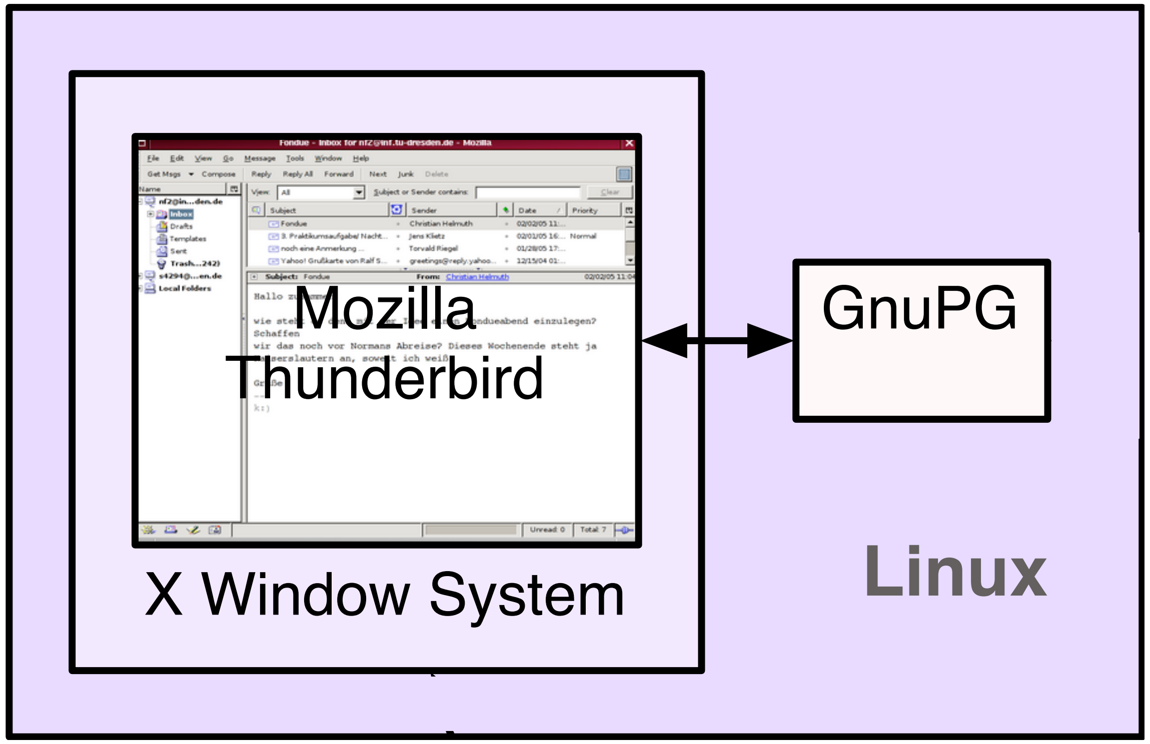
- Problems with porting applications:
  - Dependencies need to be satisfied
  - Can be complex, require lots of code
  - Stripped down applications may lack functionality / usability
- Better idea: split application
  - Make only security-critical parts run on microkernel-based OS
  - Parts of application removed from TCB

EXAMPLE: EMAIL

Digitally signed e-mails, what’s critical?

- Handling of signature keys
- Requesting passphrase to unlock secret signature key
- Presenting e-mail message:
  - Before sending: „**W**hat **Y**ou **S**ee **I**s **W**hat **Y**ou **S**ign“
  - After receiving: verify signature, identify sender

STANDARD EMAIL APP



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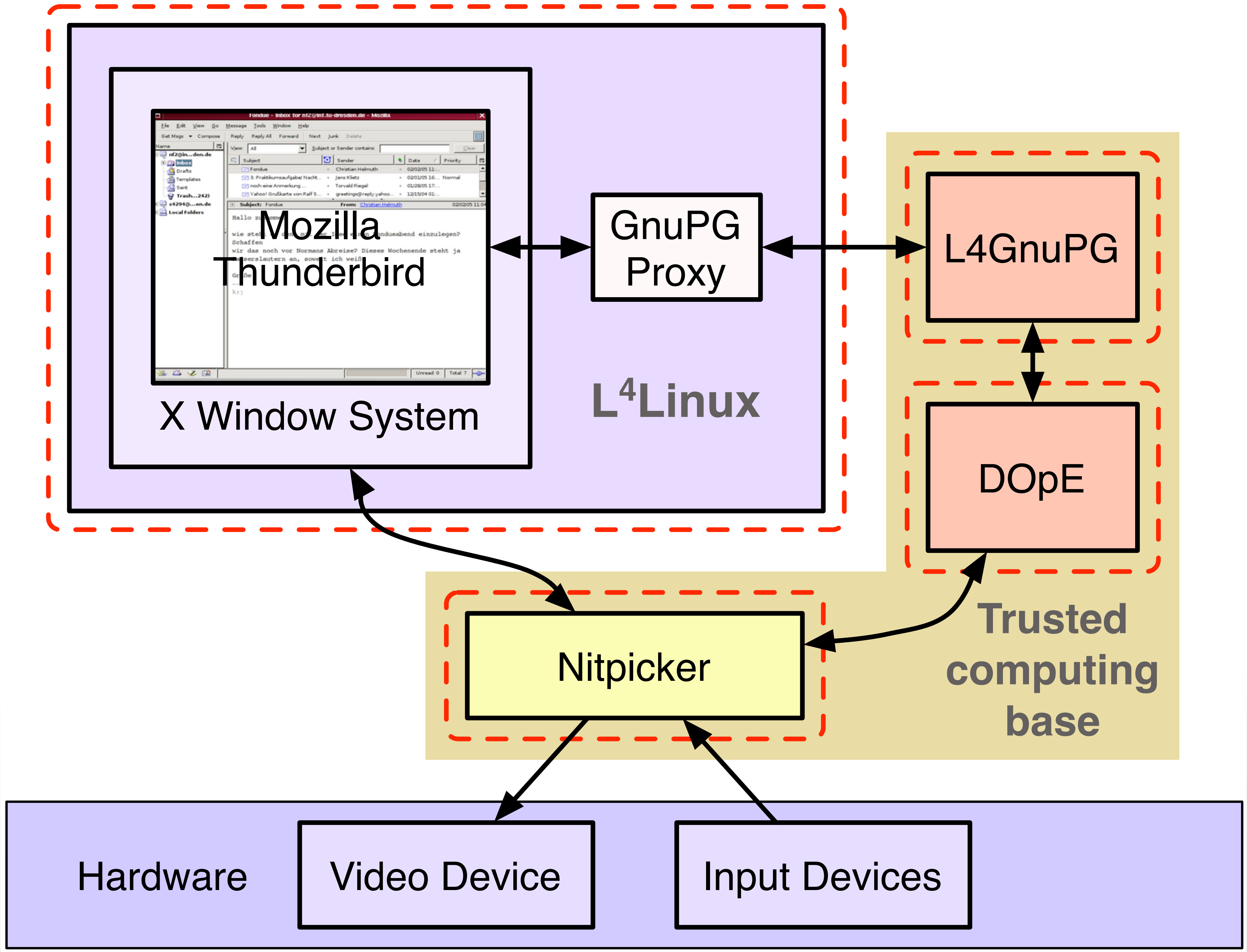
SPLIT EMAIL APP



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TCB REDUCTION

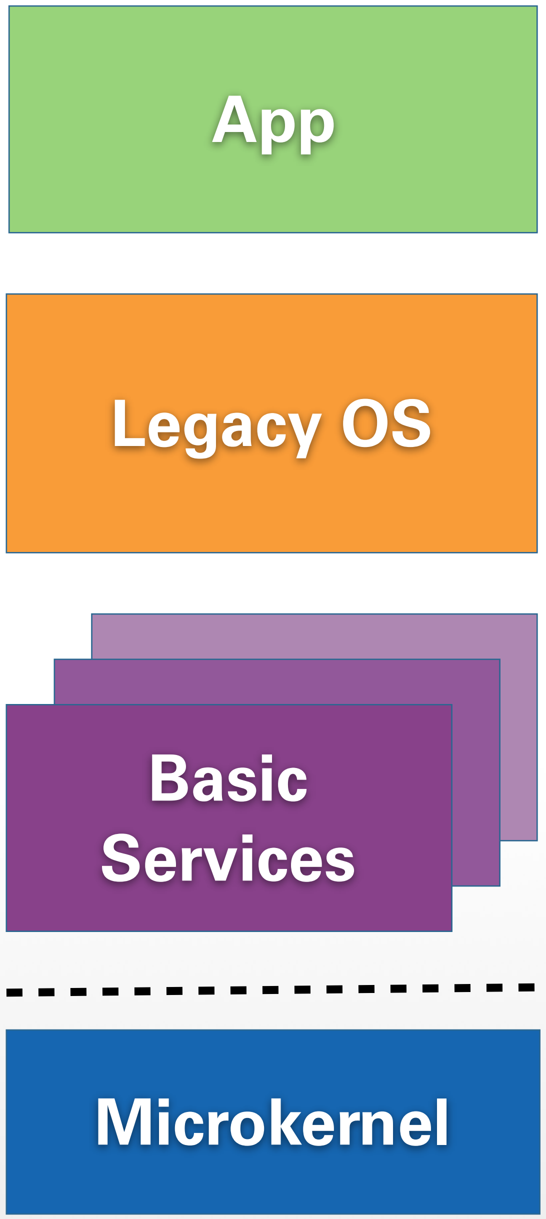
- *1,500,000*+ SLOC no longer in TCB:
  - Linux kernel, drivers, X-Server
  - C and GUI libraries, Thunderbird, …
- TCB size reduced to ~*150,000* SLOC:
  - GNU Privacy Guard, e-mail viewer
  - Basic L4 system
- At least 10 times less code in TCB

SPLITTING THE OS

- Splitting works for applications
- What about the complex and useful infrastructure of commodity OSes?
  - Drivers (see previous lectures)
  - Protocol stacks (e.g., TCP/IP)
  - File systems
- Starting point: Virtualized commodity OS

SIMPLE REUSE

- Run legacy OS in VM
- Reuse service: net, files, ...
- Legacy infrastructure isolated from applications
- But:
  - Applications still depend on legacy services ... in TCB?
  - Interfaces reused, security issues as well?



COMPLEXITY + BUGS

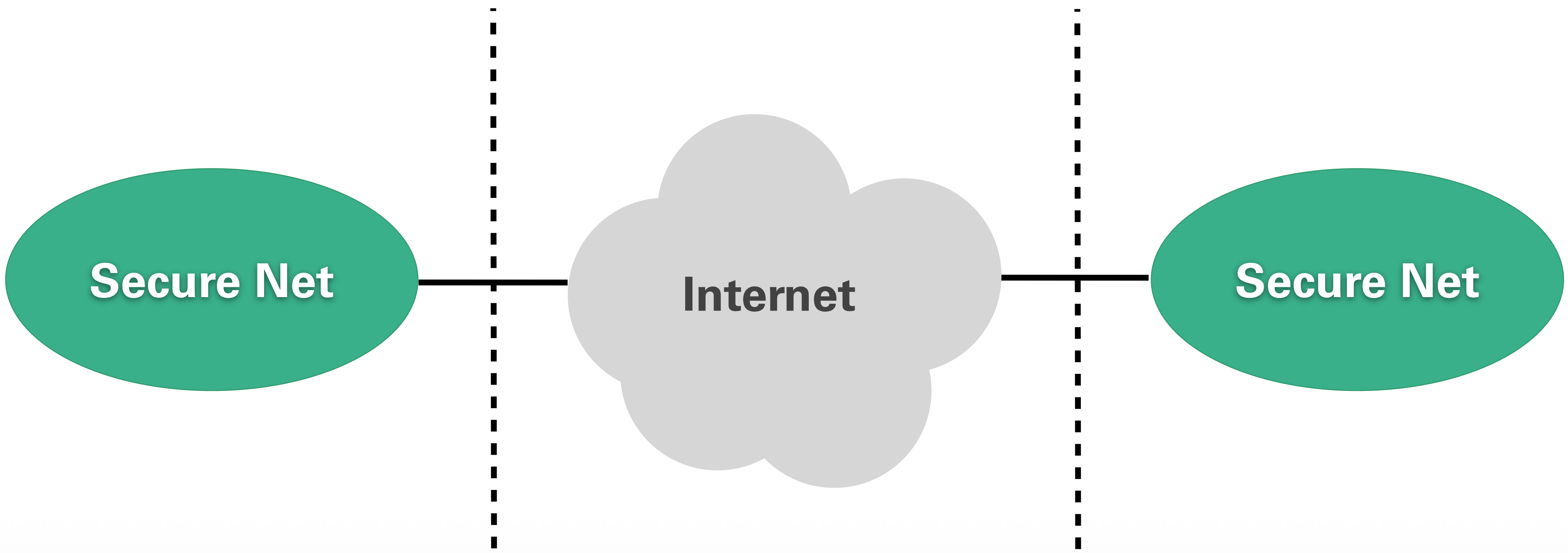
- Network and file system stacks are virtually essential subsystems
- Generally well tested
- Ready for production use
- ... but not bug free: month of Kernel Bugs 2006 [1,2]:
  - 14 exploitable flaws in file systems: UFS, ISO 9660, Ext3, SquashFS, ...
  - WiFi drivers: remotely exploitable bugs

REUSE + TRUST

- Complex protocol stacks should not be part of TCB (for confidentiality + integrity)
- Reuse untrusted infrastructure through trusted wrapper:
  - Add security around existing APIs
    - Cryptography
    - Additional checks (may require redundant data structures, if original data cannot be trusted)
- General idea similar to SSL, VPN

EXAMPLE: VPN

VPN: Confidentiality, Integrity, ~~Availability~~



SINA BOX

- SINA box used by German „BSI“:
  - VPN gateway
  - Implements IPSec & PKI
  - Intrusion detection & response
- Used for secure access to government networks, e.g. in German embassies

Image source: http://www.secunet.com/de/das-unternehmen/presse/bilddatenbank/

SINA BOX

- Hardware:
  - Differently trusted network interfaces:
    - Red: plaintext, no protection
    - Black: encrypted, MACs
- Tamper / EM protected casing
- Software:
  - Minimized and hardened Linux
  - Runs only from CD-ROM or Flash

OS COMPLEXITY

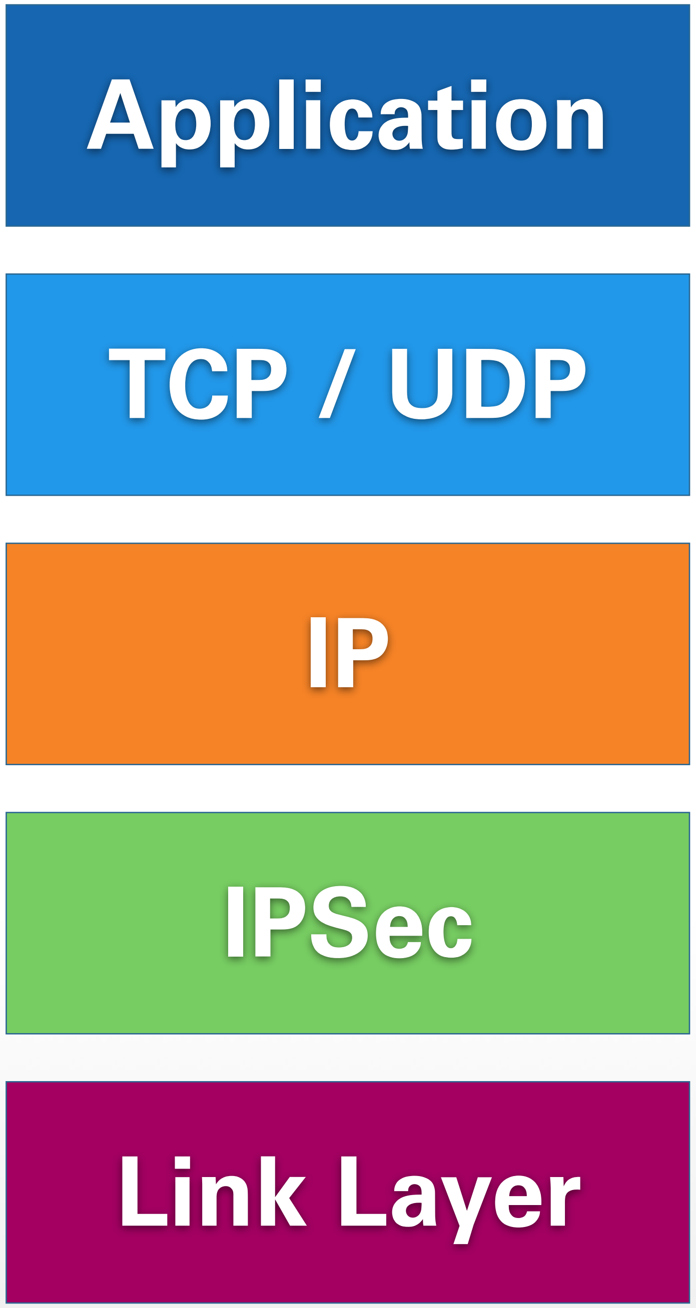
- Linux is complex!
- SLOC for Linux 2.6.18:
  - Architecture specific: 817,880
  - x86 specific: 55,463
  - Drivers: 2,365,256
  - Common: 1,800,587
- Typical config: ~ 2,000,000
- Minimized & hardened: ~ 500,000

MIKRO-SINA

- Research project „Mikro-SINA“
- Goals:
  - Reduce TCB of VPN gateway software
  - Enable high-level evaluation for high assurance scenarios
  - Ensure confidentiality and integrity of sensitive data within the VPN
  - Exploit microkernel architecture

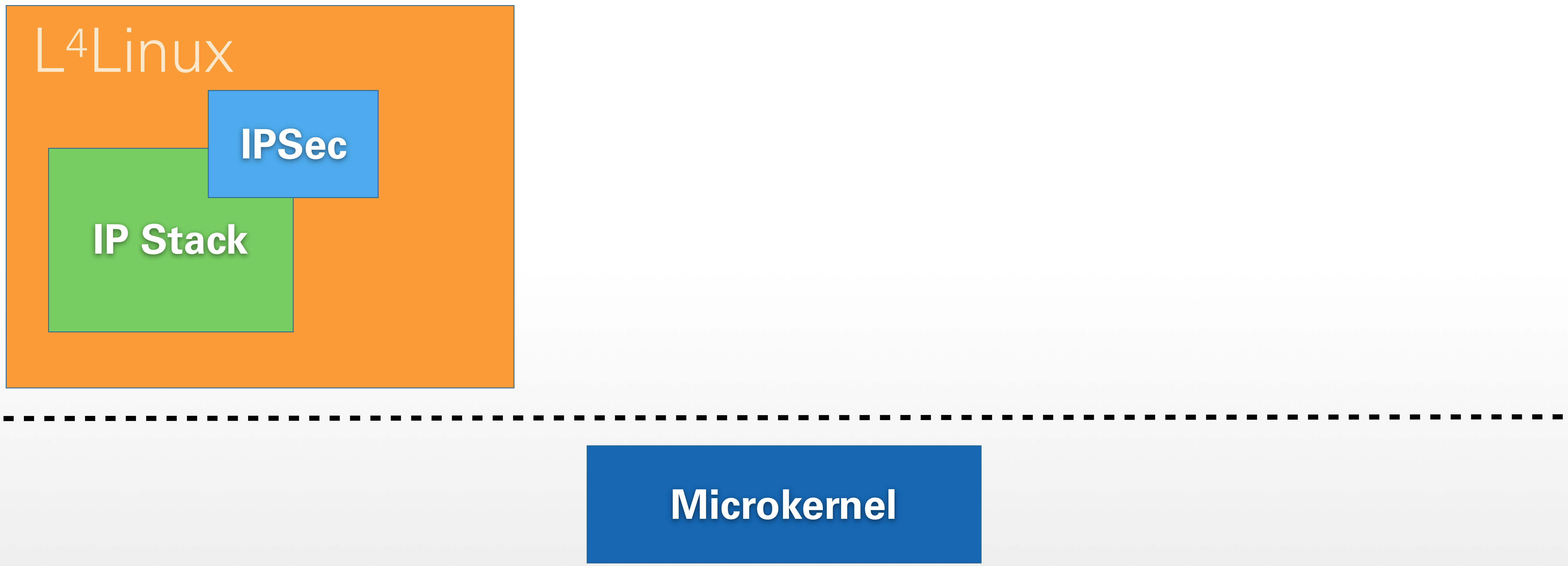
IPSEC BASICS

- Protocol suite for securing IP-based communication
- Authentication header (**AH**)
  - Integrity
  - Authentication
- Encapsulating Security Payload (**ESP**)
  - Confidentiality
- Key management / exchange



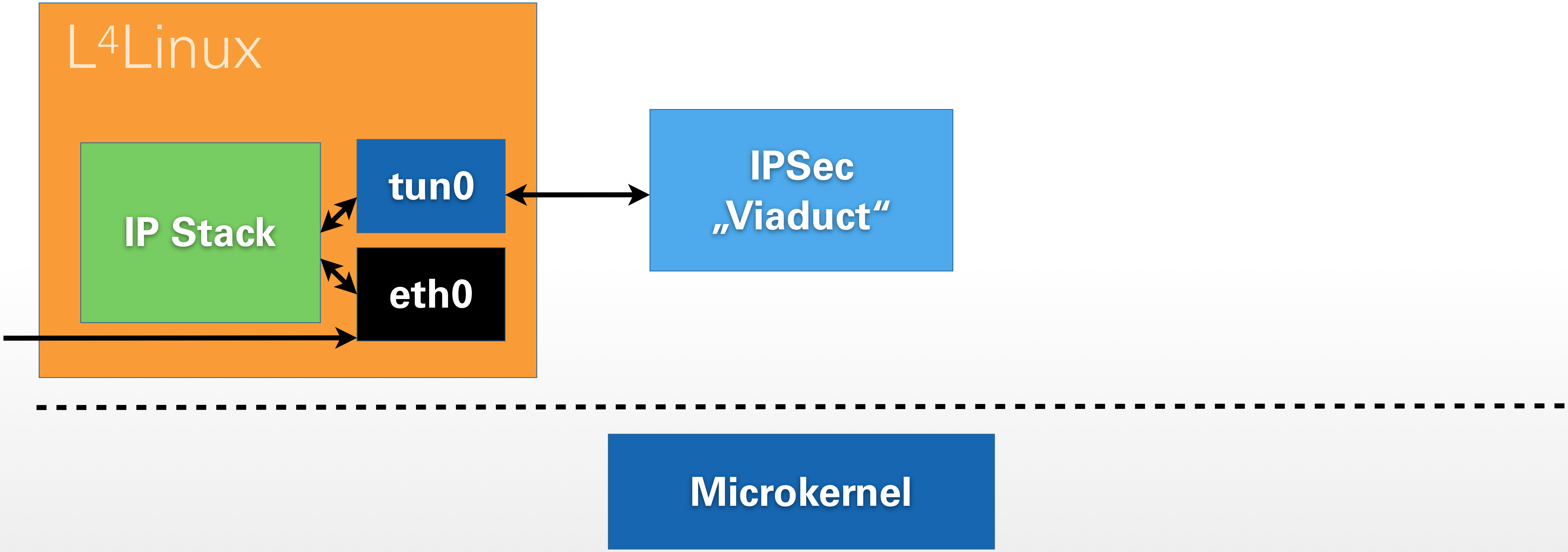
IPSEC IN L4LINUX

- IPSec is security critical component
- ... but is integrated into Linux kernel



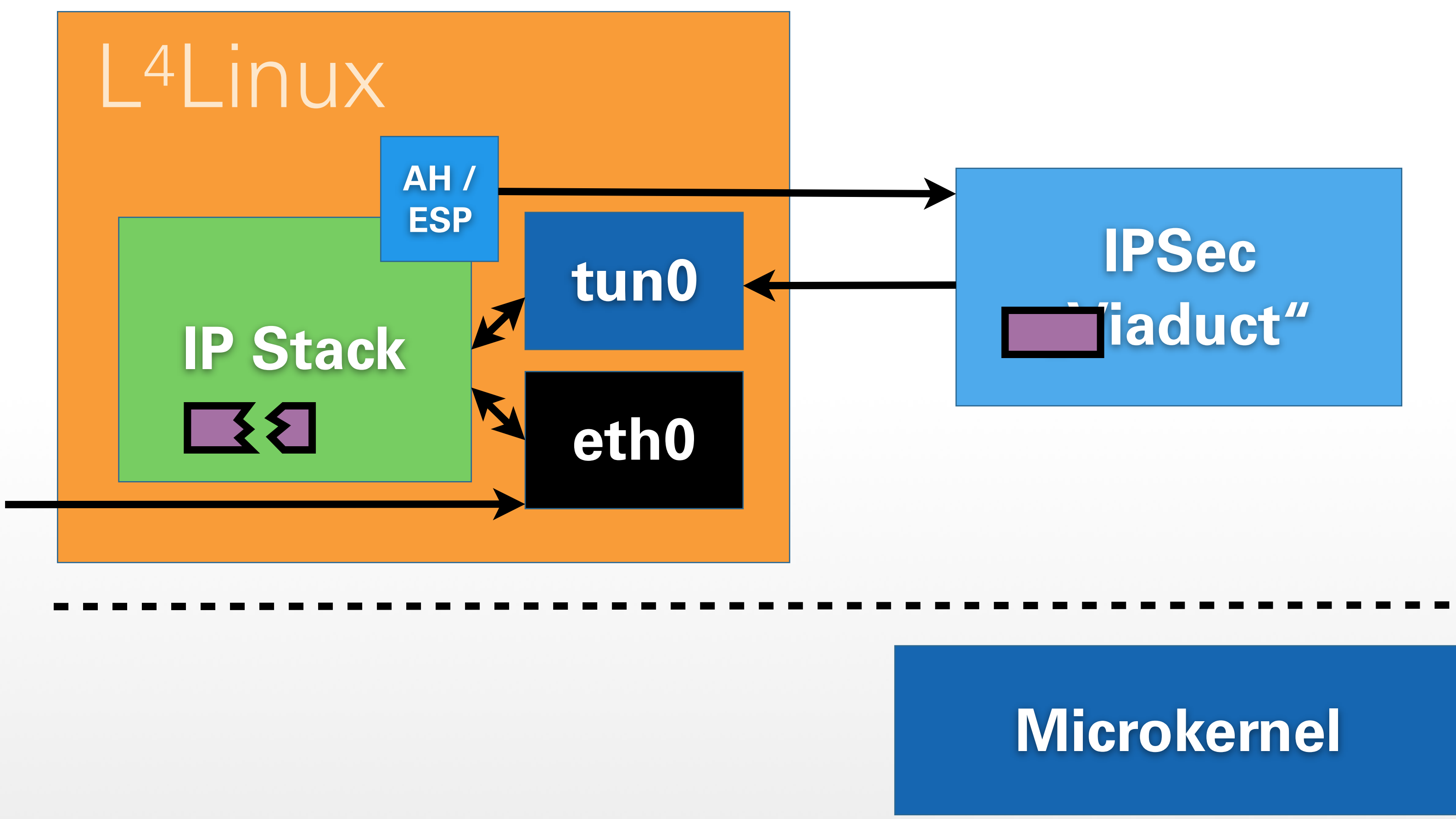
IPSEC „VIADUCT“

- Idea: isolate IPSec in „Viaduct“
- IPSec packets sent/received through TUN/TAP device



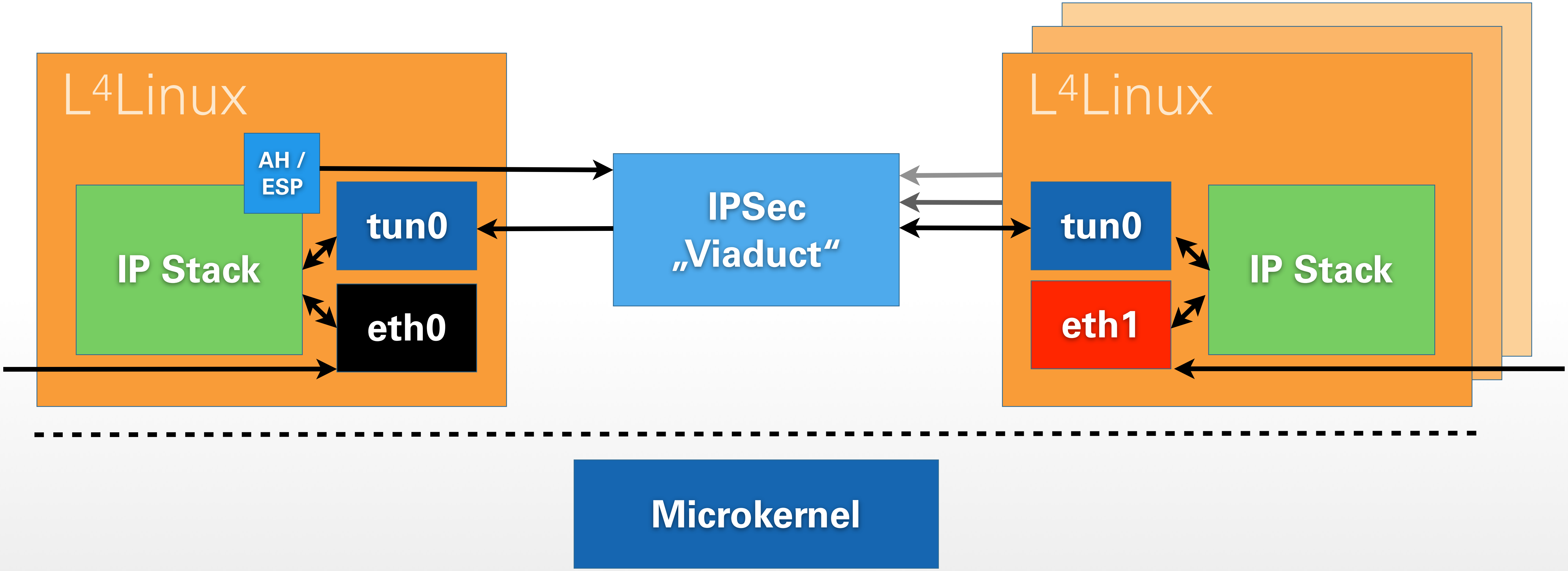
FRAGMENTATION

- Problem: Routers can fragment IPSec packets on the way
- Let L4Linux reassemble them



CONFIDENTIALITY

- Untrusted L4Linux must not see both plaintext and encrypted data
- Dedicated L4Linux for black/red networks

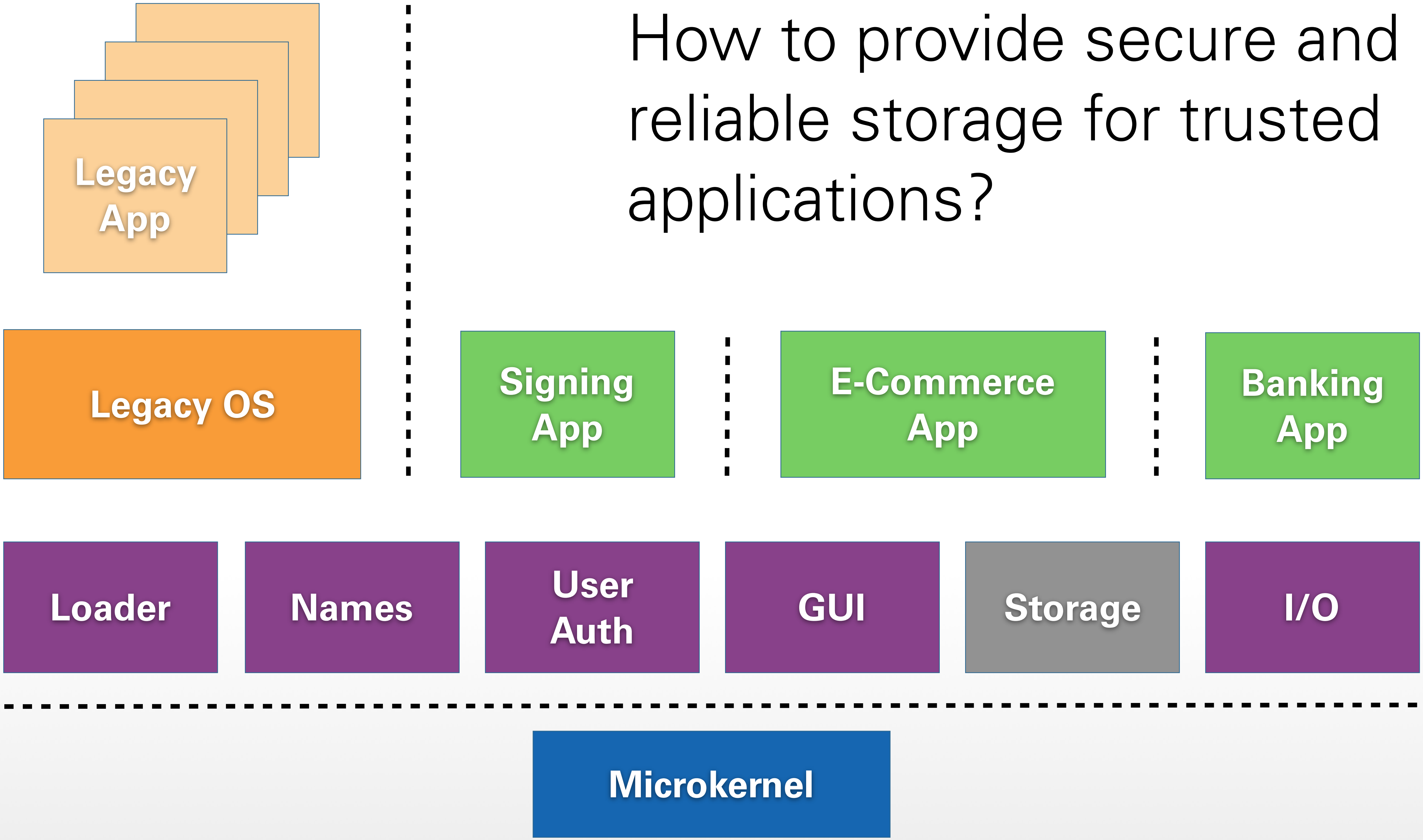


MIKRO-SINA

- Result: trusted wrapper for VPN
- Small TCB (see [6] for details):
  - 5,000 SLOC for „Viaduct“
  - Fine grain isolation
  - Principle of least privilege
- Extensive reuse of legacy code:
  - Drivers
  - IP stack

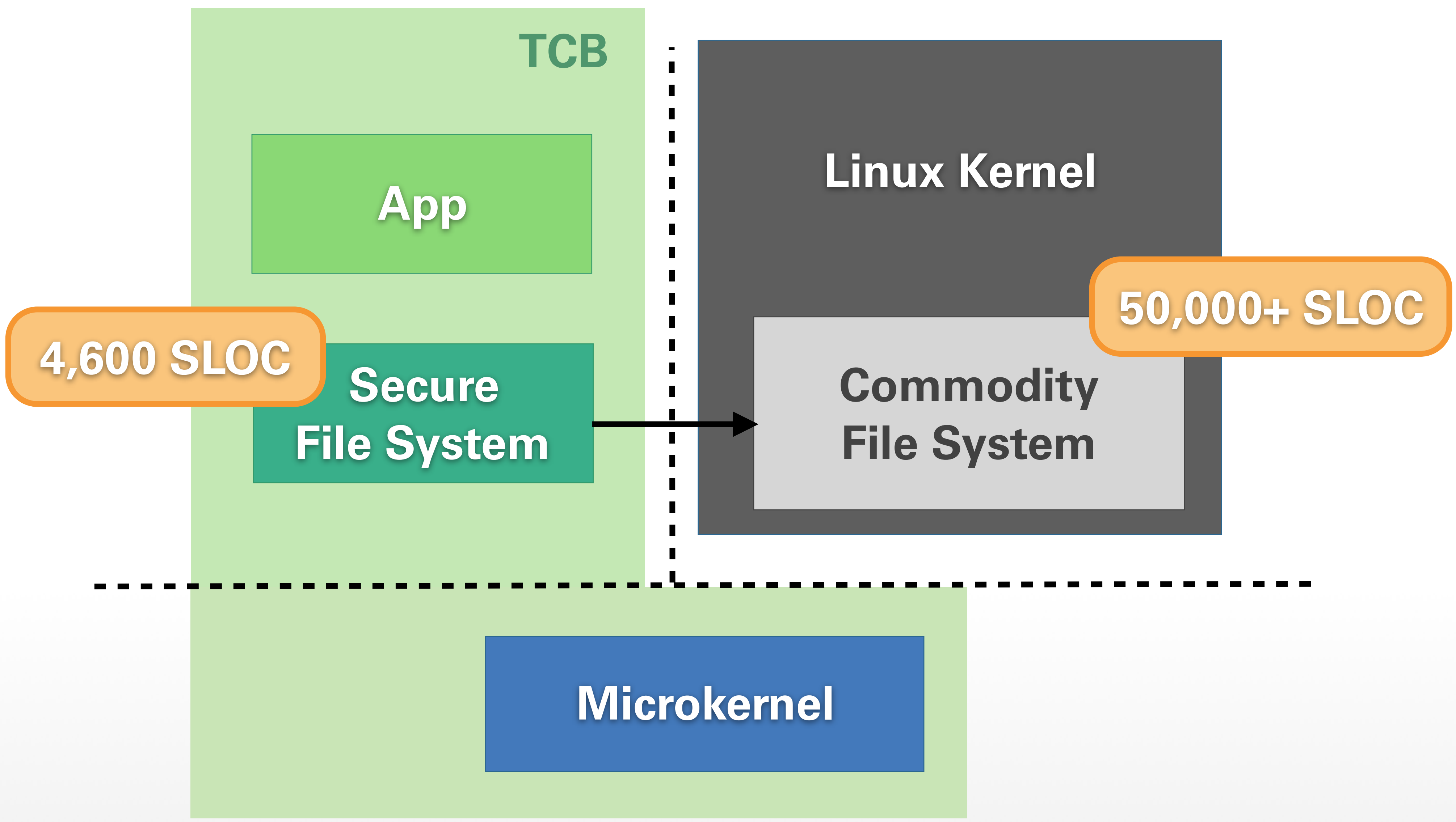
EXAMPLE: STORAGE

How to provide secure and reliable storage for trusted applications?



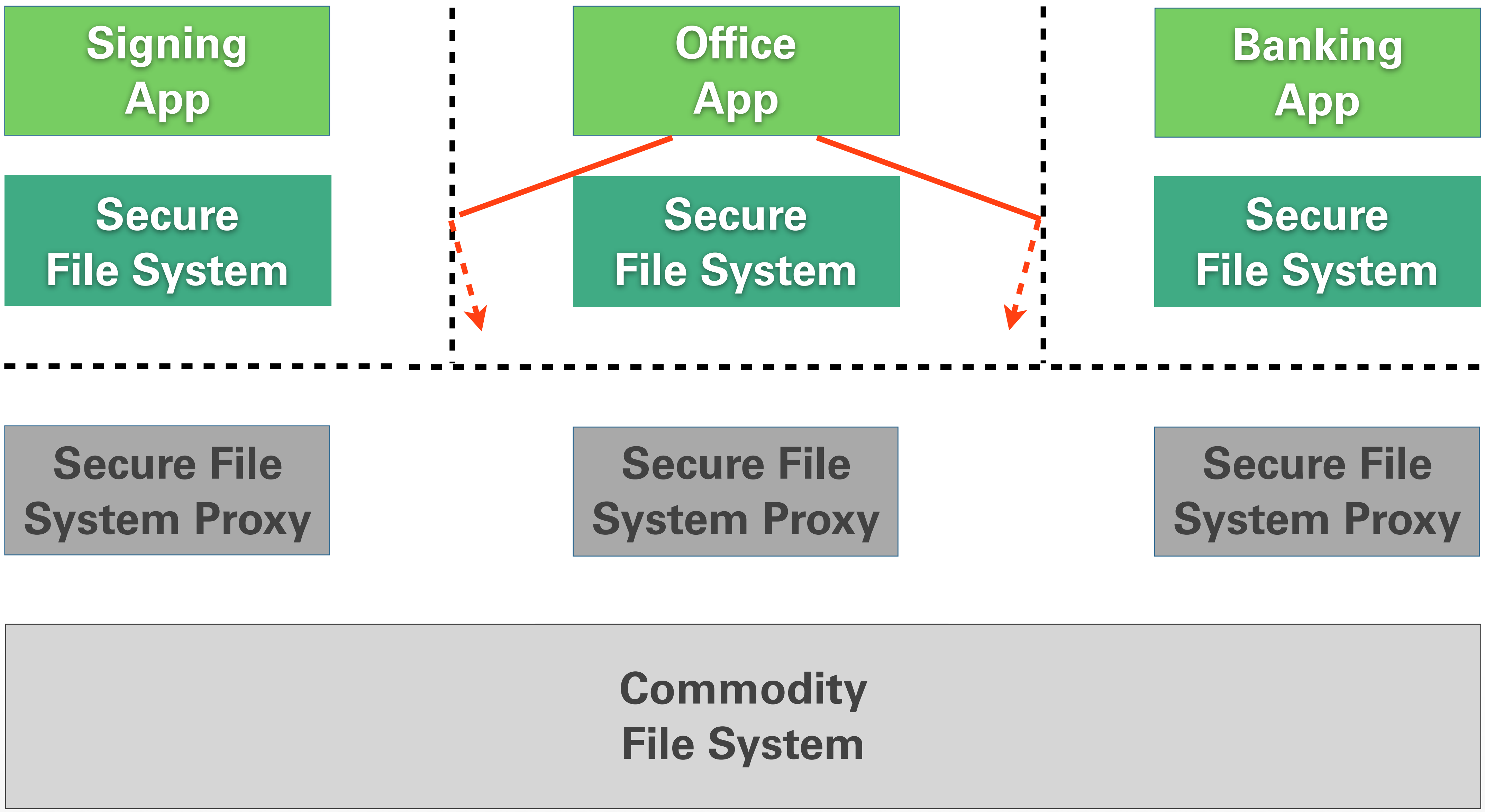
VIRTUAL PRIVATE…

VPFS: Confidentiality, Integrity, ~~Availability~~



See [3] for details

VPFS STACK

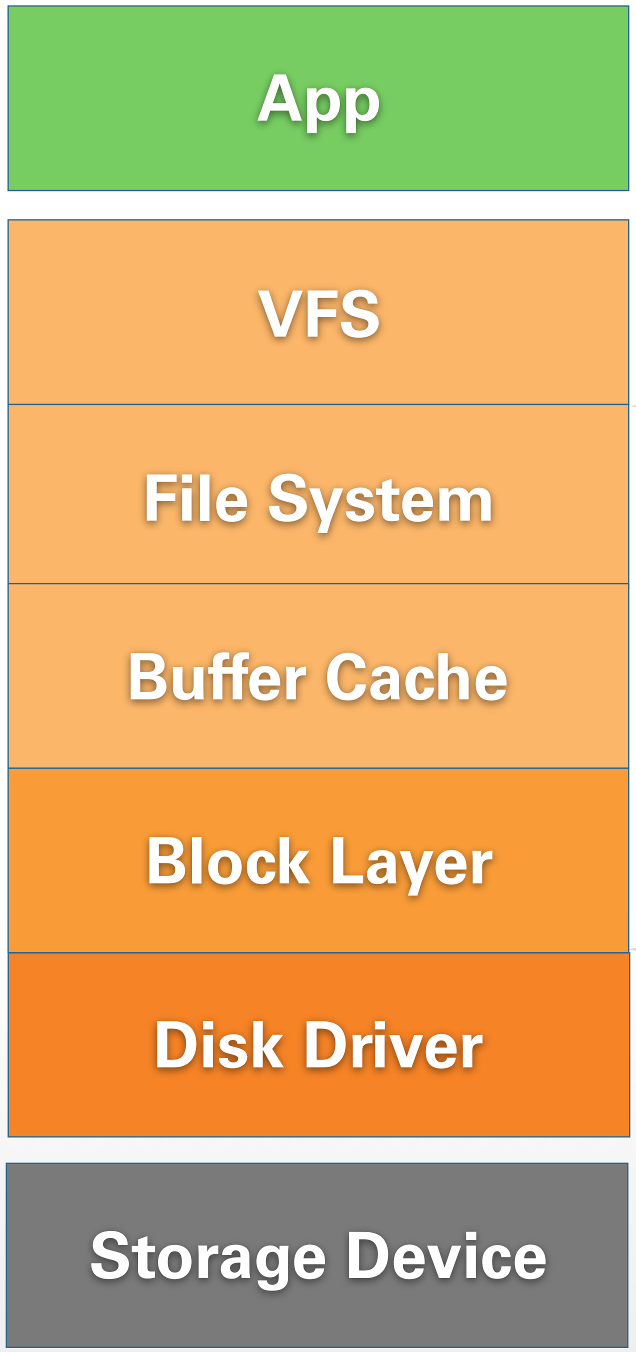


Isolate applications and their private storage: configure communication capabilities such that each application can access its private instance of the secure file system exclusively

SECURITY GOALS

- **Confidentiality:** only authorized applications can access file system, all untrusted software cannot get any useful information
- **Integrity:** all data and meta data is correct, complete, and up to date; otherwise report integrity error
- **Recoverability:** damaged data in untrusted file system can be recovered from trusted backup

POPULAR SOLUTIONS



File-level protection

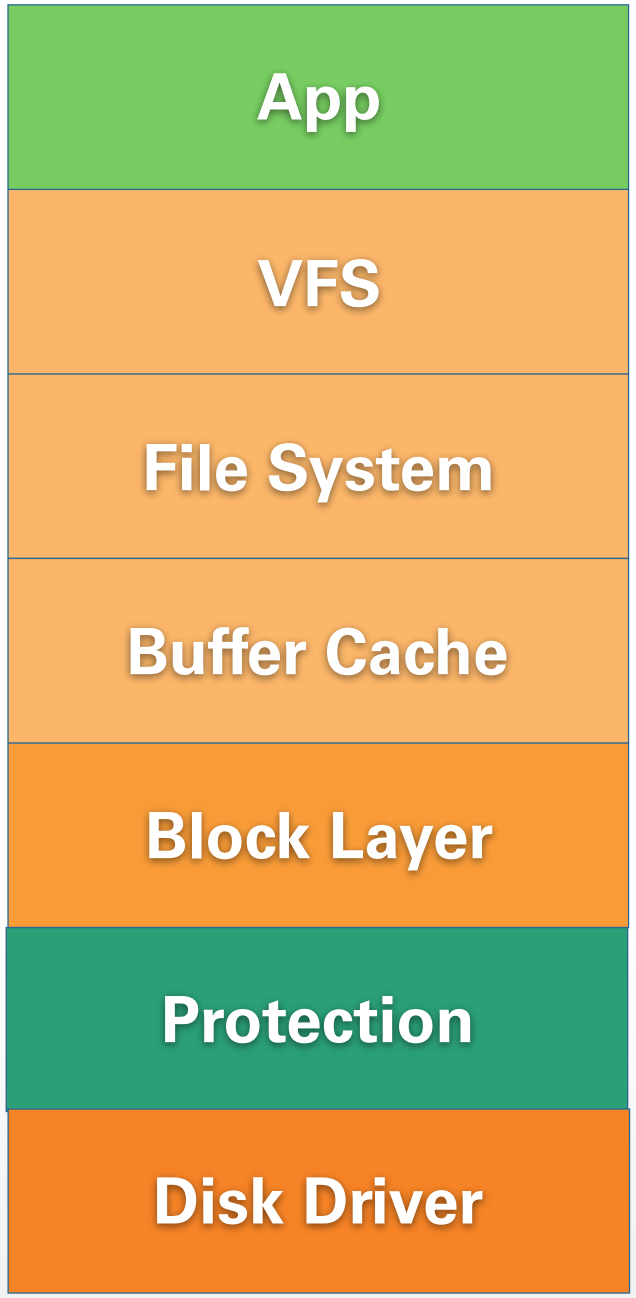
CFS	Cryptographic File System for UNIX
EFS	Microsoft Encrypting File System
ecryptfs	Linux kernel support + tools
EncFS	Based on FUSE

Volume-level protection

TrueCrypt, **Filevault 2**
dm_crypt
Bitlocker
Encrypted volumes in smartphones, etc.

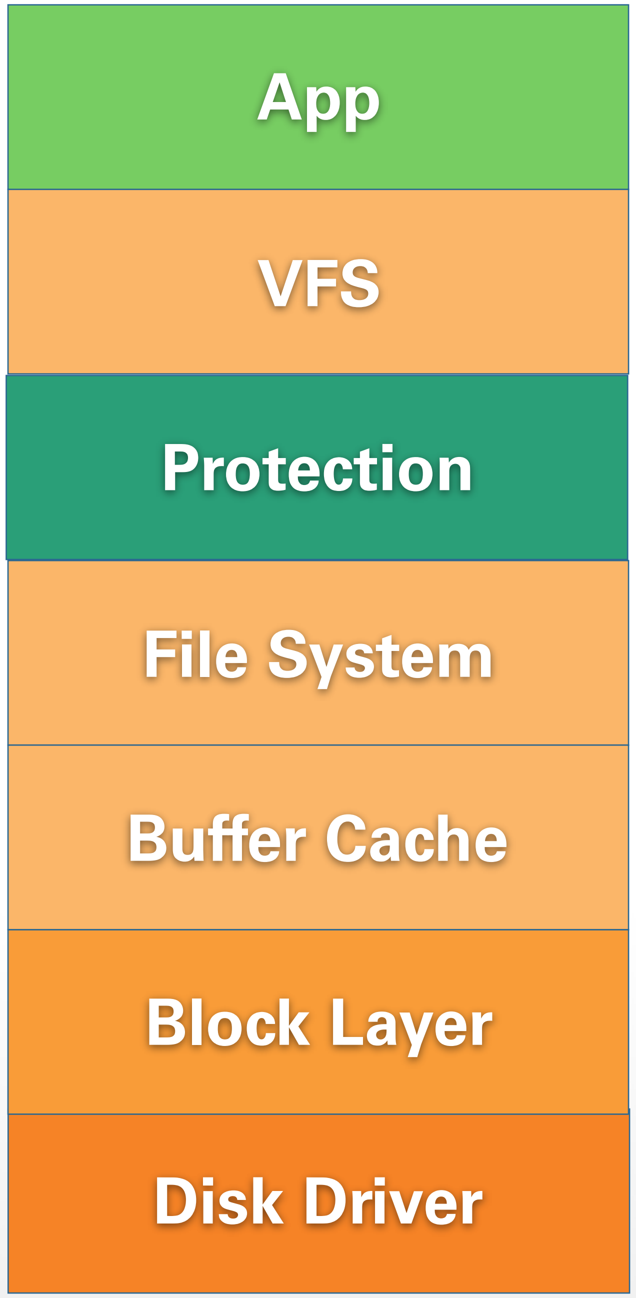
DESIGN OPTIONS

- First end of design space: Protect whole file system at block layer:
  - Transparent encryption of all data and metadata
  - Block-level integrity ???
  - Most parts of file system stack are part of TCB
  - Attack surface still big

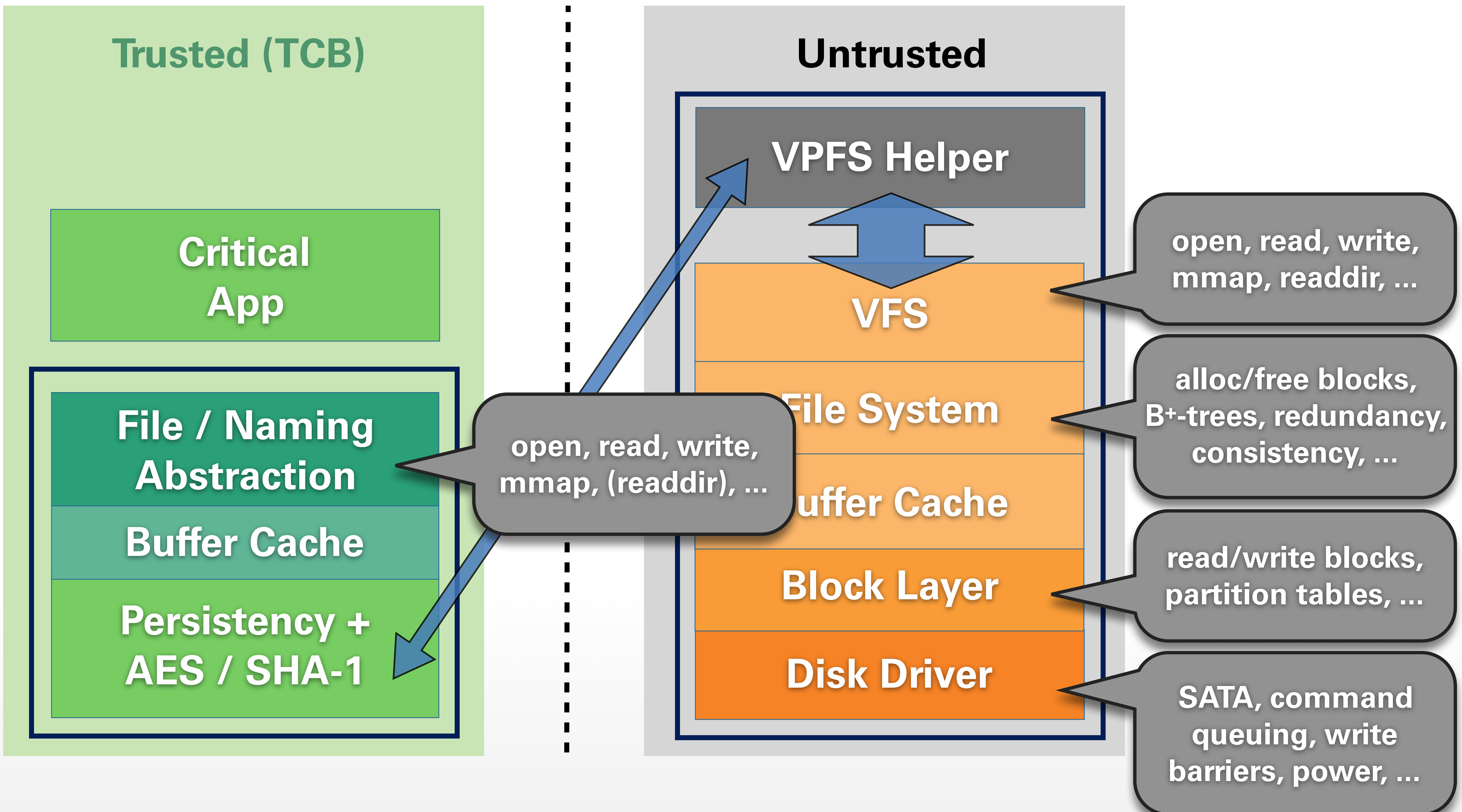


DESIGN OPTIONS

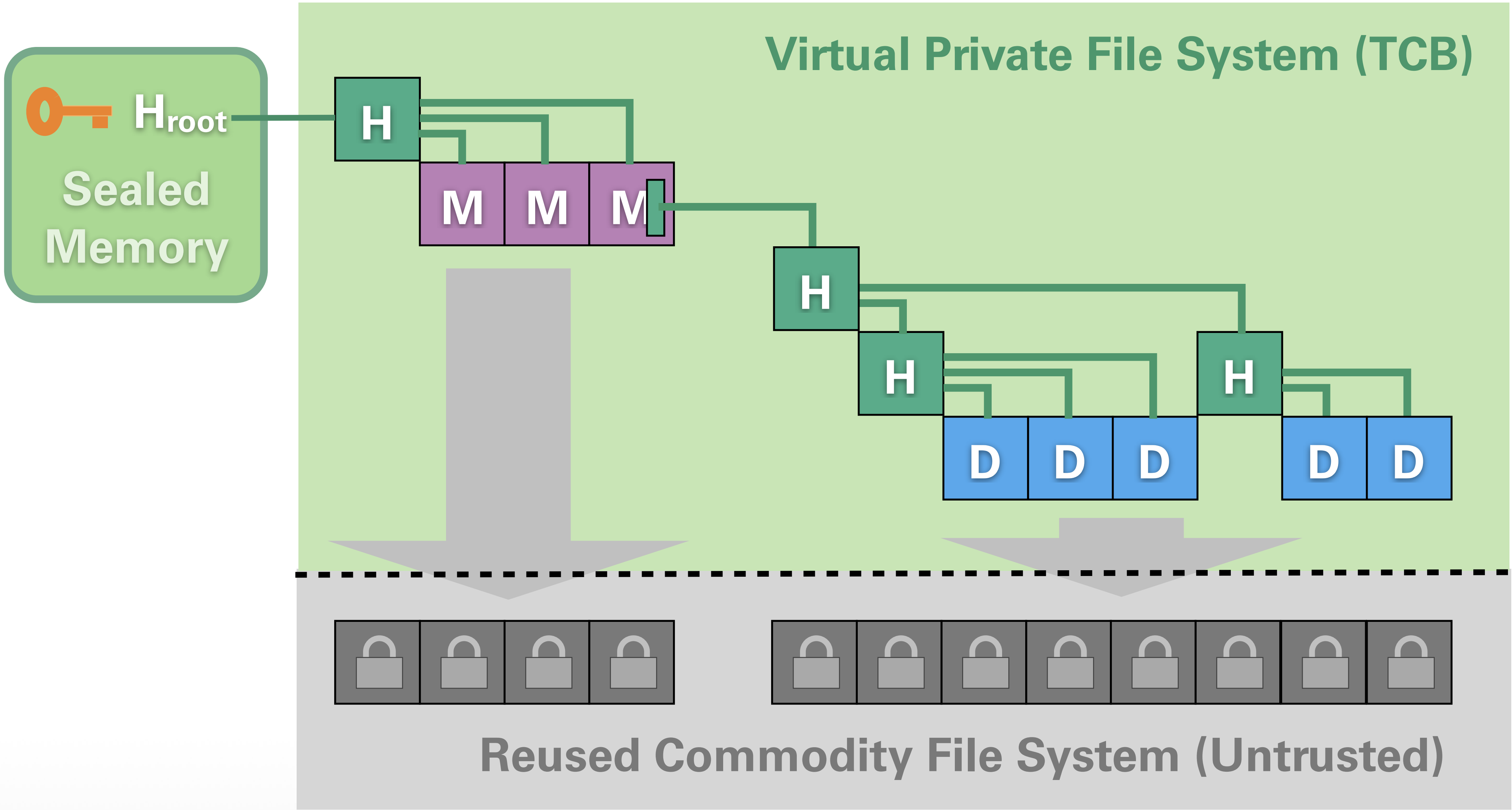
- Second end of design space: Protect individual files:
  - Stacked file system
  - Encryption of all data and some metadata (names, directories, …)
  - More flexibility for integrity
  - Most parts of file system stack <u>not</u> part of TCB
  - Ideal for trusted wrapper



TRUSTED WRAPPER



VPFS APPROACH

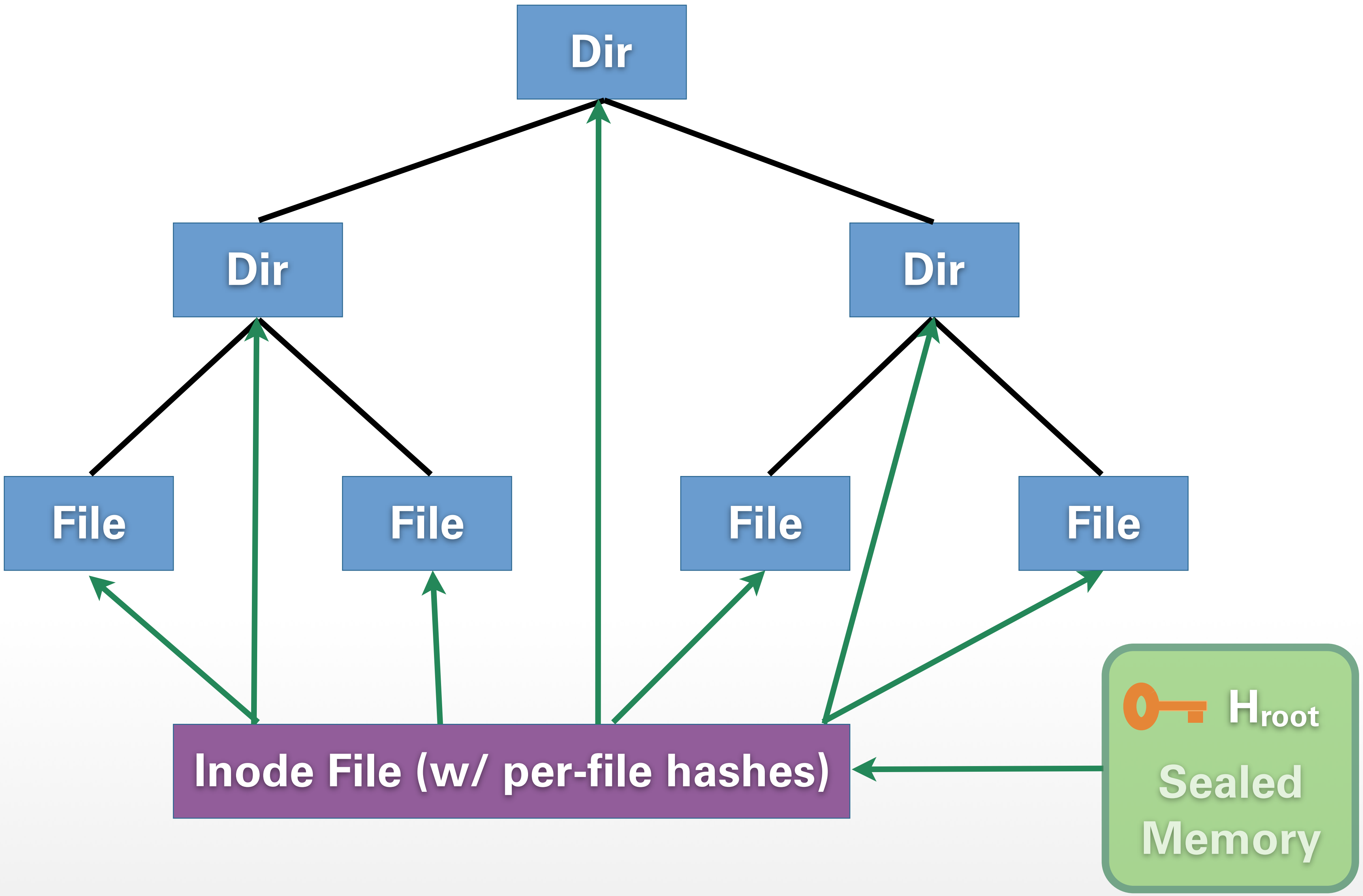


- Encrypted files in commodity file system
- Merkle **hash tree** to detect tampering

VPFS APPROACH

- Trusted part of VPFS enforces security:
  - Encryption / decryption on the fly
  - Plaintext only in trusted buffer cache
  - Files in untrusted commodity file system store encrypted blocks
  - Hash tree protects integrity of complete file system
  - Single hash of root node stored securely

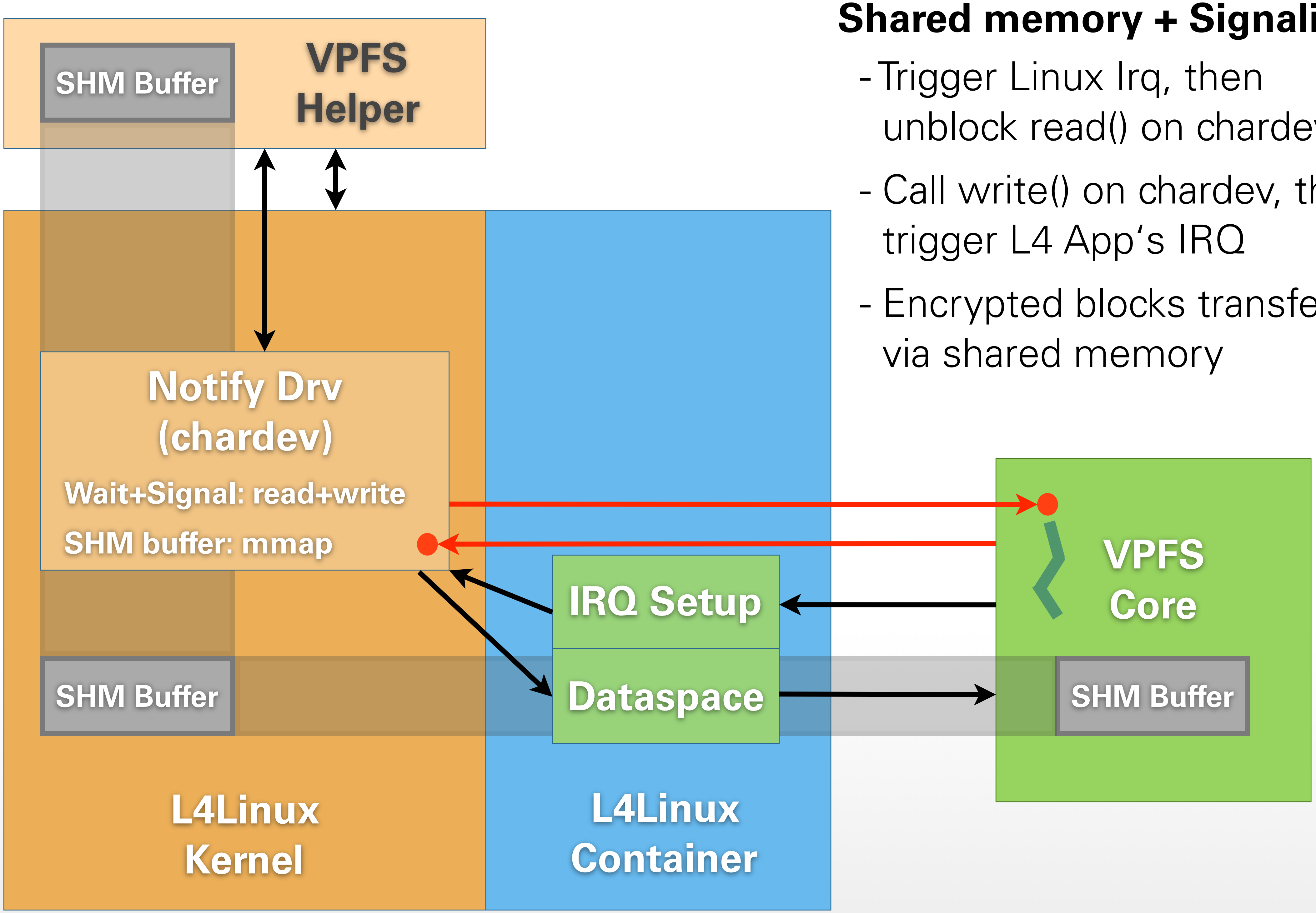
MULTIPLE FILES



EXTENSIVE REUSE

- VPFS reuses Linux file system stack:
  - Drivers, block device layer
  - Optimizations (buffer cache, read ahead, write batching, ...)
  - Allocate / free disk storage for files
- Cooperation: proxy driver in L^4Linux

PROXY DRIVER



Shared memory + Signaling:

- Trigger Linux Irq, then unblock read() on chardev
- Call write() on chardev, then trigger L4 App's IRQ
- Encrypted blocks transferred via shared memory

VPFS SUMMARY

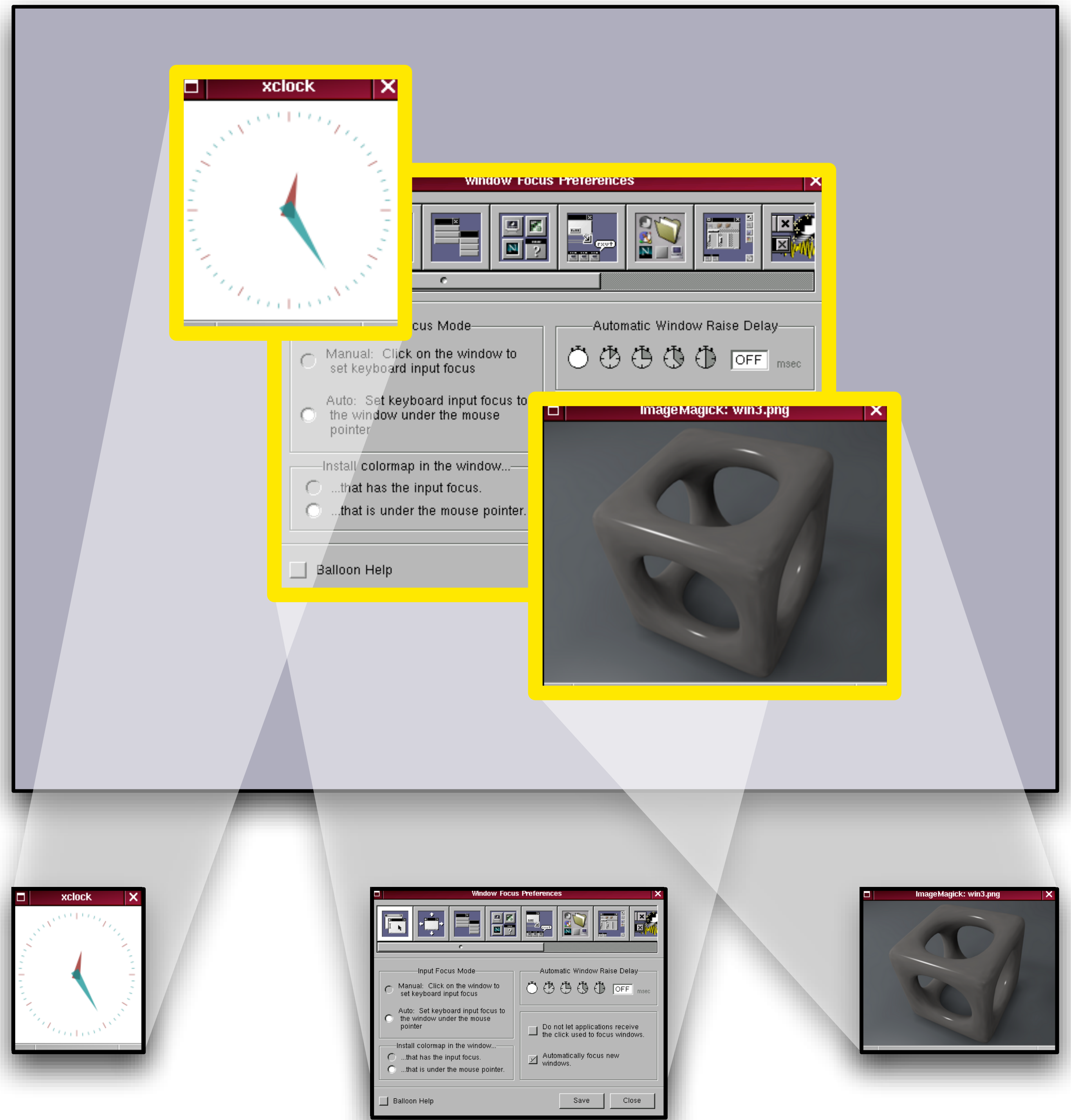
- Trusted wrappers for file systems work!
- VPFS is general purpose file system
- Significant reduction in code size:
  - Untrusted Linux file system stack comprises **50,000+** SLOC
  - VPFS adds **4,000** to **4,600** SLOC to application TCB [3]
  - jVPFS adds another **350** SLOC for secure journaling to protect against crashes [4]

USER INTERFACES

SCREEN SHARING

- Isolated applications run in different domains of trust, but separate screens are inconvenient
- The Nitpicker solution [5]:
  - Let all windows share the same screen ...
  - ... but securely:
    - Make windows & applications identifiable
    - Prevent them from spying on each other: route input securely, no screenshots

CONCEPTS

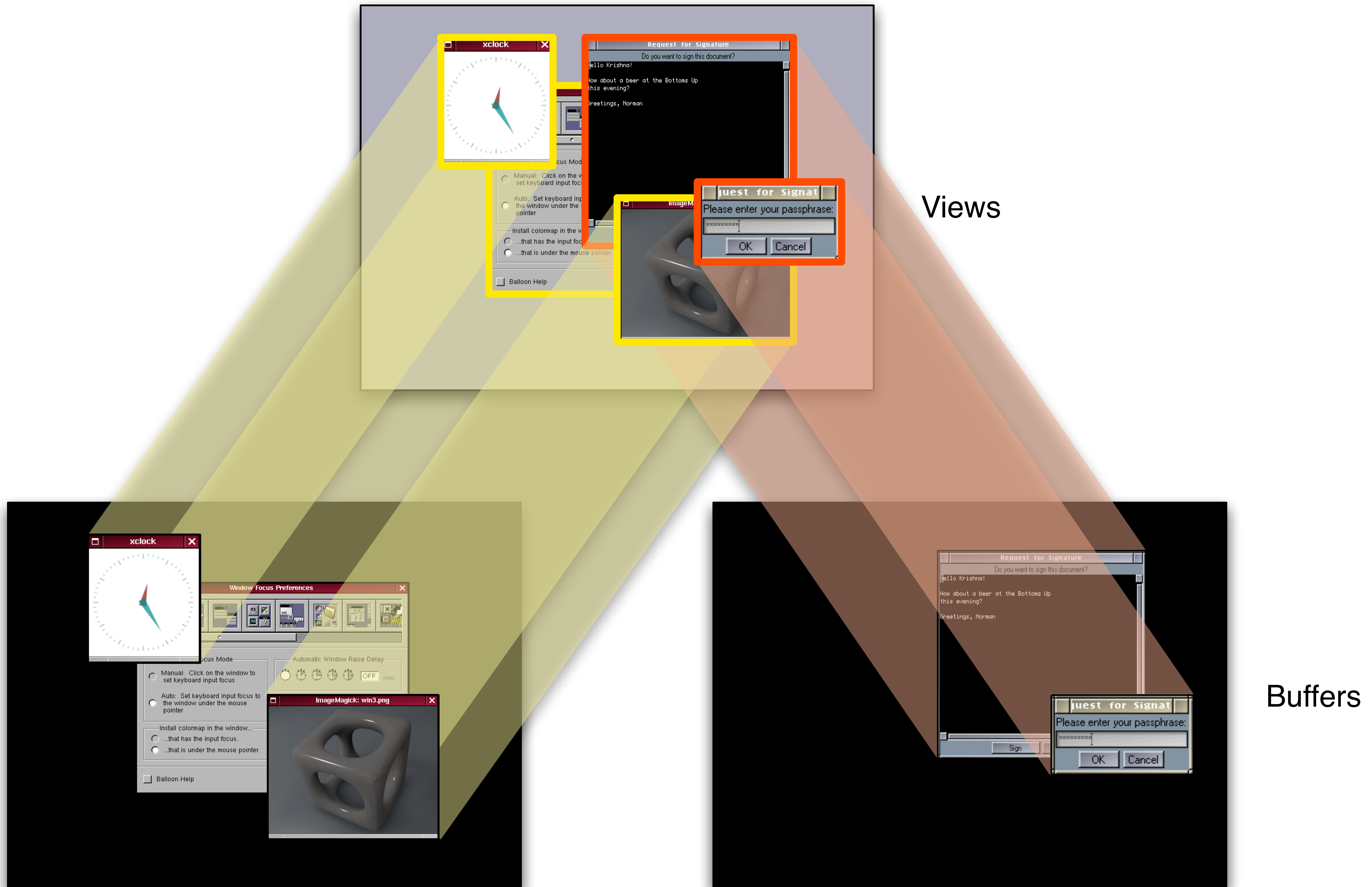


Views

Buffers

Image source: [5]

HOW IT WORKS



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NITPICKER IN ACTION

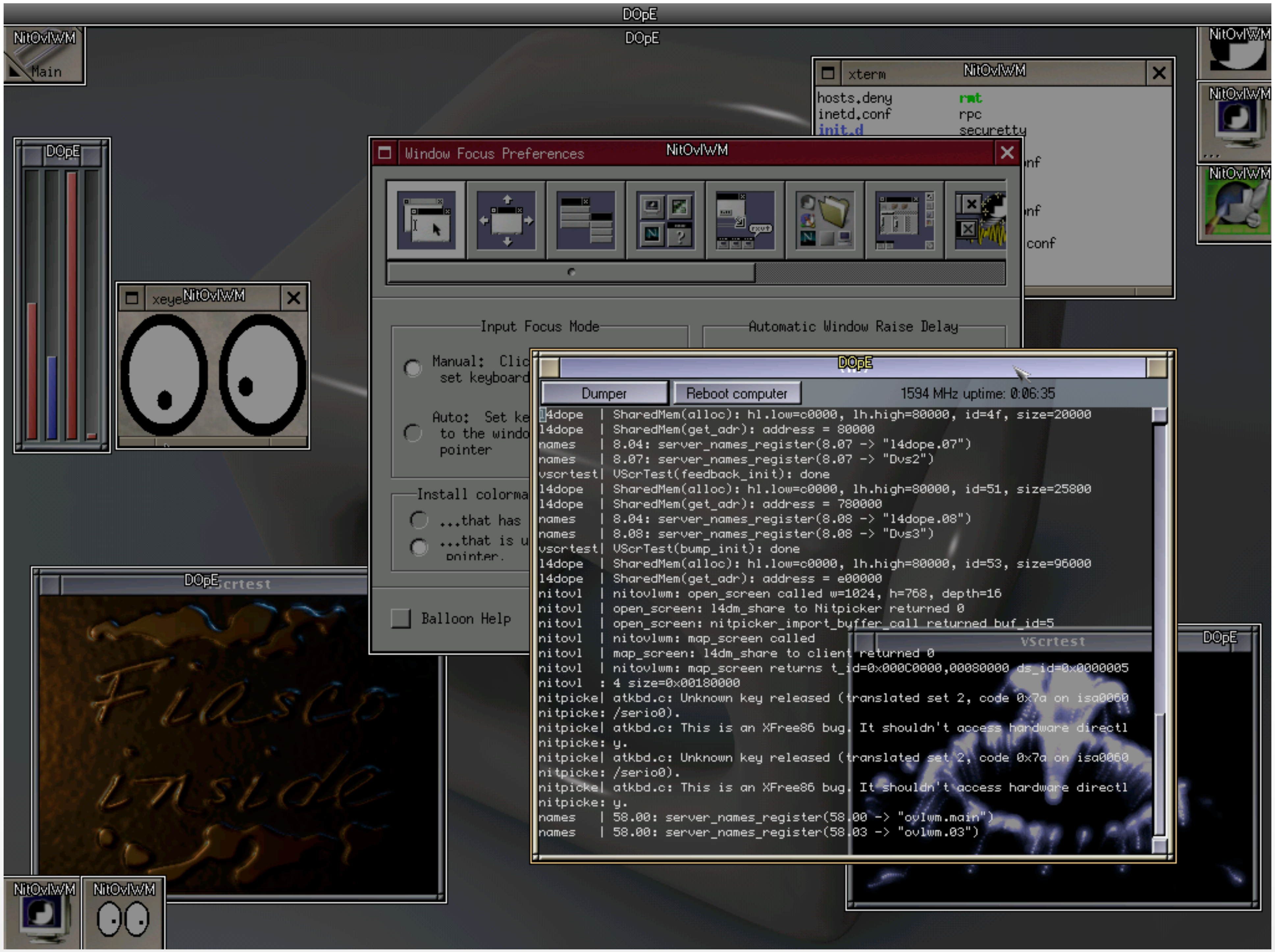

Image source: [5]

DEMO

SUMMARY

- Secure reuse of untrusted legacy infrastructure
- Split apps + OS services for smaller TCB
- Nizza secure system architecture:
  - Strong isolation
  - Application-specific TCBs
  - Legacy Reuse
  - Trusted Wrapper

COMING UP

- Next week, January 16:
  - Lecture on "Trusted Computing"
    - Where does VPFS store its secrets?
    - How to prevent tampering with stored data?
    - How to trust in what Nitpicker shows on screen?
  - *???*

REFERENCES

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- [2] http://projects.info-pull.com/mokb/
- [3] Carsten Weinhold and Hermann Härtig, „VPFS: Building a Virtual Private File System with a Small Trusted Computing Base", Proceedings of the 3rd ACM SIGOPS/EuroSys European Conference on Computer Systems, April 2008, Glasgow, Scotland UK
- [4] Carsten Weinhold and Hermann Härtig, „jVPFS: Adding Robustness to a Secure Stacked File System with Untrusted Local Storage Components", Proceedings of the 2011 USENIX Annual Technical Conference, Portland, OR, USA, June 2011
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- [8] http://support.apple.com/kb/HT3754
- [9] http://jailbreakme.com