Konfigurierbare Systemsoftware (KSS)

VL 5 – Variability Management in the Large: The VAMOS Approach

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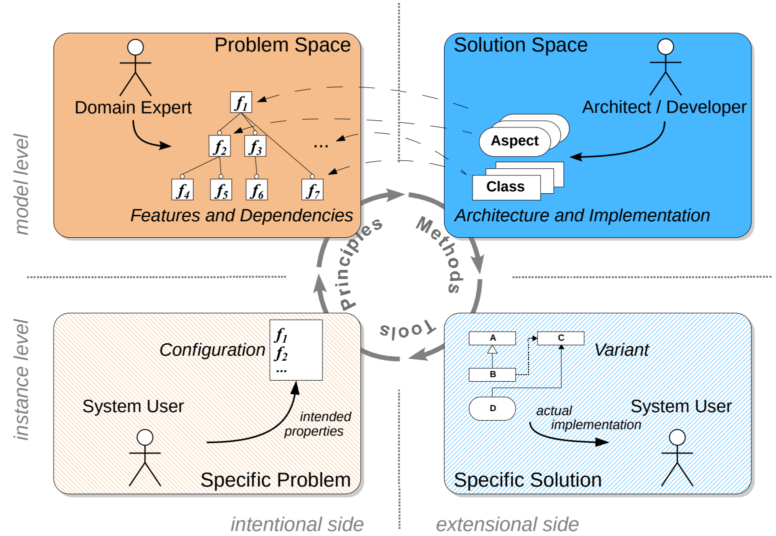
http://www4.informatik.uni-erlangen.de/Lehre/SS12/V_KSS

About this Lecture



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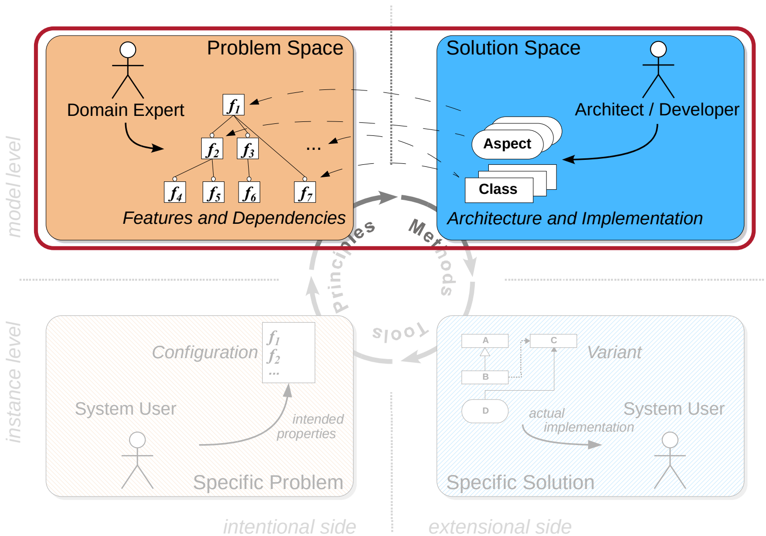
About this Lecture



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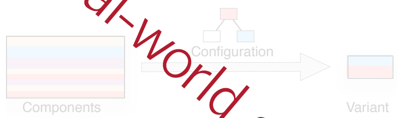
Implementation Techniques: Classification

↪ ??

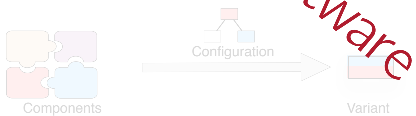
Real-world software uses them all!

- Decompositional Approaches



  - Text-based filtering (untyped)
  - Preprocessors

- Compositional Approaches



  - Language-based composition mechanisms (typed)
  - OOP, AOP, Templates

- Generative Approches

  - Metamodel-based generation of components (typed)
  - MDD, C++ TMP, generators

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Agenda

33 optional, independent features

one individual variant
for each human being

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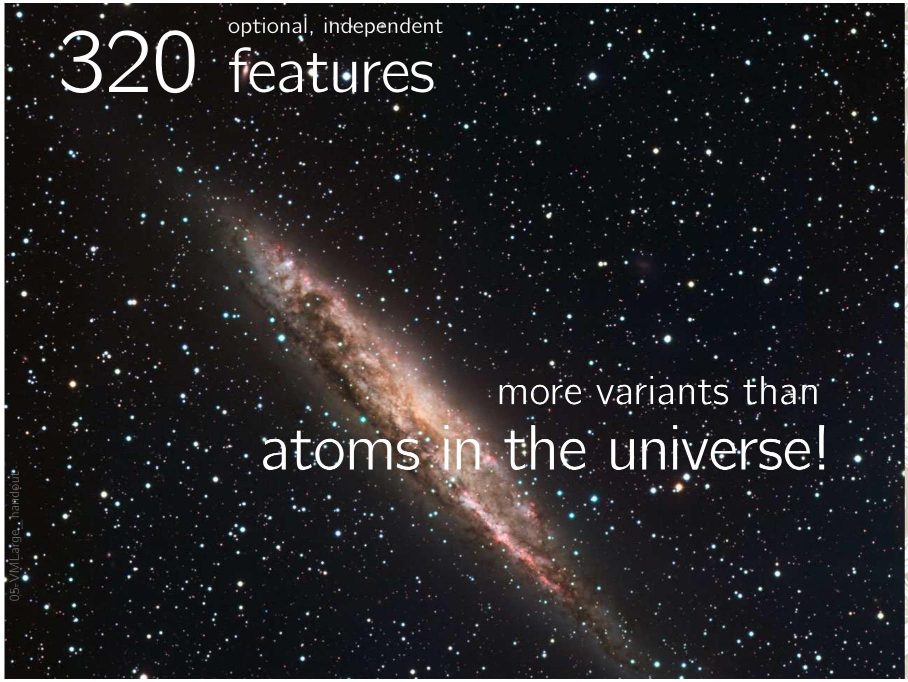

320 optional, independent features

more variants than
atoms in the universe!

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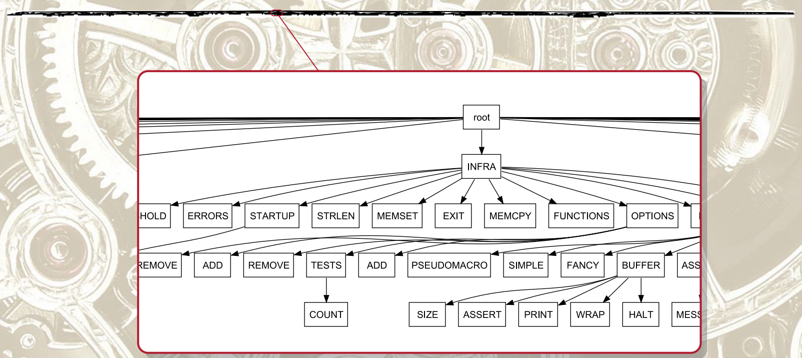
Typical Configurable Operating Systems...

ecos

1,250 features



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Typical Configurable Operating Systems...

eCos

1,250 features

Challenges: ↦ **VAMOS***

- How to maintain this?
- How to test this?
- Why so many features anyway?

* VAriability Management in Operating Systems

12,000 features

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Agenda

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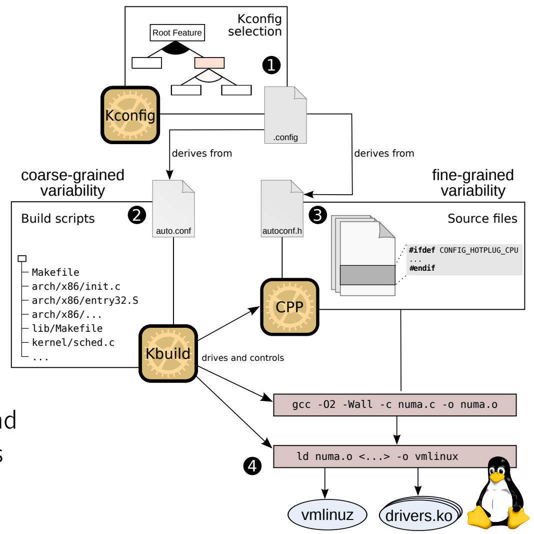
The Linux Configuration and Generation Process

1. Configuration with an KCONFIG frontend
2. Compilation of a subset of files
3. Selection of a subset of CPP Blocks
4. Linking of the kernel and loadable kernel modules



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Dominancy and Hierarchy of Variability

- l_0: Feature Modelling — 12,000 features
- l_1: Coarse-grained: KBUILD — 31,000 source files
- l_2: Fine-grained: CPP — 89,000 `#ifdef` blocks
- l_3: Lanugage-level: GCC — → `if(CONFIG_SMP) ...`
- l_4: Link-time: LD — → branches in linker scripts
- l_5: Run-time: INSMOD, MODPROBE, ...

KCONFIG controlled Variability

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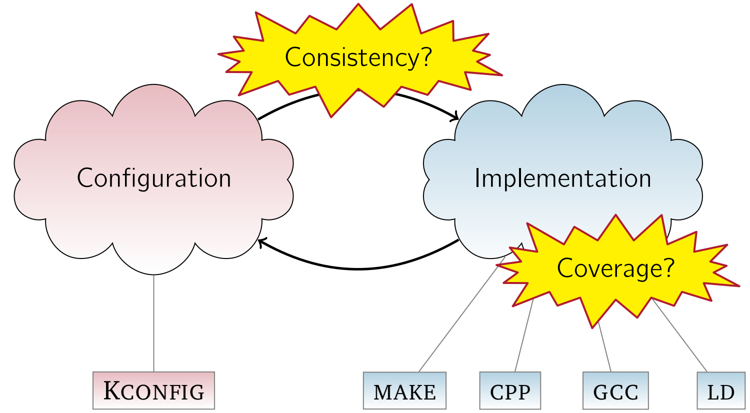
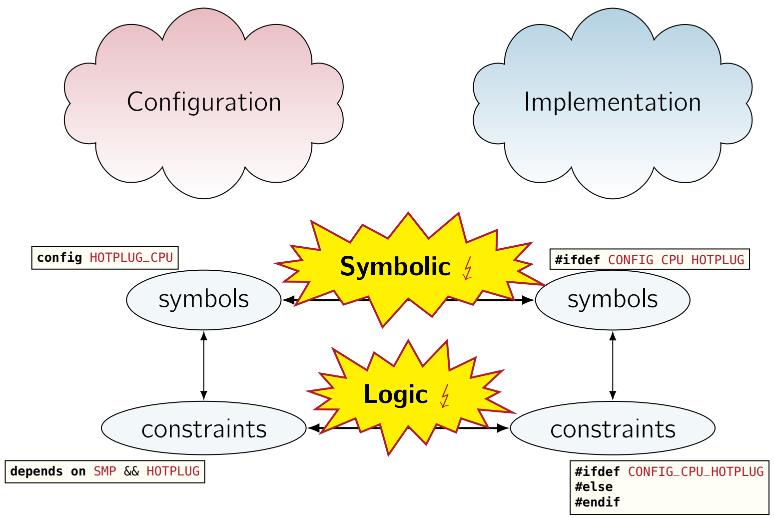
Challenges with Implemented Variability



- Central declaration of configurability: KCONFIG
- Distributed implementation of configurability: MAKE, CPP, GCC, LD

Agenda

Problem Analysis: Configuration Consistency



Problem Analysis: Symbolic Inconsistency [7]

```
config HOTPLUG_CPU
    bool "Support for hot-pluggable CPUs"
    depends on SMP && HOTPLUG
    ---help---
```

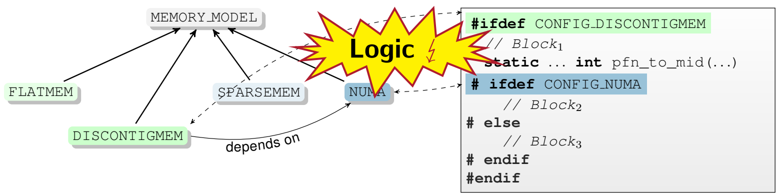
```
static int
  hotplug_cfd(struct notifier_block *nfb, unsigned long action, void *hcpu)
  {
    // [...]
          switch (action) {
          case CPU_UP_PREPARE:
          case CPU_UP_PREPARE_FROZEN:
      // [...]
#ifdef CONFIG_CPU_HOTPLUG
          case CPU_UP_CANCELED:
          case CPU_UP_CANCELED_FROZEN:

          case CPU_DEAD:
          case CPU_DEAD_FROZEN:
                  free_cpumask_var(cfd->cpumask);
                  break;
#endif
          };
          return NOTIFY_OK;
  }
```

Symbolic ϟ

Result:
Fix for a critical bug

Problem Analysis: Logic Inconsistency [7]



- Feature `DISCONTIGMEM` **implies** feature `NUMA`
- Inner blocks are not actually configuration-dependent
  - *Block*$_2$ is **always** selected ↦ **undead**
  - *Block*$_3$ is **never** selected ↦ **dead**

  } **configurability defects**

⤳ Linux contains **superfluous** `#ifdef` Blocks!

Result:
Code cleanup

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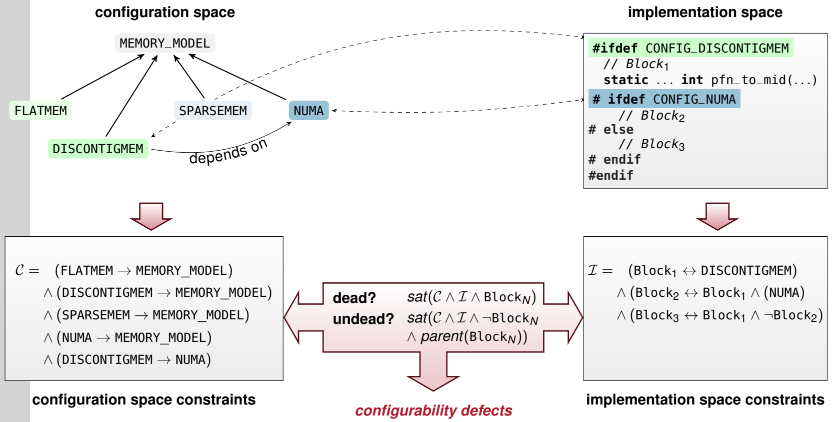
Solution Approach: Consistency Validation

Problem and solution space are analyzed for configuration points:



⇒ and transformed into propositional formulas

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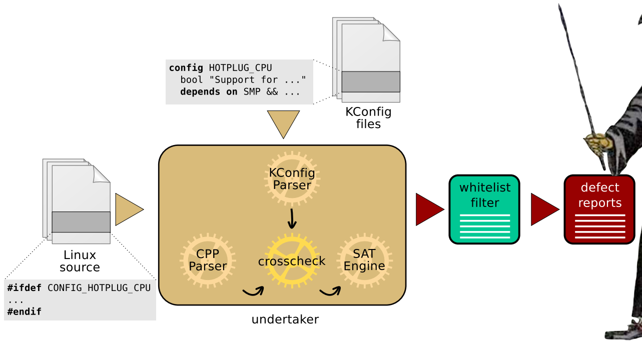
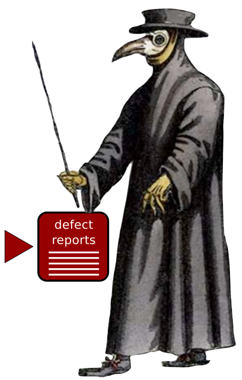
Implementation: The UNDERTAKER [7]

Job: Find (and eventually bury) dead `#ifdef`-code!





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Implementation: The UNDERTAKER [7]

Job: Find (and eventually bury) dead `#ifdef`-code!

- We have found **1776** configurability defects in Linux v2.6.35
- Submitted **123** patches for **364** defects
- **20** are confirmed **new bugs** (affecting binary code)
- Cleaned up **5129** lines of cruft code

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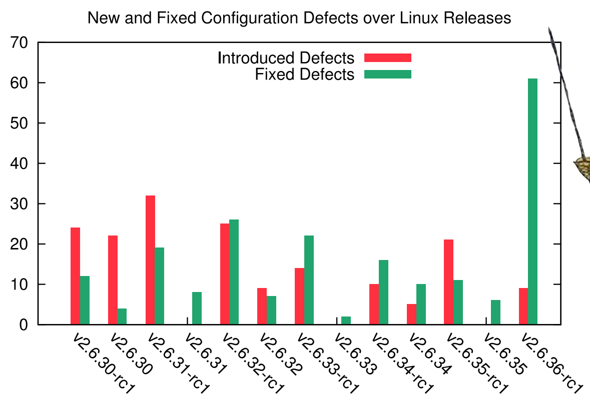
Implementation: The UNDERTAKER [7]

Job: Find (and eventually bury) dead `#ifdef`-code!



How good is this, *really?*

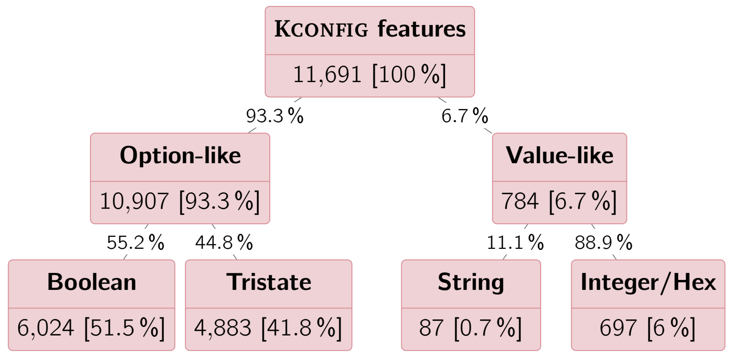
Agenda

Common Beliefs About Variability in Linux

1. Most variability is expressed by boolean (or tristate) switches.
2. arch-x86 is the largest and allyesconfig selects most features.
3. Variability is mostly implemented with the CPP.
4. The Linux *kernel* is highly configurable.

Linux v3.1: Feature Distribution by Type

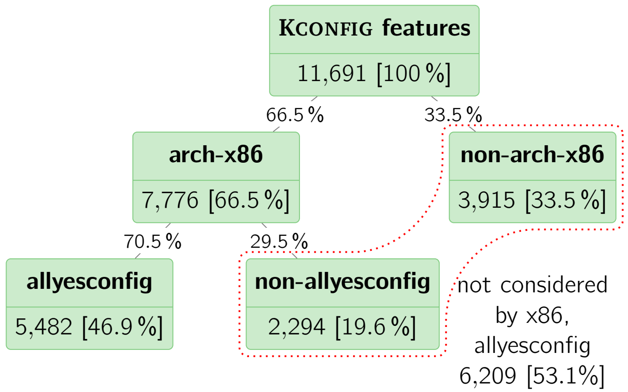
1. Most variability is expressed by boolean (or tristate) switches



⇒ Almost all features in Linux are option-like

Linux v3.1: Coverage of arch-x86 / allyesconfig

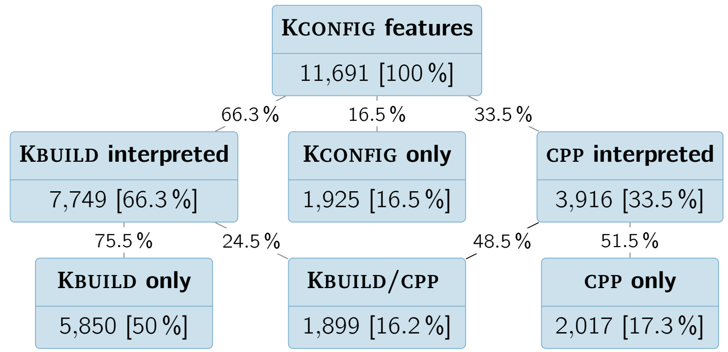
❷ arch-x86 is the largest and allyesconfig selects most features



⇒ `arch-x86/allyesconfig` is not nearly a full configuration

Linux v3.1: Distribution by Granularity

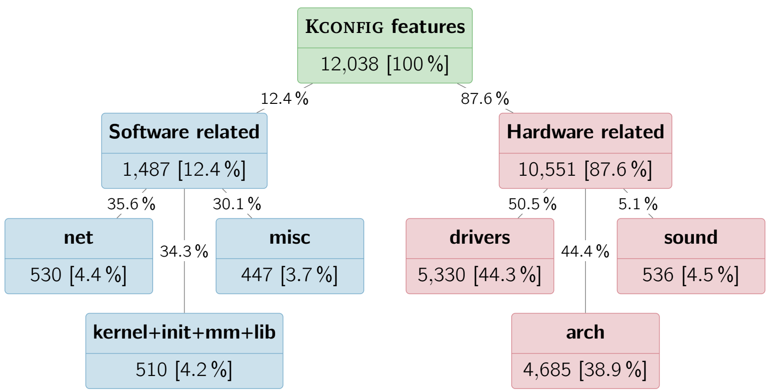
❸ Variability is mostly implemented with the CPP



⇒ KBUILD implements more than two thirds of all variation points

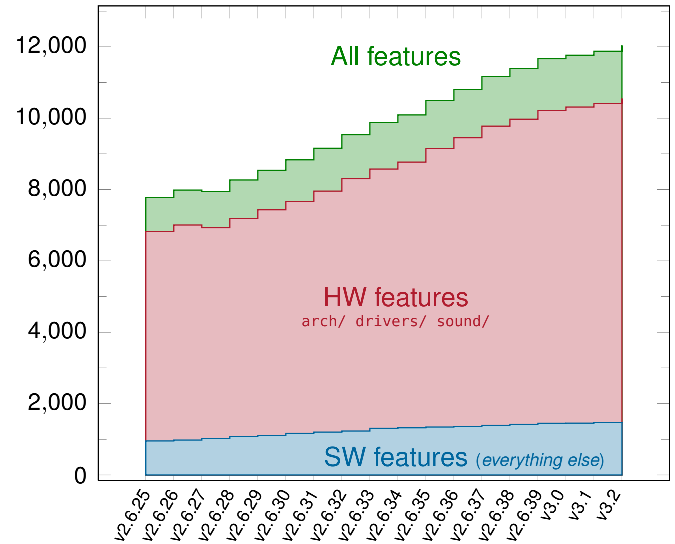
Linux v3.2: Distribution by HW/SW

❹ The Linux *kernel* is highly configurable

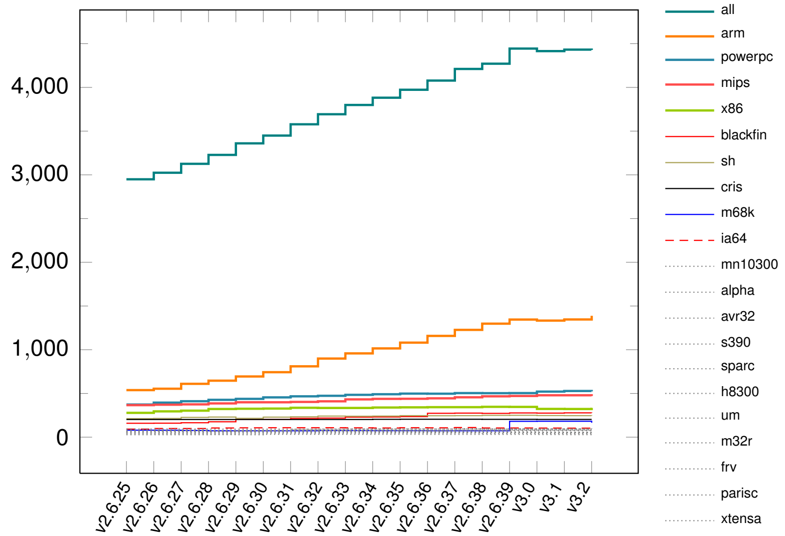


⇒ Software features account for only twelve percent of all variation points

Linux Feature Growth over Time (#Features, 2007–2012)



Linux Feature Growth over Time (#Features in arch, 2007–2012)



Results: Where Have all the Features Gone?

1. Most variability is expressed by boolean (or tristate) switches ✔
   - more than 93 percent of all features are option-like
     ⇝ it is acceptable for tools to ignore value-type features
2. arch-x86 is the largest and allyesconfig selects most features ✘
   - more than 53 percent are not covered by this configuration
     ⇝ other parts of Linux are probably less tested and error-prone!
3. Variability is mostly implemented with the CPP ✘
   - more than 66 percent of all features are handled by the build system, only 17 percent are handled by C++ only
     ⇝ variability extraction from KBUILD is necessary
4. The Linux *kernel* is highly configurable ✘
   - only 12 percent of all features configure software only
   - variability is mostly induced by advances in hardware
     ⇝ complexity will increase further

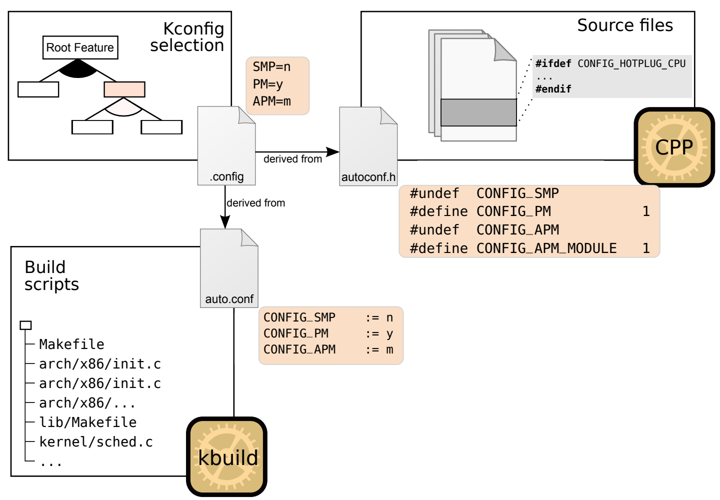
Challenges: Variability Extraction from the Build System

- Variability extraction ↦ which file is selected by which feature?
- Usual approach for variability extraction [5, 7] (KCONFIG, CPP, ...):

  source → parse & transform → *propositional formula*

- Parsing does not work well for MAKE-languages
  - declarative and Turing-complete languages
  - special features, like `shell`, `foreach`, `eval`, `addprefix`, ...
- Linux's KBUILD is built on top of (GNU) MAKE
  - nevertheless, researchers have tried parsing to extract variability
    - KBUILDMINER by Berger, She, Czarnecki, et al. [1]
    - Nadi parser by Nadi and Holt [4]
  - resulting tools are too brittle at best
    - work for a (few) Linux version(s) only
    - each usage of a special feature requires manual tailoring

Linux Build Process Revisited



Variability Extraction from KBUILD with GOLEM [2]

Basic idea: Systematic probing and inferring of implications

SPLC '12: Dietrich, et al. [2]

- *Dancing Makefiles*
- Identification of KCONFIG references
- Recursion into subdirectory while considering constraints

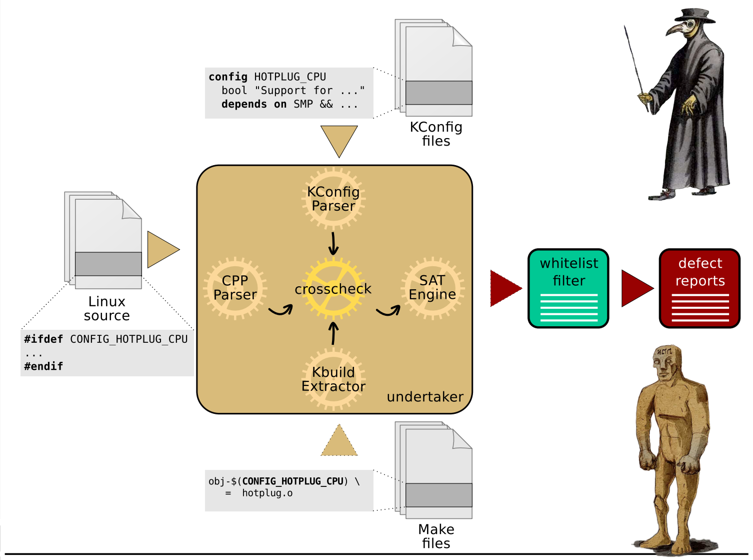
```
obj-y                += fork.o
obj-$(CONFIG_SMP)    += spinlock.o
obj-$(CONFIG_APM)    += apm.o

obj-$(CONFIG_PM)     += power/
```

- Robust with respect to architecture and version

⇒ no adaptations on or for KBUILD!

Kernelversion	found inferences	
v2.6.25	6,274	(93.7%)
v2.6.28.6	7,032	(93.6%)
v2.6.33.3	9,079	(94.9%)
v2.6.37	10,145	(95.1%)
v3.2	11,050	(95.4%)

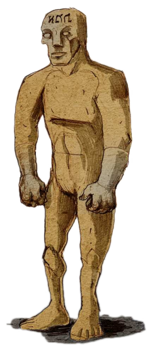
Case Study: Configuration Consistency ↪ 5–17



Case Study: Configuration Consistency ↪ 5–17

Configuration defects in Linux v3.2:

Without KBUILD constraints	
Code defects	1835
Referential defects	415
Logical defects	83
Sum:	**Σ 2333**
With KBUILD constraints	
Code defects	1835
Referential defects	439
Logical defects	299
Sum:	**Σ 2573**



Result: +10%

Summary

- Real-world system software offers thousands of features
  - eCos: 1,250 features
  - Linux: 12,000 features
  - } mostly induced by hardware!
  - central declaration (ecosConfig, KCONFIG)
  - distributed, multi-paradigm implementation (MAKE, CPP, GCC, ...)
- This imposes great challenges for management and maintenance
  - how to ensure configurability consistency?
  - how to ensure configuration coverage?
  - how to keep pace with the constant feature increase?
- A strong call for adequate tool support ↦ VAMOS
  - already found thousands and fixed hundreds of defects and bugs
  - more to come!

Referenzen

[1] Thorsten Berger, Steven She, Krzysztof Czarnecki, et al. *Feature-to-Code Mapping in Two Large Product Lines.* Tech. rep. University of Leipzig (Germany), University of Waterloo (Canada), IT University of Copenhagen (Denmark), 2010.

[2] Christian Dietrich, Reinhard Tartler, Wolfgang Schröder-Preikschat, et al. "A Robust Approach for Variability Extraction from the Linux Build System". In: *Proceedings of the 16th Software Product Line Conference (SPLC '12).* (Salvador, Brazil, Sept. 2–7, 2012). (To appear). New York, NY, USA: ACM Press, 2012. URL: `http://www4.informatik.uni-erlangen.de/Publications/2012/dietrich_12_splc_draft.pdf`.

[3] Christian Dietrich, Reinhard Tartler, Wolfgang Schröder-Preikschat, et al. "Understanding Linux Feature Distribution". In: *Proceedings of the 2nd AOSD Workshop on Modularity in Systems Software (AOSD-MISS '12).* (Potsdam, Germany, Mar. 27, 2012). Ed. by Christoph Borchert, Michael Haupt, and Daniel Lohmann. New York, NY, USA: ACM Press, 2012. ISBN: 978-1-4503-1217-2. DOI: `10.1145/2162024.2162030`.

[4] Sarah Nadi and Richard C. Holt. "Mining Kbuild to Detect Variability Anomalies in Linux". In: *Proceedings of the 16th European Conference on Software Maintenance and Reengineering (CSMR '12).* (Szeged, Hungary). Ed. by Tom Mens, Yiannis Kanellopoulos, and Andreas Winter. To appear. Washington, DC, USA: IEEE Computer Society Press, 2012.

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[5] Julio Sincero, Reinhard Tartler, Daniel Lohmann, et al. "Efficient Extraction and Analysis of Preprocessor-Based Variability". In: *Proceedings of the 9th International Conference on Generative Programming and Component Engineering (GPCE '10).* (Eindhoven, The Netherlands). Ed. by Eelco Visser and Jaakko Järvi. New York, NY, USA: ACM Press, 2010, pp. 33–42. ISBN: 978-1-4503-0154-1. DOI: `10.1145/1868294.1868300`.

[6] Reinhard Tartler, Daniel Lohmann, Christian Dietrich, et al. "Configuration Coverage in the Analysis of Large-Scale System Software". In: *ACM SIGOPS Operating Systems Review* 45.3 (Jan. 2012), pp. 10–14. ISSN: 0163-5980. DOI: `10.1145/2094091.2094095`.

[7] Reinhard Tartler, Daniel Lohmann, Julio Sincero, et al. "Feature Consistency in Compile-Time-Configurable System Software: Facing the Linux 10,000 Feature Problem". In: *Proceedings of the ACM SIGOPS/EuroSys European Conference on Computer Systems 2011 (EuroSys '11).* (Salzburg, Austria). Ed. by Christoph M. Kirsch and Gernot Heiser. New York, NY, USA: ACM Press, Apr. 2011, pp. 47–60. ISBN: 978-1-4503-0634-8. DOI: `10.1145/1966445.1966451`.