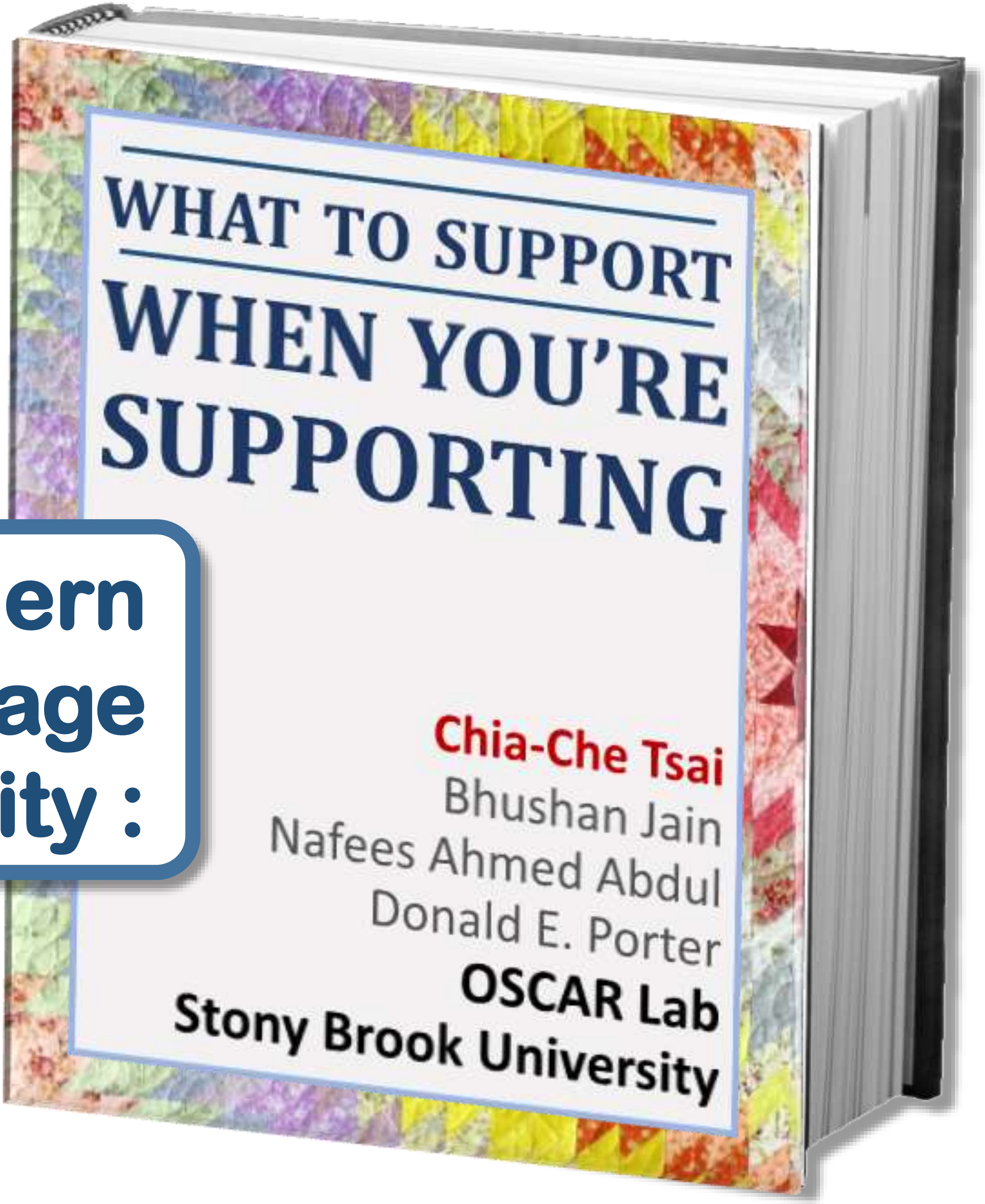
A Study of Modern Linux API Usage and Compatibility :



WHAT TO SUPPORT WHEN YOU'RE SUPPORTING

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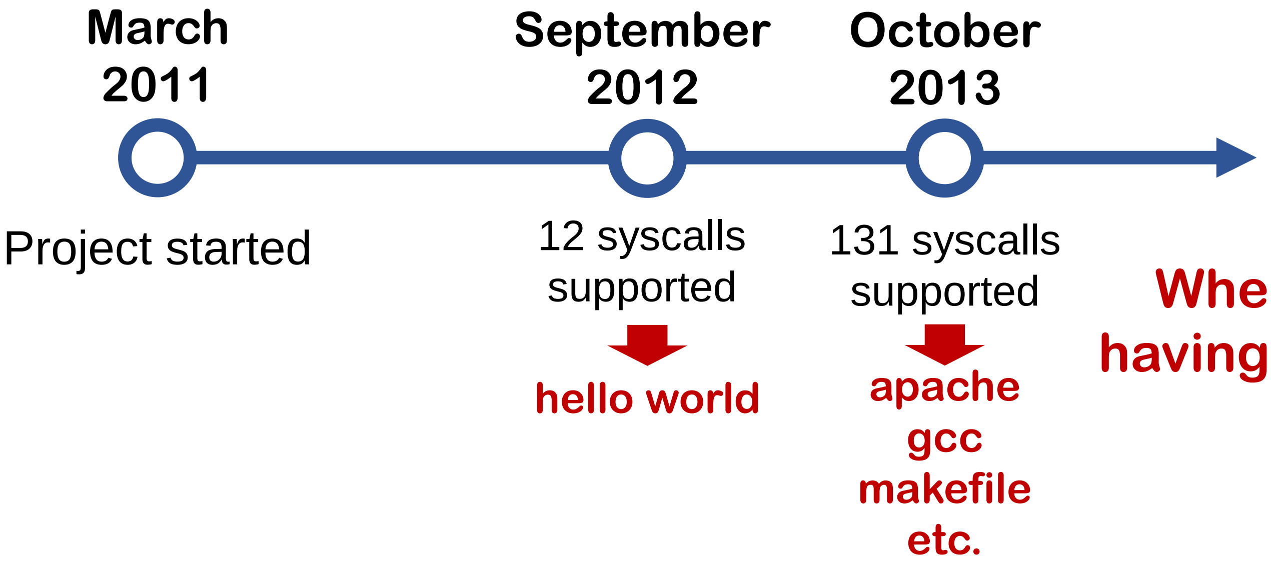
System Building: When You Become a Parent

Our experience from building a OS with Linux API support (*Graphene library OS* [Eurosys'14]):



March 2011

Project started

September 2012

12 syscalls supported

hello world

October 2013

131 syscalls supported

apache
gcc
makefile
etc.

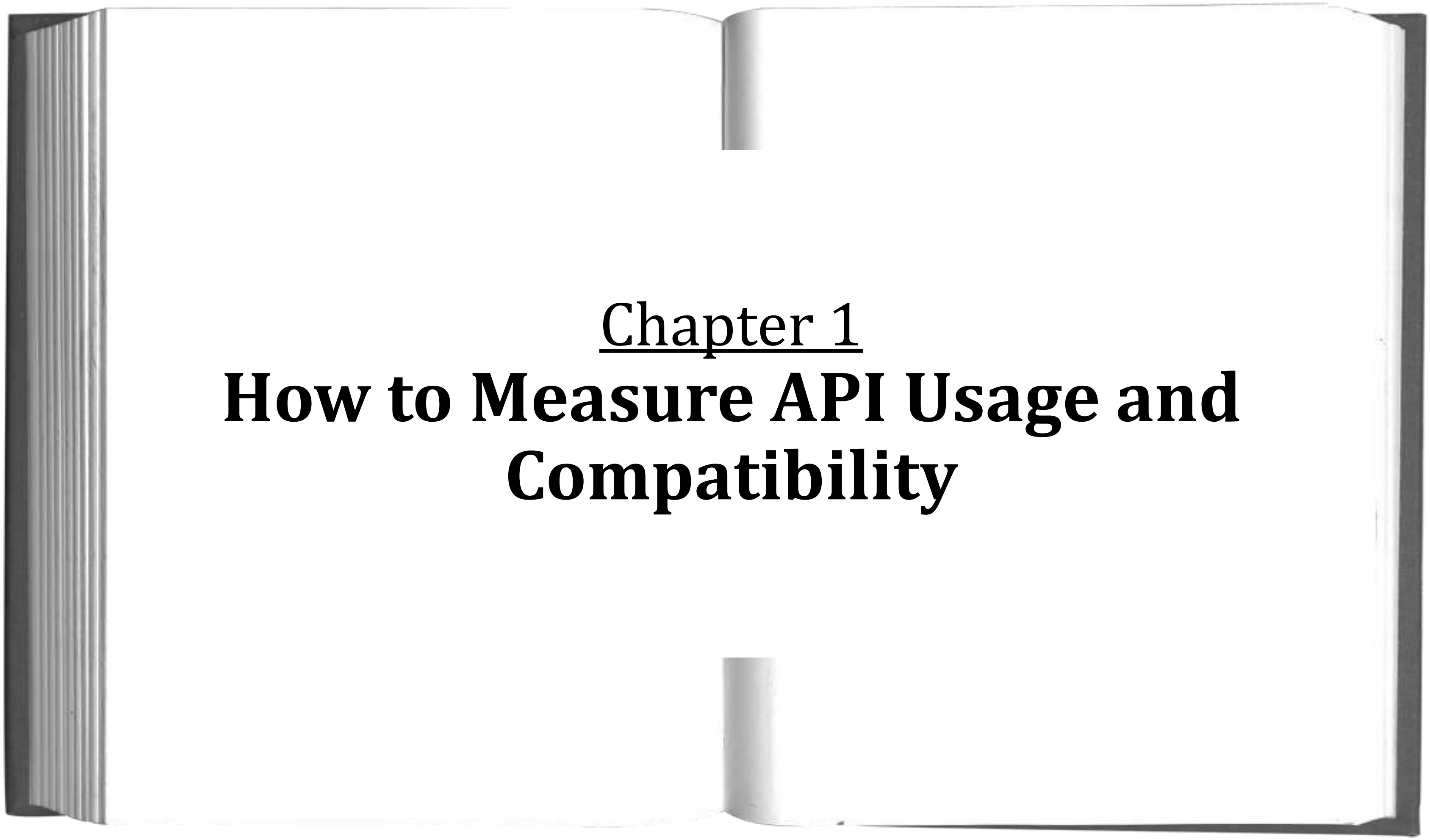
When can we claim having a decent system ?

API compatibility is measured as all-or-nothing

(impractical for system developers)

What to Expect from This Paper:

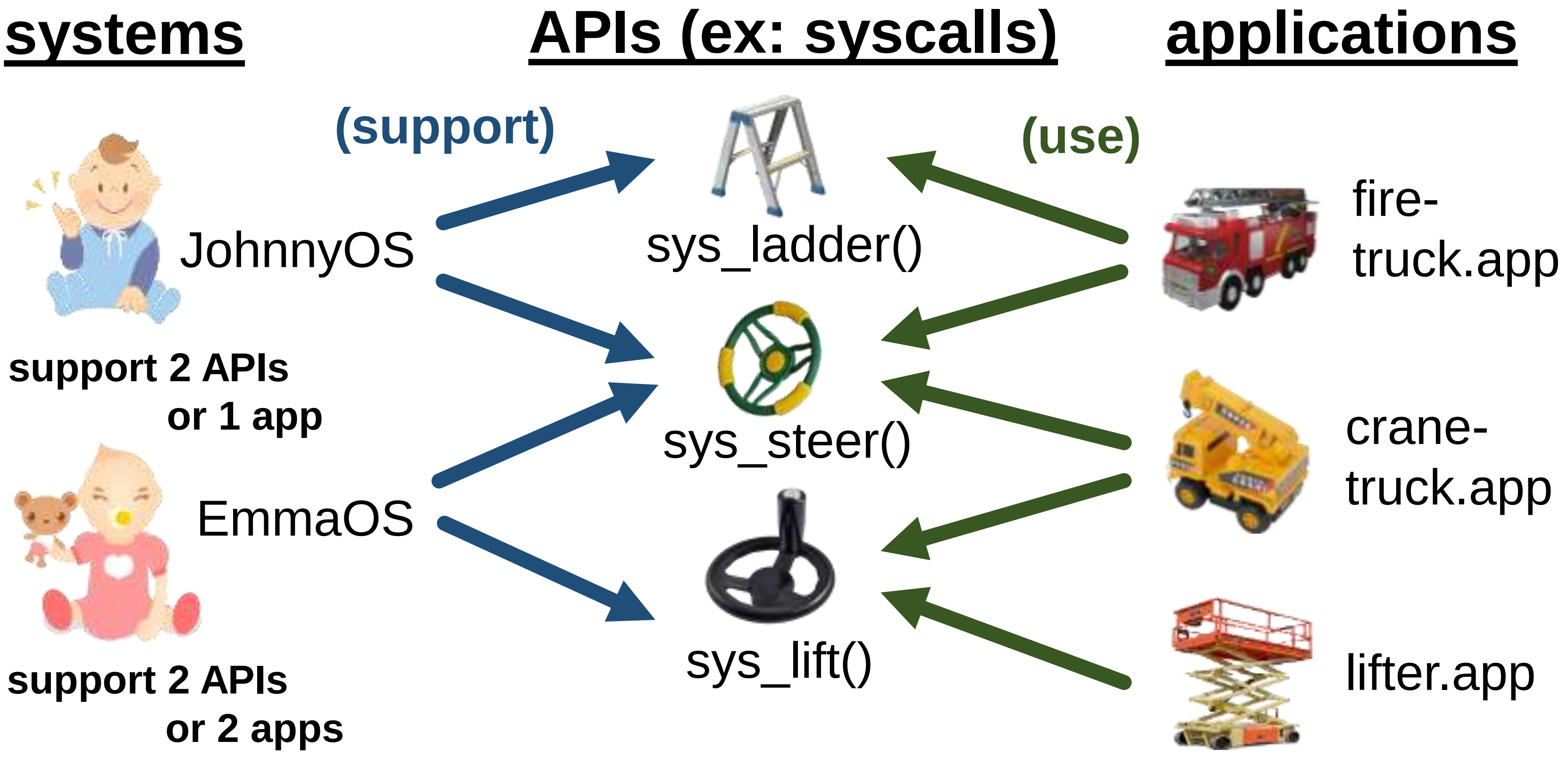
- **A method to quantify properties of API support:**
  - From importance of APIs to completeness of systems
  - Practical, generalizable to other OSes
- **A study on modern Linux APIs:**
  - Including different API types (e.g., syscalls, ioctl opcodes)
  - How Linux users rely on Linux APIs
  - An optimal path to build a Linux-compatible system



Chapter 1

How to Measure API Usage and Compatibility

First Thought: # of APIs or Applications



systems

APIs (ex: syscalls)

applications

(support)

(use)

JohnnyOS

support 2 APIs
or 1 app

EmmaOS

support 2 APIs
or 2 apps

sys_ladder()

sys_steer()

sys_lift()

fire-truck.app

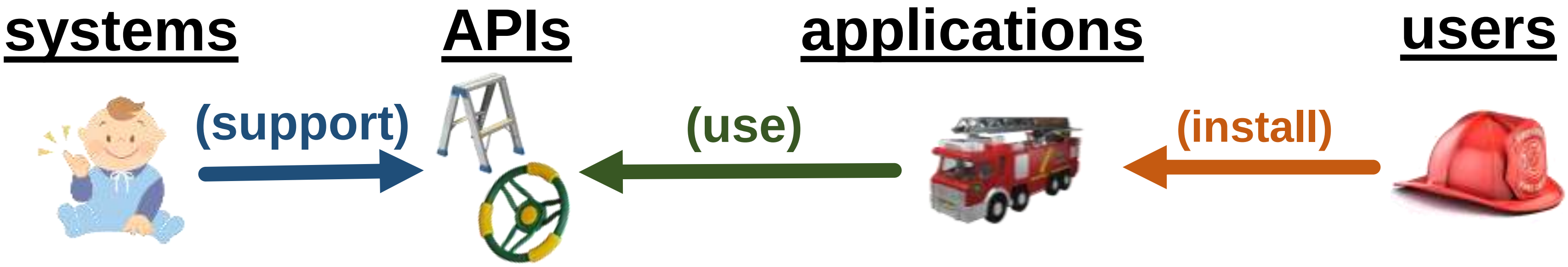
crane-truck.app

lifter.app

Can we conclude who has better API compatibility?

(No, we cannot)

Taking Popularity into Consideration



systems (support) → **APIs** ← (use) **applications** ← (install) **users**

APIs are not equally popular
(e.g., sys_read > sys_sync)

Neither are applications
(e.g., Bash > CVS)

Static binary analysis

Installation statistics
(e.g., Ubuntu popularity contest)

New metrics to reflect both users and app developers' choices

We Need 2 Metrics for Building API Support

- Which APIs should I implement first?

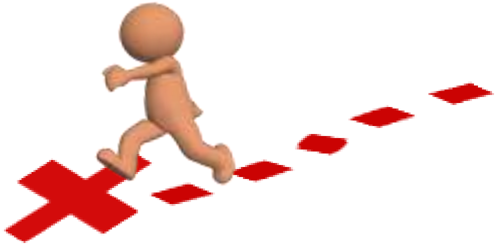
API Importance

(API usage)

- What is the progress of API support in my system?

Weighted Completeness

(system's API compatibility)



A Metric for APIs: API Importance

API importance = **Probability that a random user installs any applications using the API**

sys_steer()

(use)

cranetruck.app
(installed by
60% of users)

firetruck.app
(installed by
80% of users)

$$= \Pr\left[\begin{array}{l}\text{crane-truck.app is installed}\\ \text{or fire-truck.app is installed}\end{array}\right]$$

$$\leq 1-(1-60\%)(1-80\%) = 92\%$$

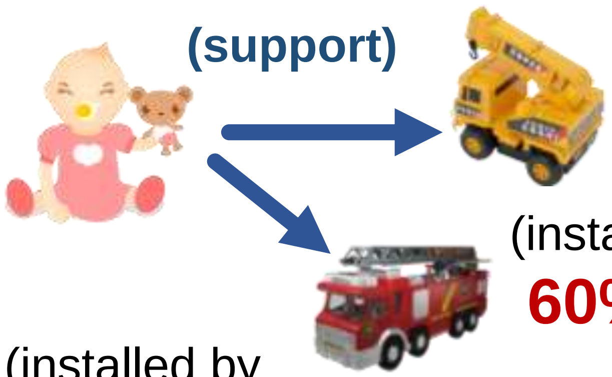
(upper bound)

**If the API is missing,
how many users will complain?**

A Metric for Systems: Weighted Completeness

weighted completeness =

Fraction of installed applications to be supported by the system, for a random user



(support)

(installed by **60%** of users)

(installed by **80%** of users)

$$\approx \frac{E\left[\begin{array}{l}\#\ \text{cranetruck.app installed} \\ +\ \ \#\ \text{firetruck.app installed}\end{array}\right]}{E\left[\ \#\ \text{applications installed}\ \right]}$$

(Example: 5 apps in average)

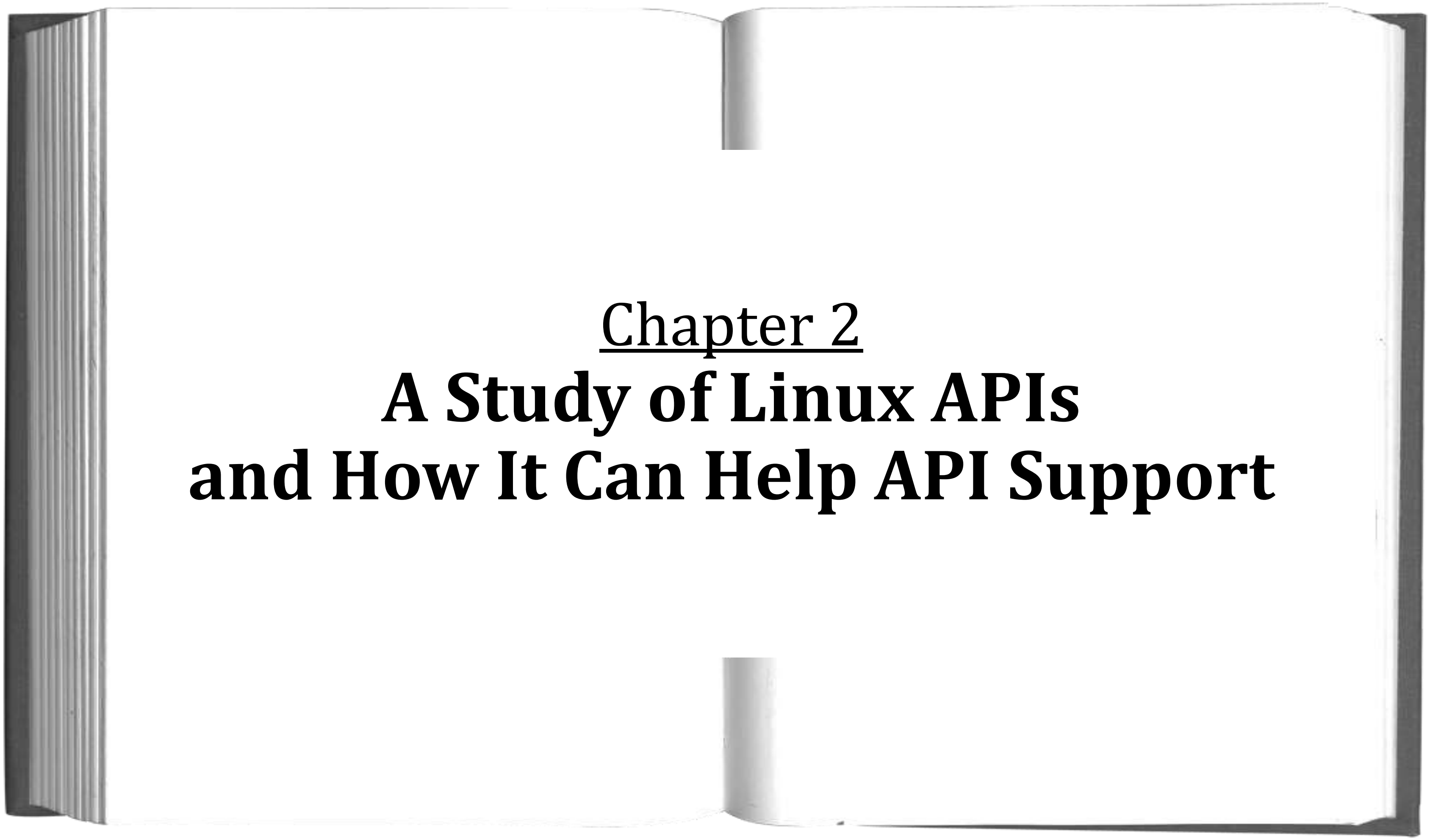
$$\approx (0.6+0.8) \div 5 = 28\%$$

If a user switches to the new system, how many apps will still work?

Quick Summary

- **API Importance (for each API):**
  % of users that install any apps using the APIs

- **Weighted Completeness (for the whole system):**
  % of a user’s installed apps supported by the system



Chapter 2

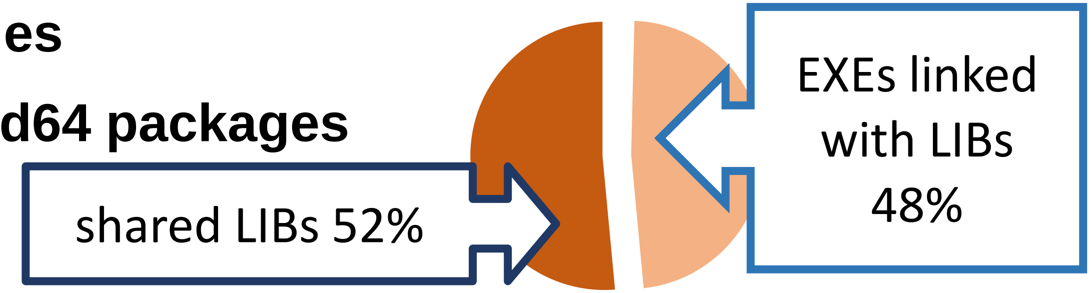
A Study of Linux APIs and How It Can Help API Support

A Large-Scale Linux API Study

- Applications Sample: Ubuntu 15.04 official repositories

66,275 ELF binaries

in 22,459 amd64 packages



shared LIBs 52%

EXEs linked with LIBs 48%

- Installation statistics: Popularity Contest

2.7 million installations (http://popcon.ubuntu.com)

0.2 million installations (http://popcon.debian.org)

A large, representative sample to draw meaningful observations

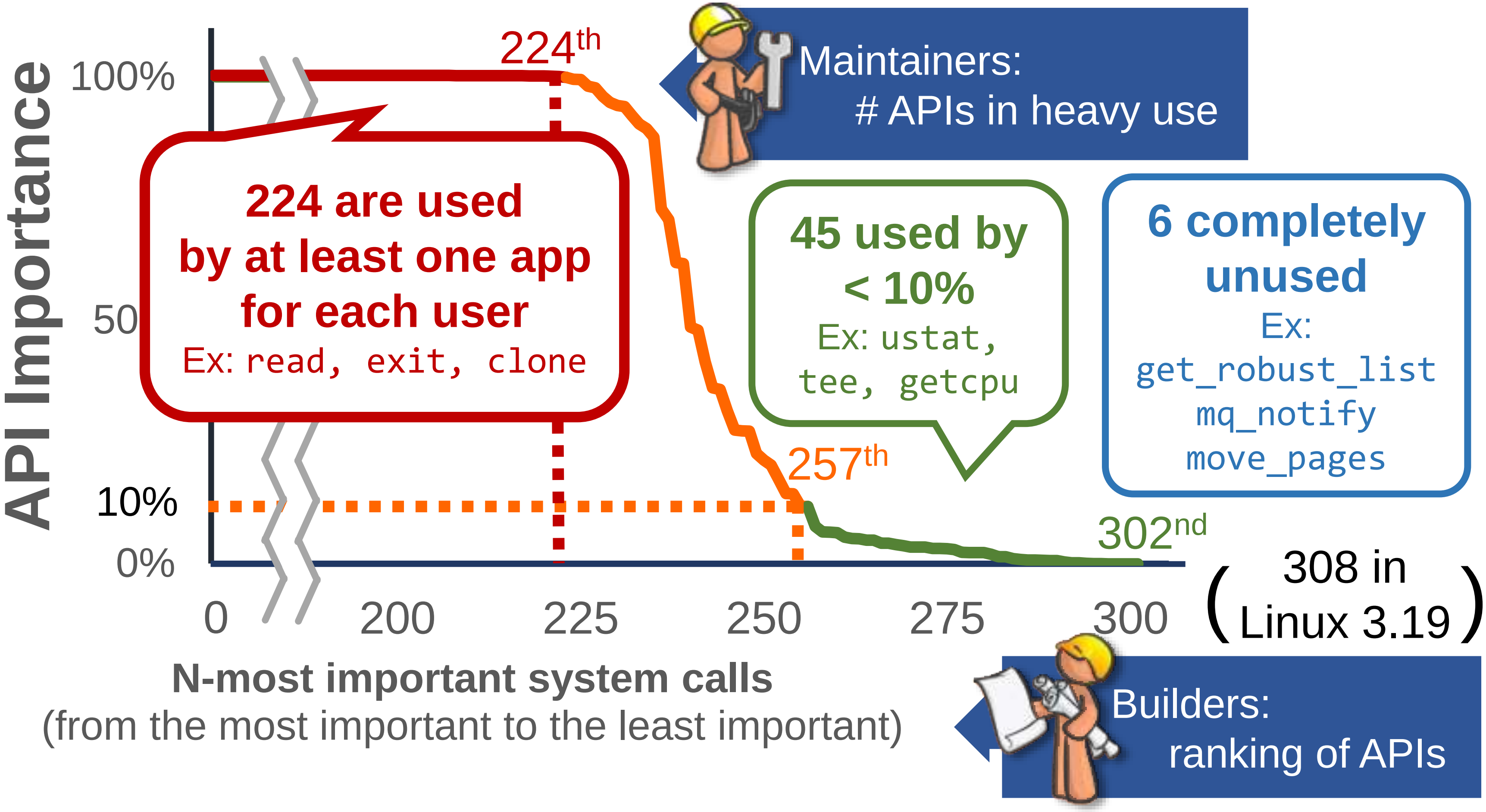
Tons that You Can Find in the Study

- **For researchers: (in the paper)**
  - Observations to motivate ideas

- **For maintainers: (in the paper)**
  - Evidences to justify or guide decisions

- **For builders:**
  - Rationale for prioritizing APIs to implement
  - Quantifying system building goals

Prioritizing Linux System Calls



224 are used by at least one app for each user
Ex: `read, exit, clone`

45 used by < 10%
Ex: `ustat, tee, getcpu`

6 completely unused
Ex:
`get_robust_list`
`mq_notify`
`move_pages`

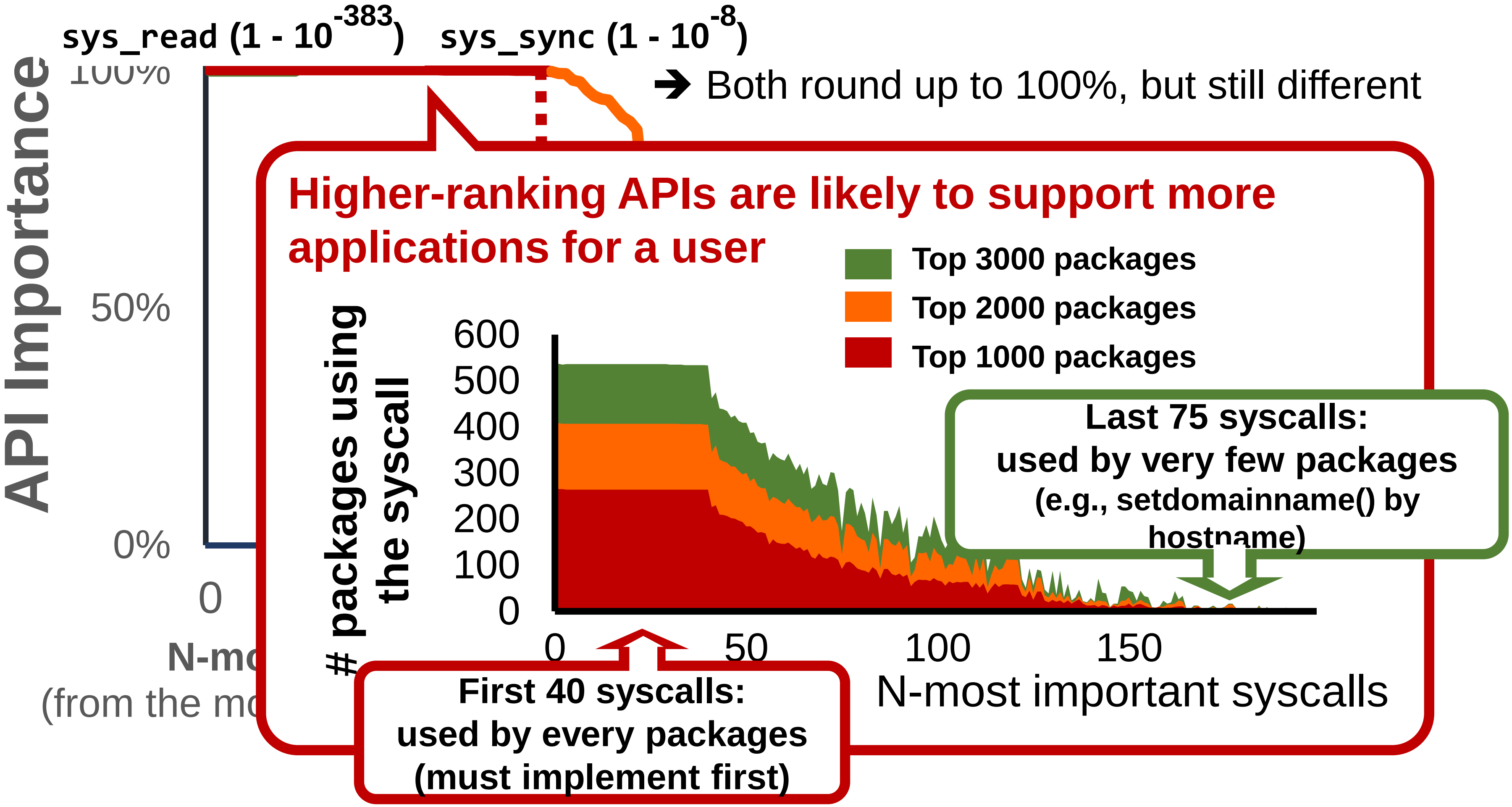
(308 in Linux 3.19)

Maintainers:
# APIs in heavy use

Builders:
ranking of APIs

Even if importance is ~100%, ranking is meaningful for prioritizing APIs to support

Using API Importance As Heuristic



sys_read (1 - 10^{-383})   sys_sync (1 - 10^{-8})

➔ Both round up to 100%, but still different

Higher-ranking APIs are likely to support more applications for a user

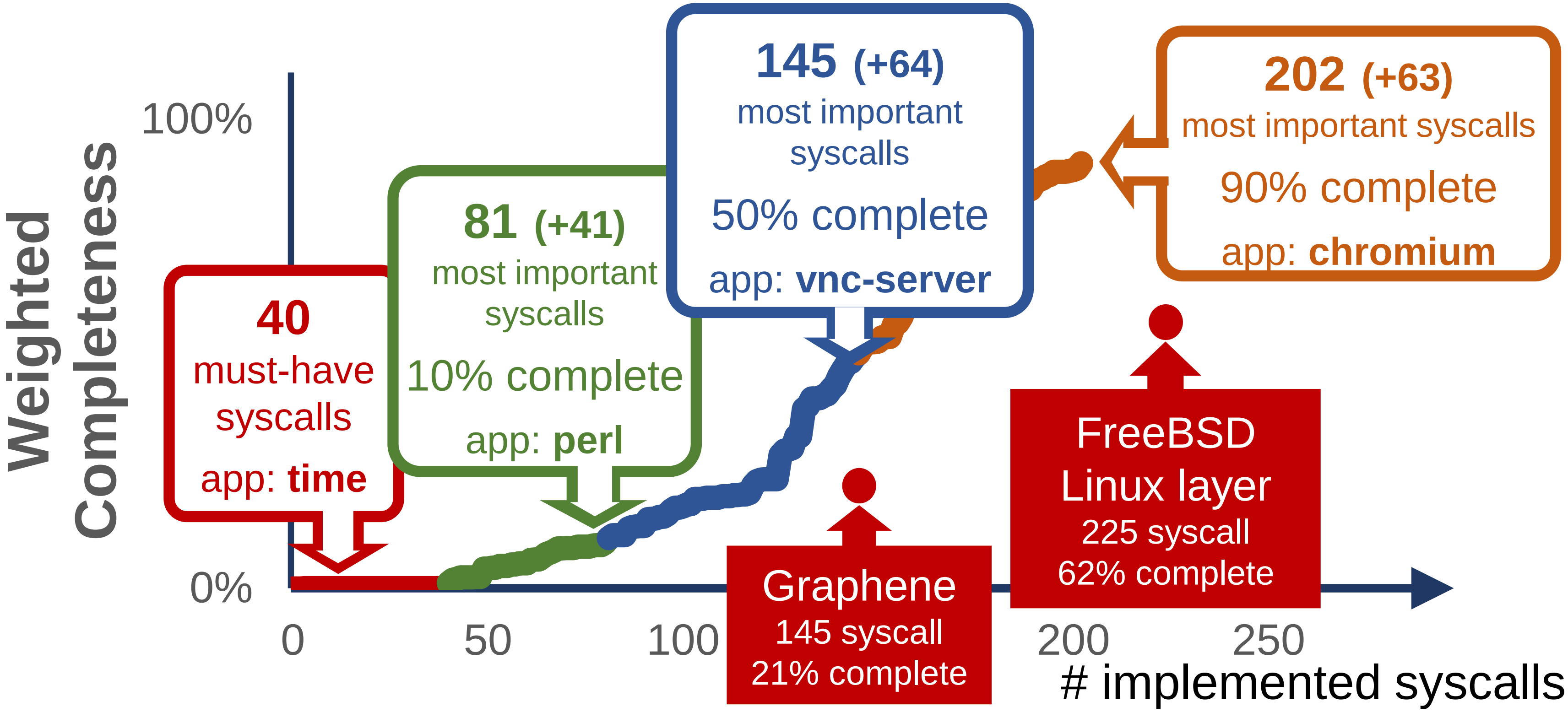
Last 75 syscalls:
used by very few packages
(e.g., setdomainname() by hostname)

First 40 syscalls:
used by every packages
(must implement first)

Ideal for prioritizing APIs to maximize weighted completeness

Evaluating the System while Building It

- Goal: maximize weighted completeness
- Approach: implement the most important APIs (syscalls) first



More nearly optimal path than only relying on developers' intuition

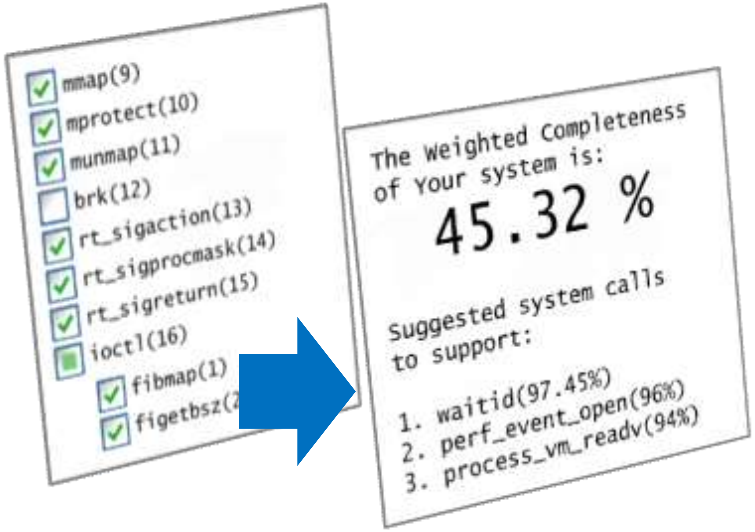
More in the Paper

- More API types:
  - Opcodes of vectored syscalls (e.g., ioctl, fcntl, prctl)
  - Pseudo-files (e.g., /proc, /dev, /sys)
  - Library functions (e.g., GNU library C)
- More systems: e.g., L4Linux, User-Mode-Linux, libc variants
- Hints for Maintainers:
  - When is the timing of deprecation?
  - Where is the sweet spot of limiting APIs (e.g., for security)?
  - What is app developers' preference?

Tool, Data and Code Available Soon!

www.oscar.cs.stonybrook.edu/api-compat-study

Online Evaluation Tool



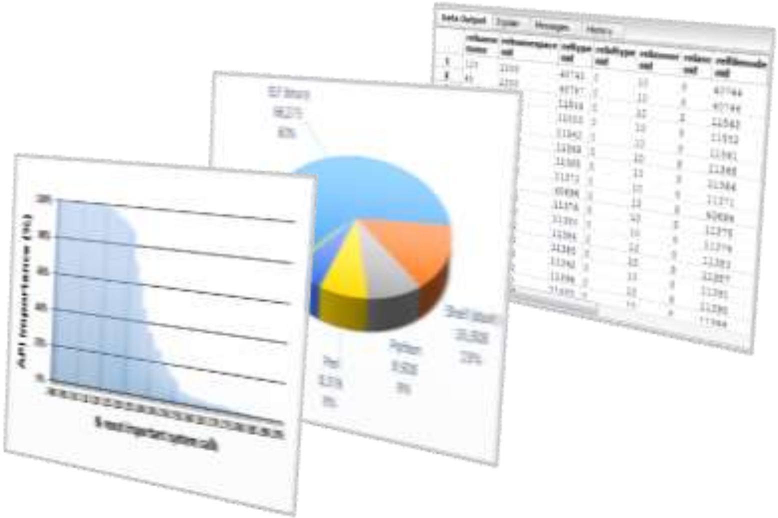
☑ mmap(9)
☑ mprotect(10)
☑ munmap(11)
☐ brk(12)
☑ rt_sigaction(13)
☑ rt_sigprocmask(14)
☑ rt_sigreturn(15)
■ ioctl(16)
☑ fibmap(1)
☑ figetbsz(2

The weighted Completeness of Your system is:

45.32 %

Suggested system calls to support:

1. waitid(97.45%)
2. perf_event_open(96%)
3. process_vm_readv(94%)



Data Set (2.6 M records) for Download

Conclusions

- **An API study that reassuringly answers the questions of system developers, from planning stage to release.**
  - **Encourage builders with better methods to strategize/evaluate.**
  - **Motivate researchers and justify maintainers' decisions.**

- **Lessons for evaluating all-or-nothing properties**

  Analysis techniques (e.g., binary analysis)
  + User studies (e.g., application popularity)

Tool / Data / Code: www.oscar.cs.stonybrook.edu/api-compat-study

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