# Variability Modeling in the Real: A Perspective from the Operating Systems Domain

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Andrzej Wasowski, Krzysztof Czarnecki

# Biologists go into the Wild for their Studies…

John Liebenberg / Barcroft Media
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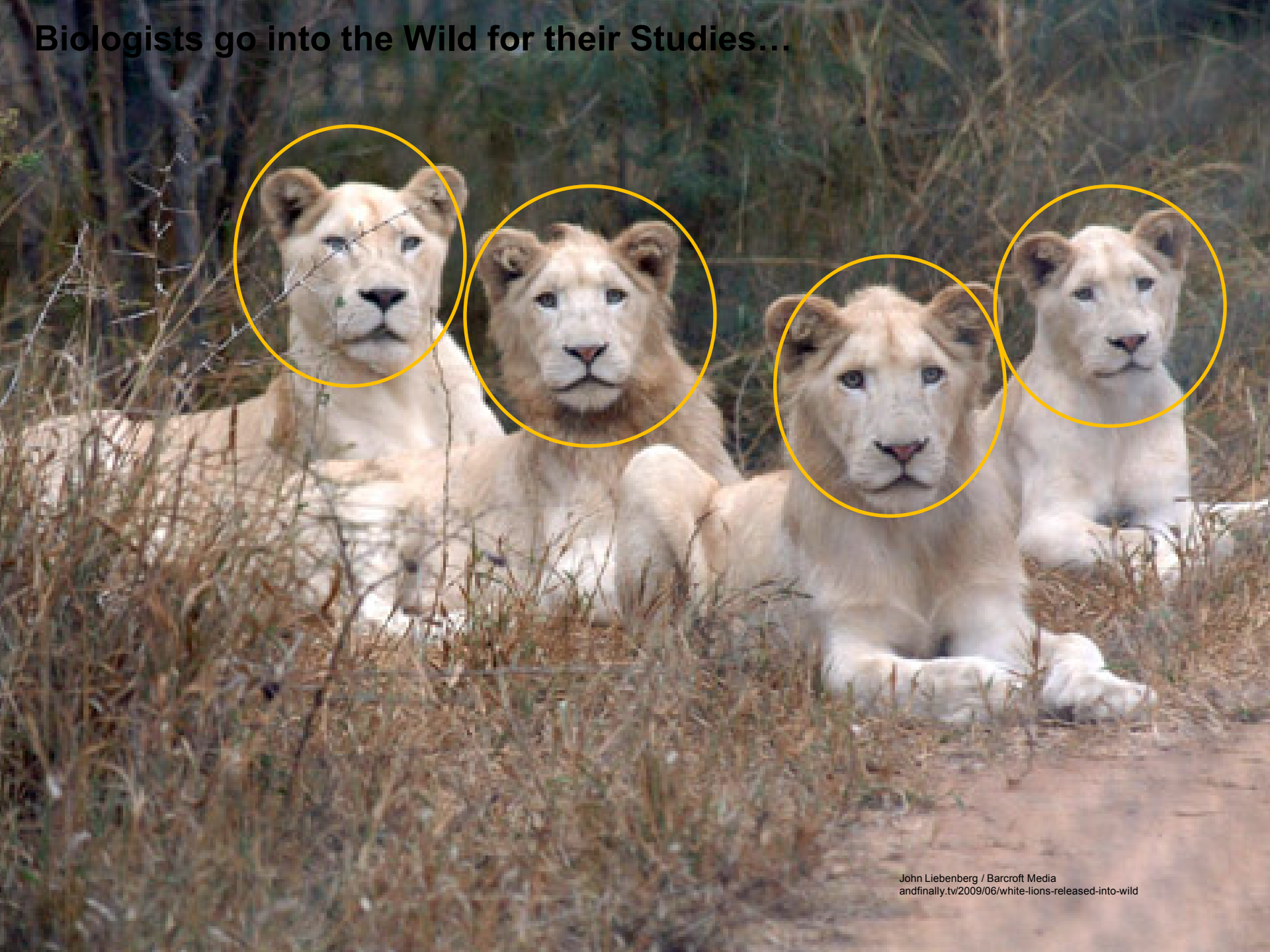

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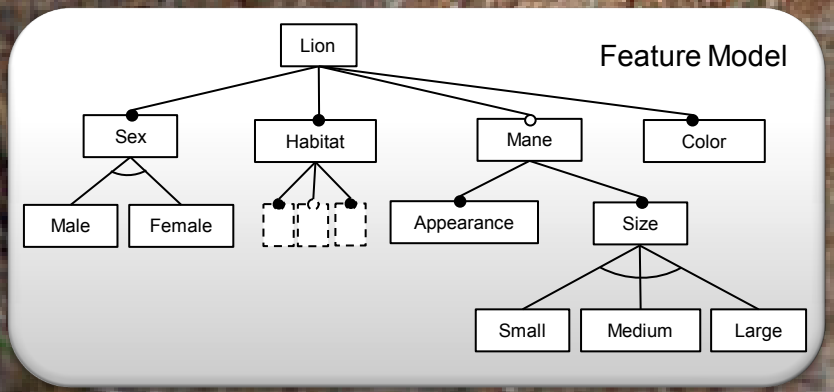


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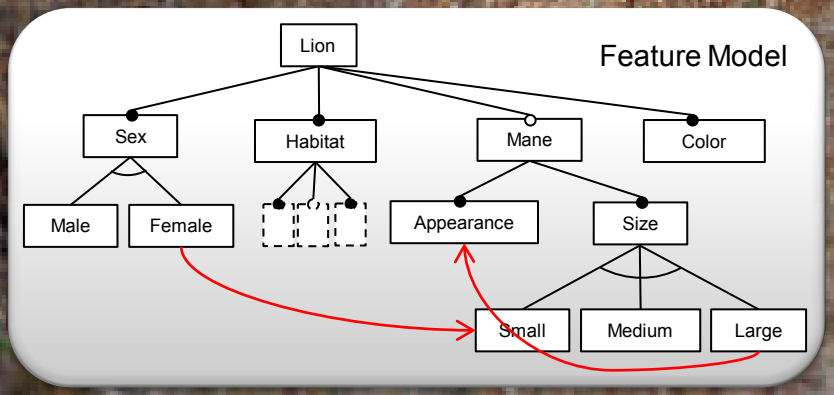


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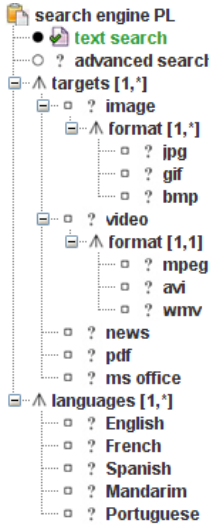
# Variability Modeling


**Variability Model**
(15810 possible configurations)



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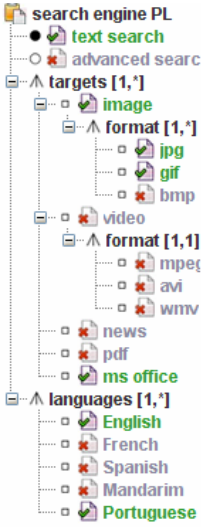


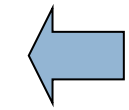

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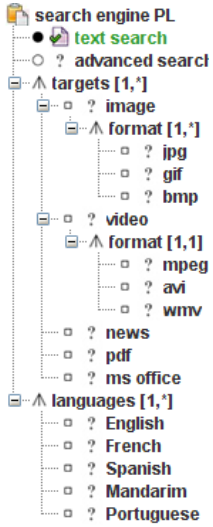




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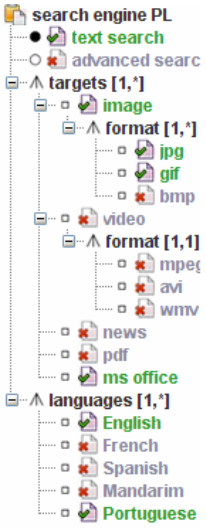


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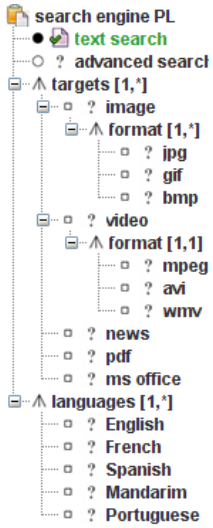


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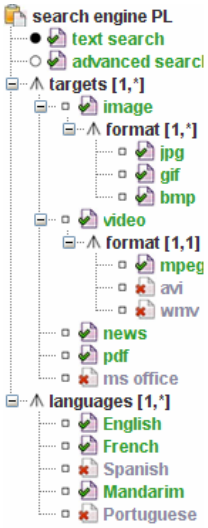
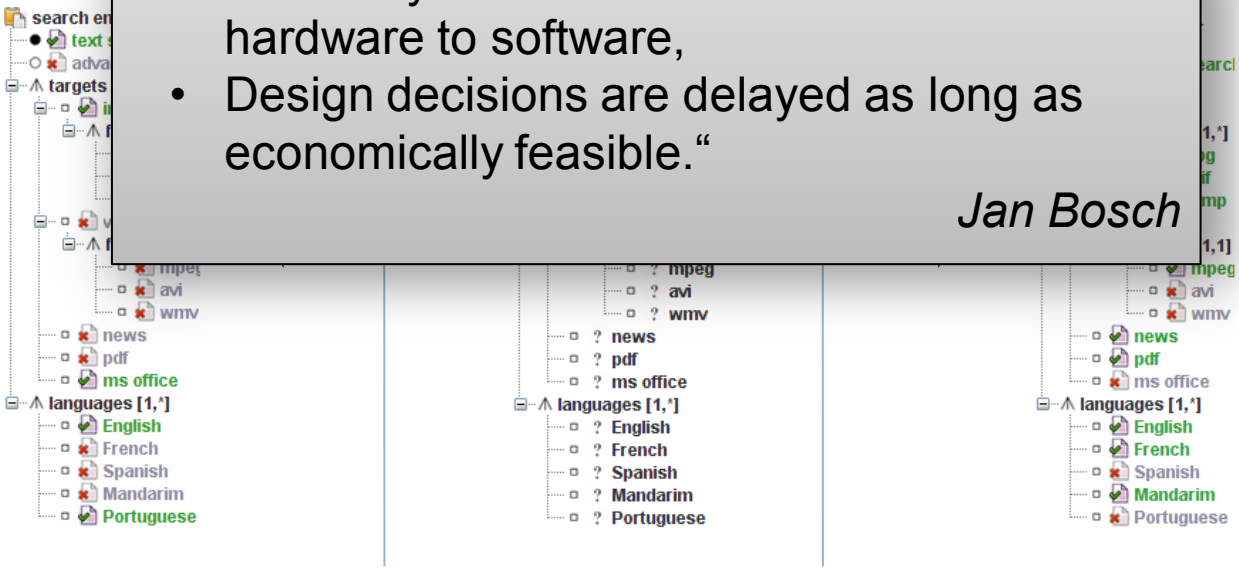


"Variability needs in software are constantly increasing, because:

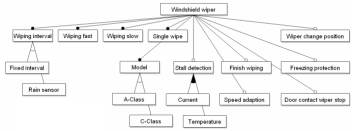
- Variability moves from mechanics and hardware to software,
- Design decisions are delayed as long as economically feasible."

*Jan Bosch*




20 Years of Feature Models
Jubilee
Celebratee
Event
Hangover
Nice
Remarkable
Congratulations to
Kyo C. Kang
VaMoS 2010
Linz, Austria

## Other Domains

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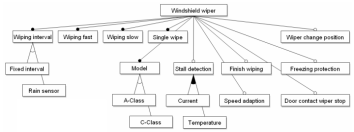




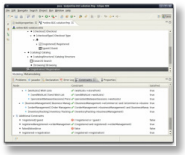
## Tools

pure·systems

BigLever Software, Inc.

AHEAD
Feature Oriented Programming

FMP



IDE Feature

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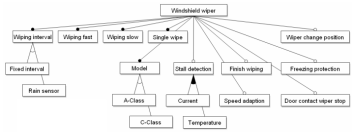



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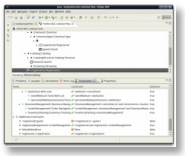

FeatureIDE

## Standardization Efforts

OMG®

OBJECT MANAGEMENT GROUP

**Common Variability Language (CVL)**

eclipse

eclipse.org/proposals/feature-model

# NOW, WHAT‘S THE PROBLEM?

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    - Few details about their **usage** given
  - *Chen et al. [SPLC09]:*
    - "There is **only little**, if any, **experimental** or detailed **comparative** analysis … of different VM approaches."
    - All VM approaches share **similar concepts**
    - Some sort of reference model needed for **model transformations**, **tools** and **future research**

# OUR STUDY…

# Three Research Questions

1. Can we provide quantitative and qualitative empirical evidence *whether* Feature Modeling concepts are used in real-world languages?

2. Are additional concepts needed?

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We study

**CONCEPTS, SEMANTICS AND USAGE OF…**

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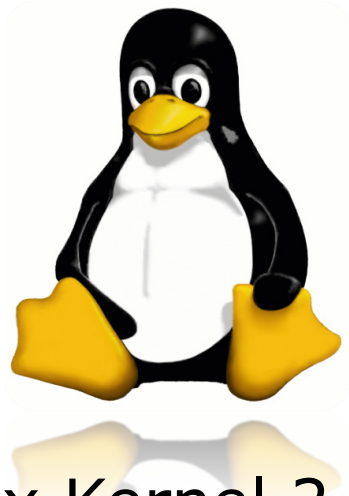

Linux Kernel 2.6.32
(22 hardware architectures,
6.4 mio. SLOC)

6320 Features (X86)

## CDL language

eCos 3.0
(embedded RTOS,
116 architectures,
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1244 Features (I386)

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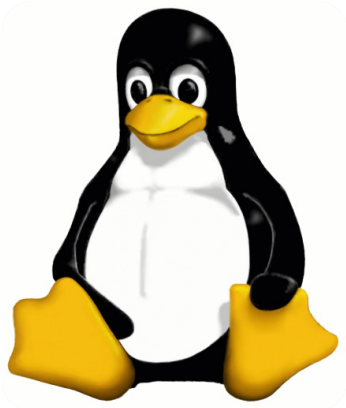

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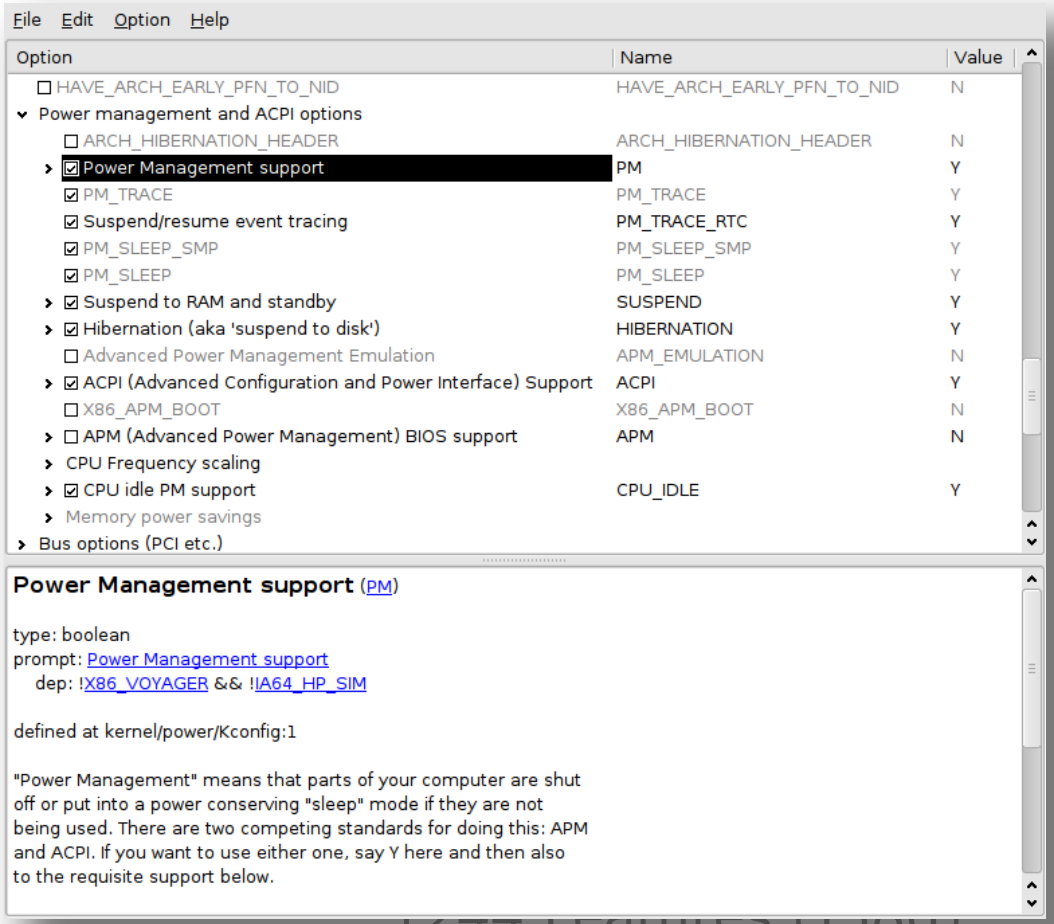

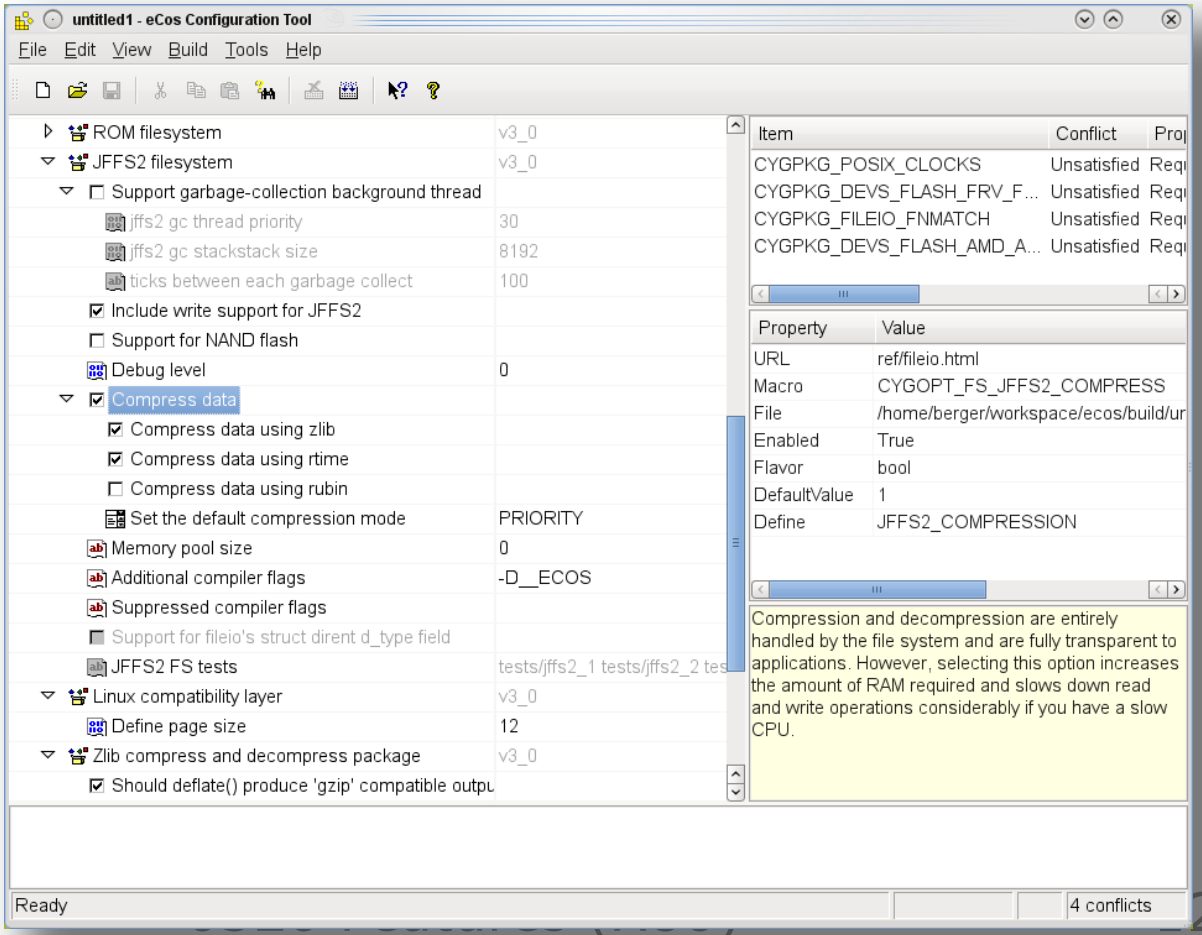


## CDL language

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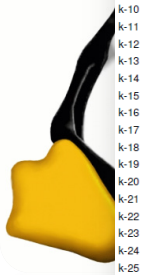
## Kconfig language

```
menuconfig MISC_FILESYSTEMS
  bool "Miscellaneous filesystems"

 if MISC_FILESYSTEMS

  config JFFS2_FS
   tristate "Journalling Flash File System" if MTD
   select CRC32 if MTD




 config JFFS2_FS_DEBUG
  int "JFFS2 Debug level (0=quiet, 2=noisy)"
  depends on JFFS2_FS
  default 0
  range 0 2
  --- help ---
    Debug verbosity of ...


 config JFFS2_FS_WRITEBUFFER
  bool
  depends on JFFS2_FS
  default HAS_IOMEM


 config JFFS2_COMPRESS
  bool "Advanced compression options for JFFS2"
  depends on JFFS2_FS

 config JFFS2_ZLIB
  bool "Compress w/zlib..." if JFFS2_COMPRESS
  depends on JFFS2_FS
  select ZLIB_INFLATE
  default y

 choice
  prompt "Default compression" if JFFS2_COMPRESS
  default JFFS2_CMODE_PRIORITY
  depends on JFFS2_FS
  config JFFS2_CMODE_NONE
   bool "no compression"
  config JFFS2_CMODE_PRIORITY
   bool "priority"
  config JFFS2_CMODE_SIZE
   bool "size (EXPERIMENTAL)"
 endchoice
endif
```

## CDL language

```
cdl_component MISC_FILESYSTEMS {
 display   "Miscellaneous filesystems"
 flavor    none
}

cdl_package CYGPKG_FS_JFFS2 {
  display    "Journalling Flash File System"
  requires   CYGPKG_CRC
  implements CYGINT_IO_FILEIO
  parent     MISC_FILESYSTEMS
  active_if  MTD

  cdl_option CYGOPT_FS_JFFS2_DEBUG {
   display          "Debug level"
   flavor           data
   default_value    0
   legal_values     0 to 2
   define           CONFIG_JFFS2_FS_DEBUG
   description      "Debug verbosity of...."
  }

  cdl_option CYGOPT_FS_JFFS2_NAND {
   flavor           bool
   define           CONFIG_JFFS2_FS_WRITEBUFFER
   calculated       HAS_IOMEM
  }

  cdl_component CYGOPT_FS_JFFS2_COMPRESS {
   display          "Compress data"
   default_value    1

     cdl_option CYGOPT_FS_JFFS2_COMPRESS_ZLIB {
      display          "Compress data using zlib"
      requires         CYGPKG_COMPRESS_ZLIB
      default_value    1
     }

     cdl_option CYGOPT_FS_JFFS2_COMPRESS_CMODE {
      display          "Set the default compression mode"
      flavor           data
      default_value    { "PRIORITY" }
      legal_values     { "NONE" "PRIORITY" "SIZE" }
   }
  }
}
```



Linux K
(22 hardw
6.4

3.0
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LOC)

6320 F

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What do we mean by variability model

# SEMANTICS?

- Configuration Space Semantics

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$$[\![\cdot]\!]_{\text{kconfig}} : \text{Kconfig} \rightarrow \mathcal{P}(\text{Confs})$$

$C_1$={(JFFS2,y),(JFFS2_DEBUG,2),…}

$C_2$={(JFFS2,m),(JFFS2_DEBUG,0),…}

$C_n$={(JFFS2,n),(JFFS2_DEBUG,0),…}

# METHODOLOGY

# Methodology - Design Space

- Reverse-engineered formal semantics (denotational style)

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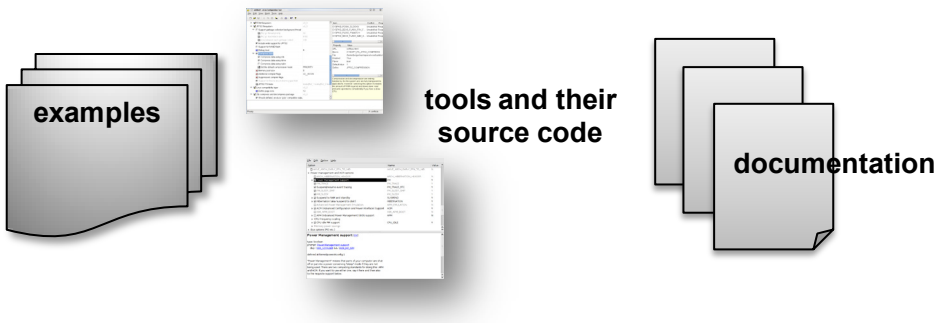

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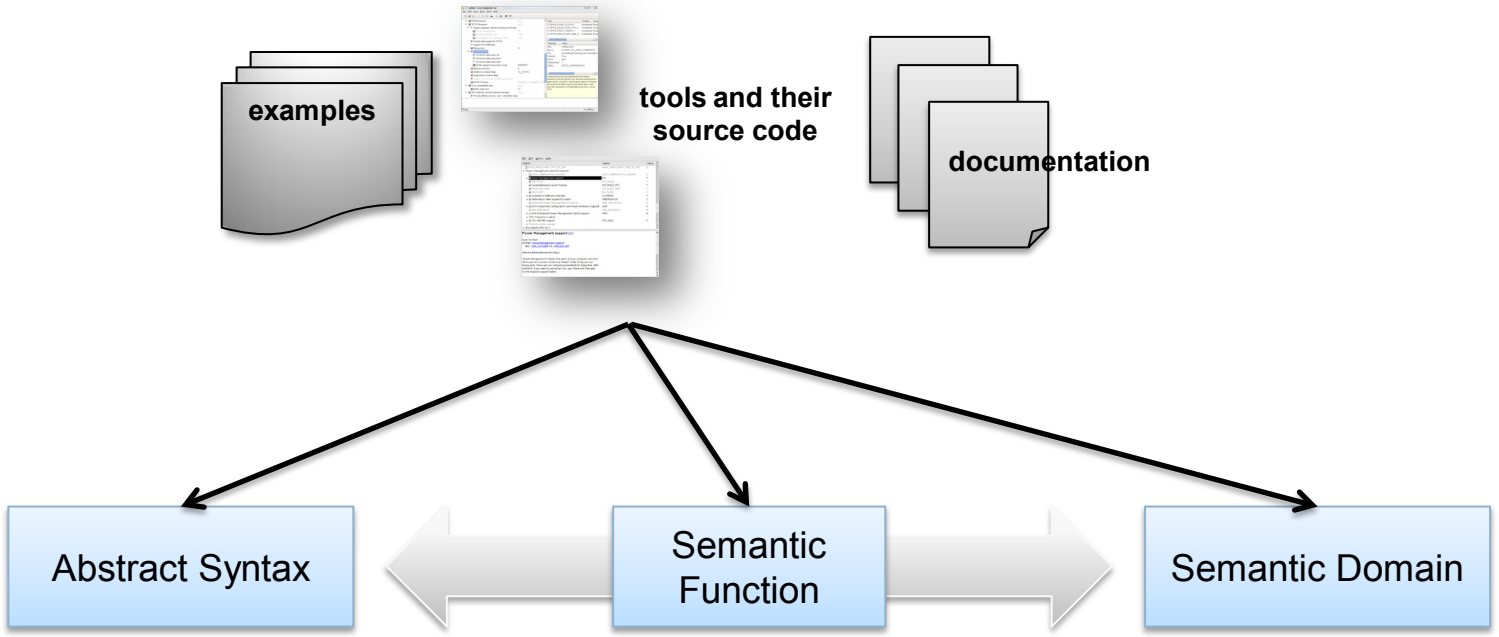

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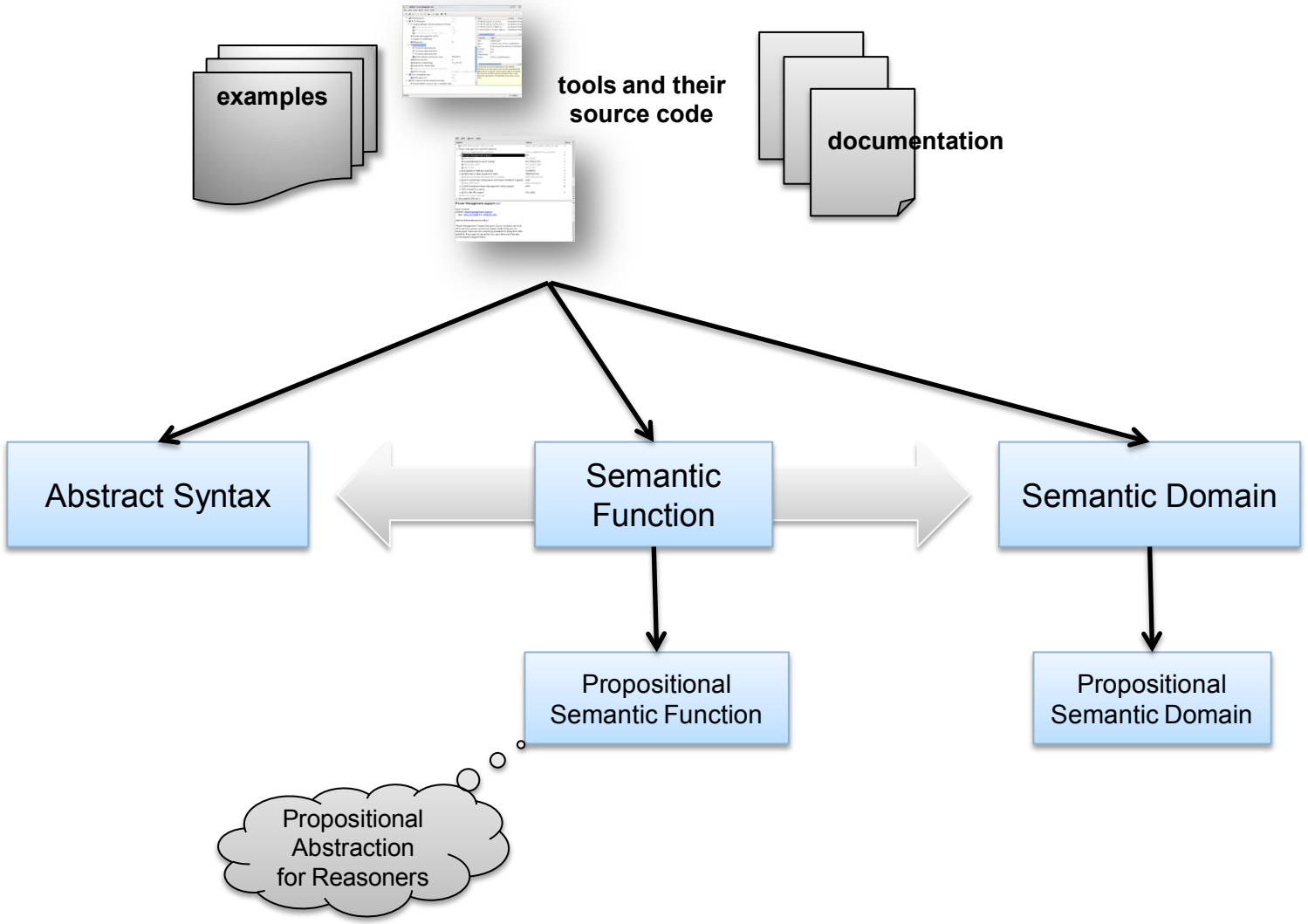
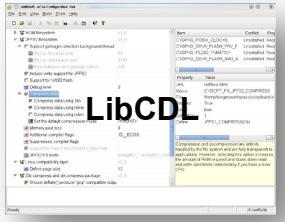
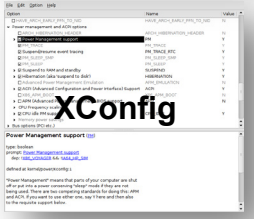


# Methodology - Language Usage

extension of configurators



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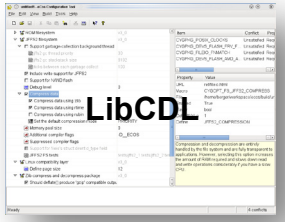
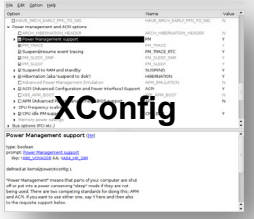
Linux and eCos models




model export

CDL

Intermediate Model




model export

Kconfig

Intermediate Model

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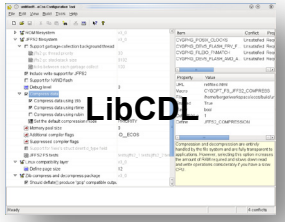
extension of configurators

Linux and eCos models

analysis infrastructure

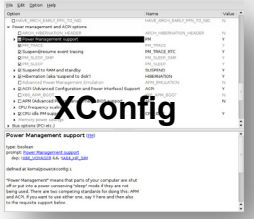



model export

CDL

Intermediate Model

parsing

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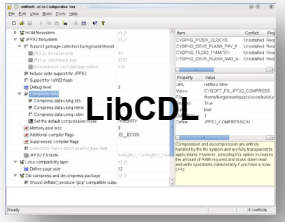


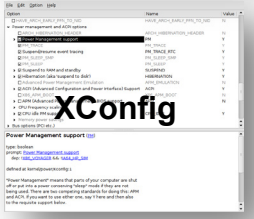


model export

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CDL

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Intermediate Model

parsing

parsing

statistics

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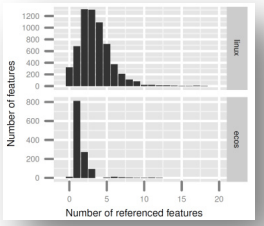

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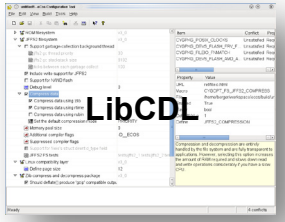
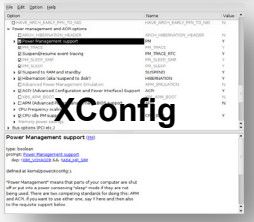



model export

model export

CDL

Intermediate Model

Kconfig

Intermediate Model

parsing

parsing

transformation

statistics

statistics

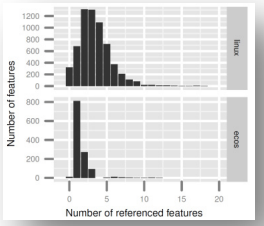
transformation

propositional abstraction

$\varphi_{ecos}$

propositional abstraction

$\varphi_{linux}$



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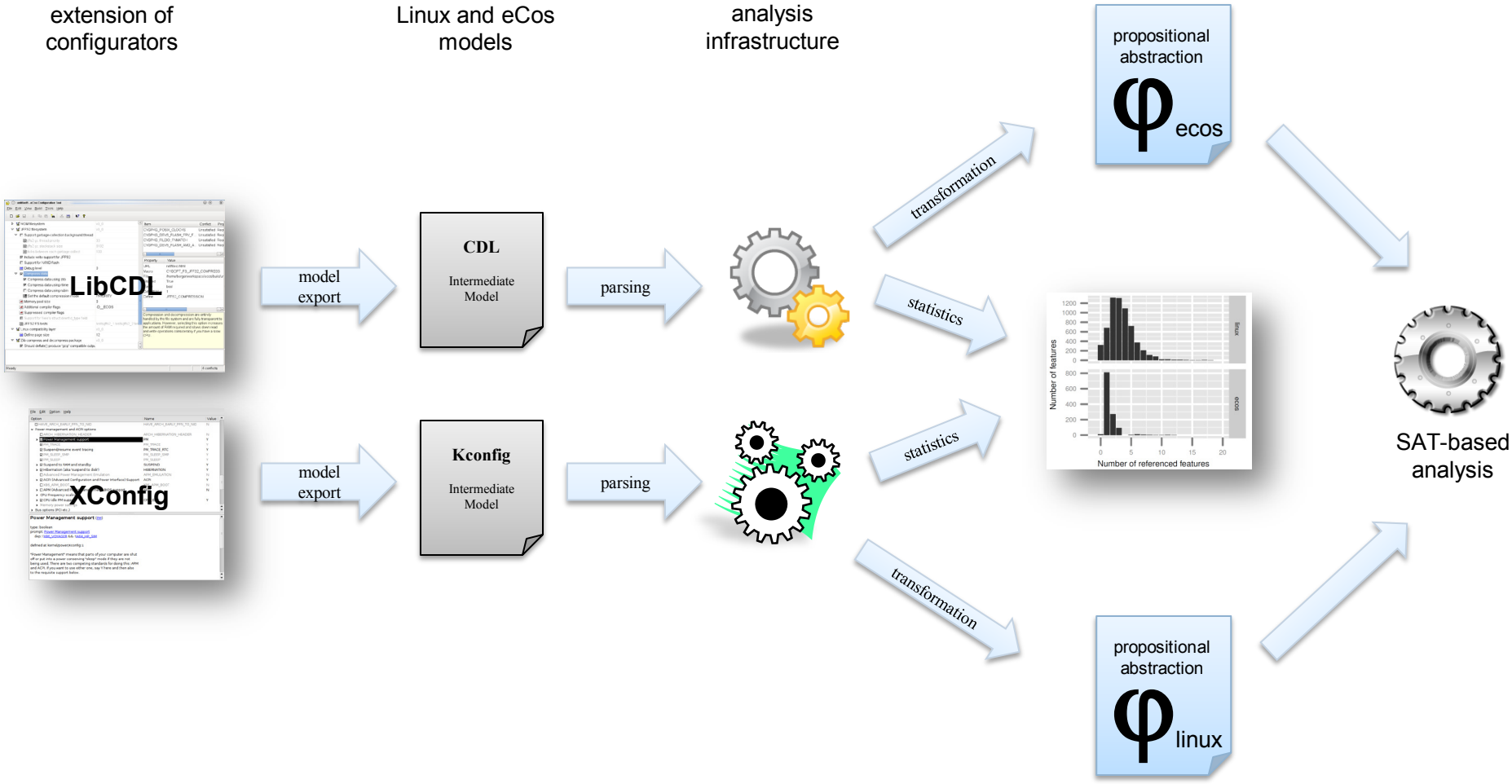

# RESULTS

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  - Hierarchy
  - Group constraints
  - Cross-tree constraints
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  - Needed many iterations to get the formal semantics right
  - Often slightly different from what we expected
- Some (but minor) violations of feature modeling rules

- Concepts:
  - Boolean (optional), Integer and String features (attributes)
  - Hierarchy
  - Group constraints
  - Cross-tree constraints
- But intricate semantic interactions
  - Needed many iterations to get the formal semantics right
  - Often slightly different from what we expected
- Some (but minor) violations of feature modeling rules
- Languages benefit from being domain-specific

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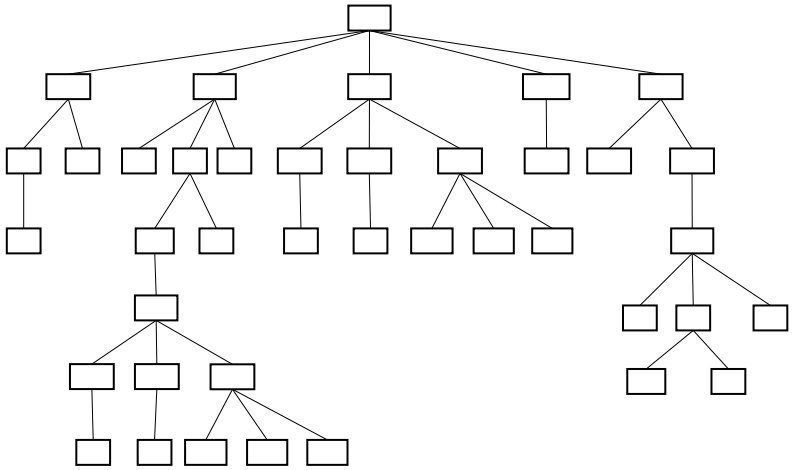

- Concepts for scalability
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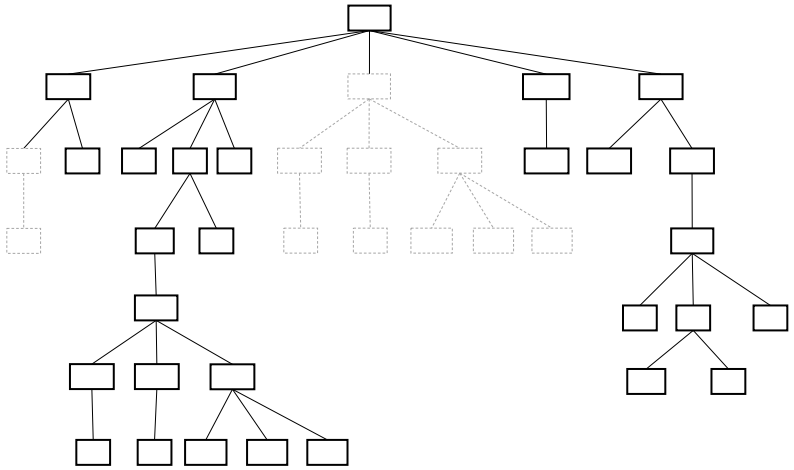

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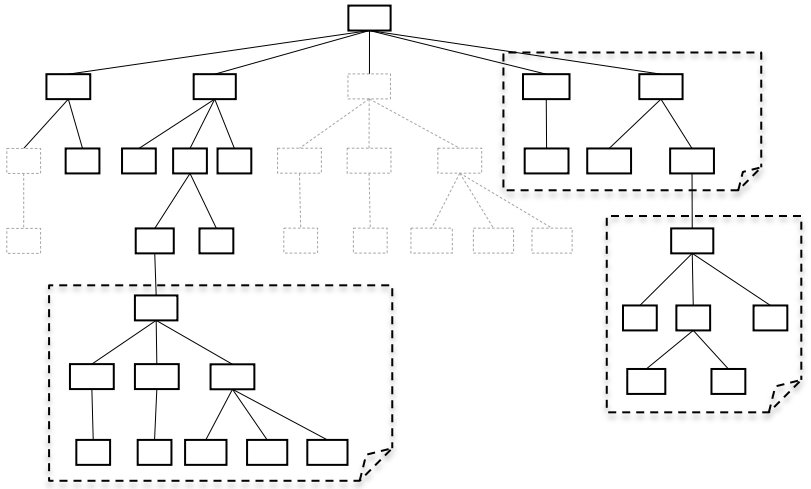

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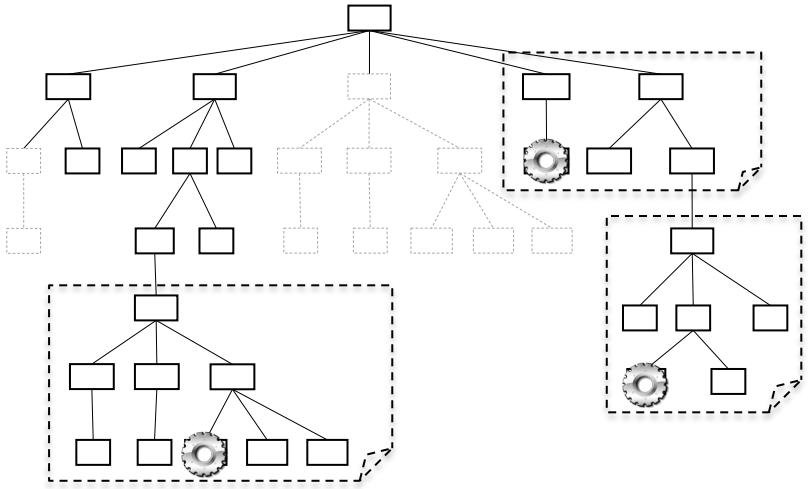

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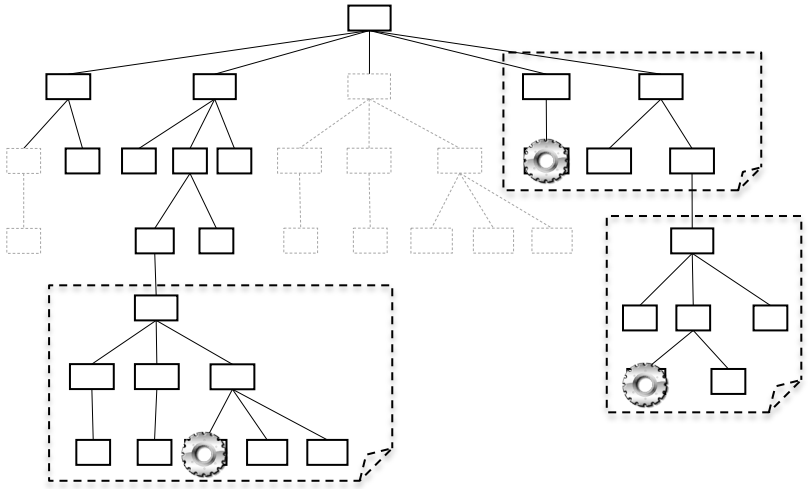

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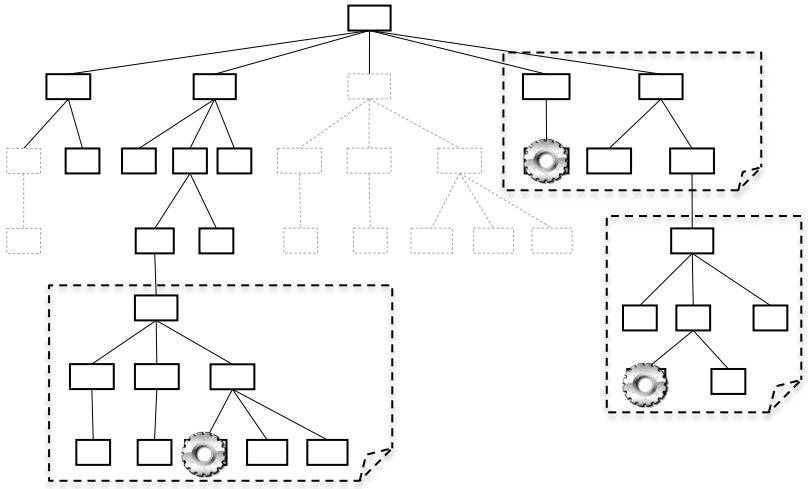

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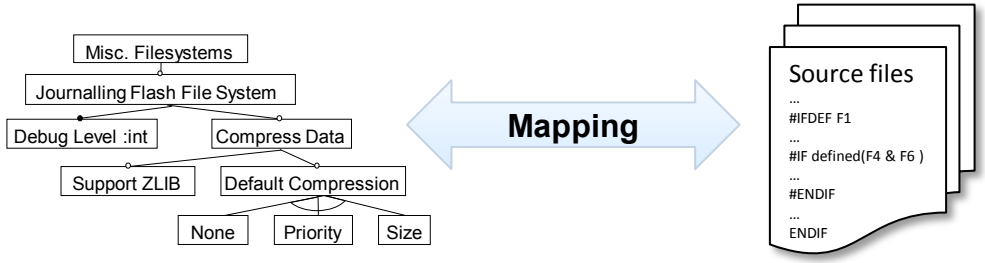
- Code mappings / build specifications



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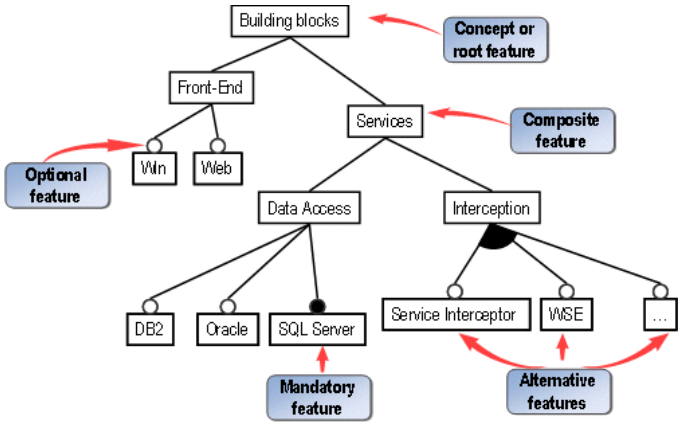
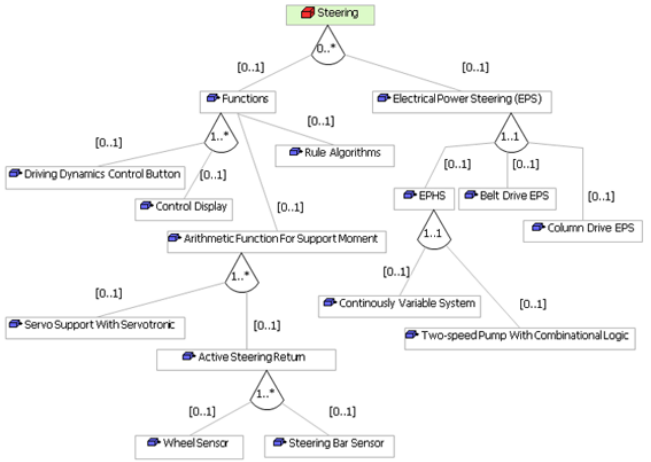
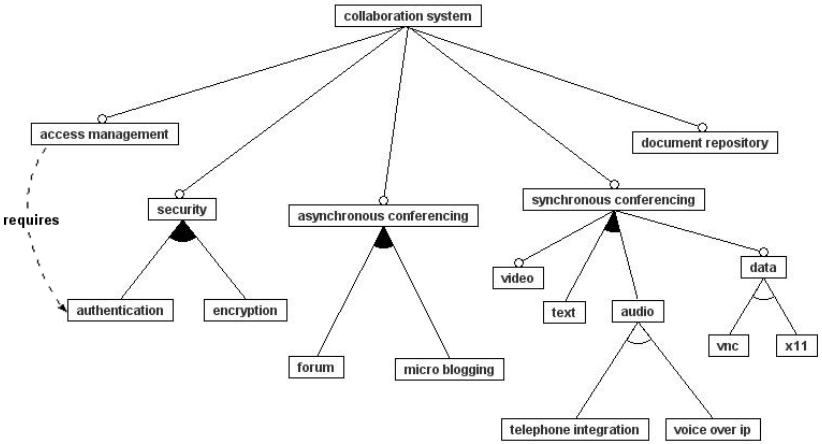



msdn.microsoft.com/en-us/library/aa925157.aspx




www.feasiple.de/description/bsp_ess_en.html




code.google.com/p/dslvariantmanagement/wiki/DemoShowCase

- But Linux and eCos models are very shallow!

| | Avg. depth | Max. depth | Max. branching | No. of leaves |
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| Linux | 4 | 8 | 158 | 5316 (84%) |
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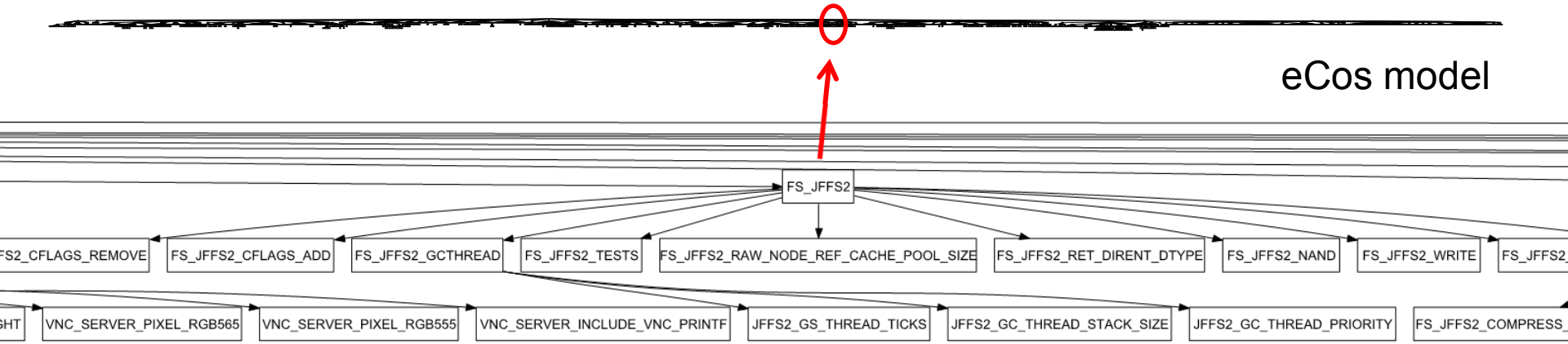


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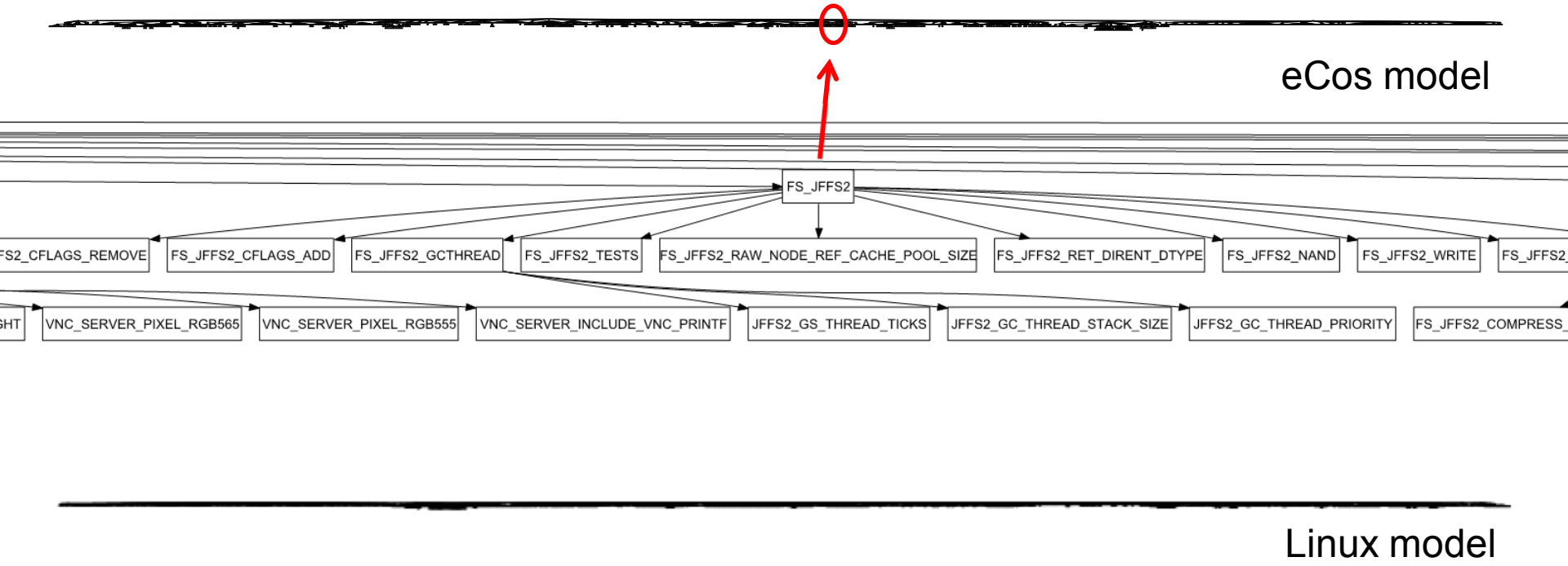


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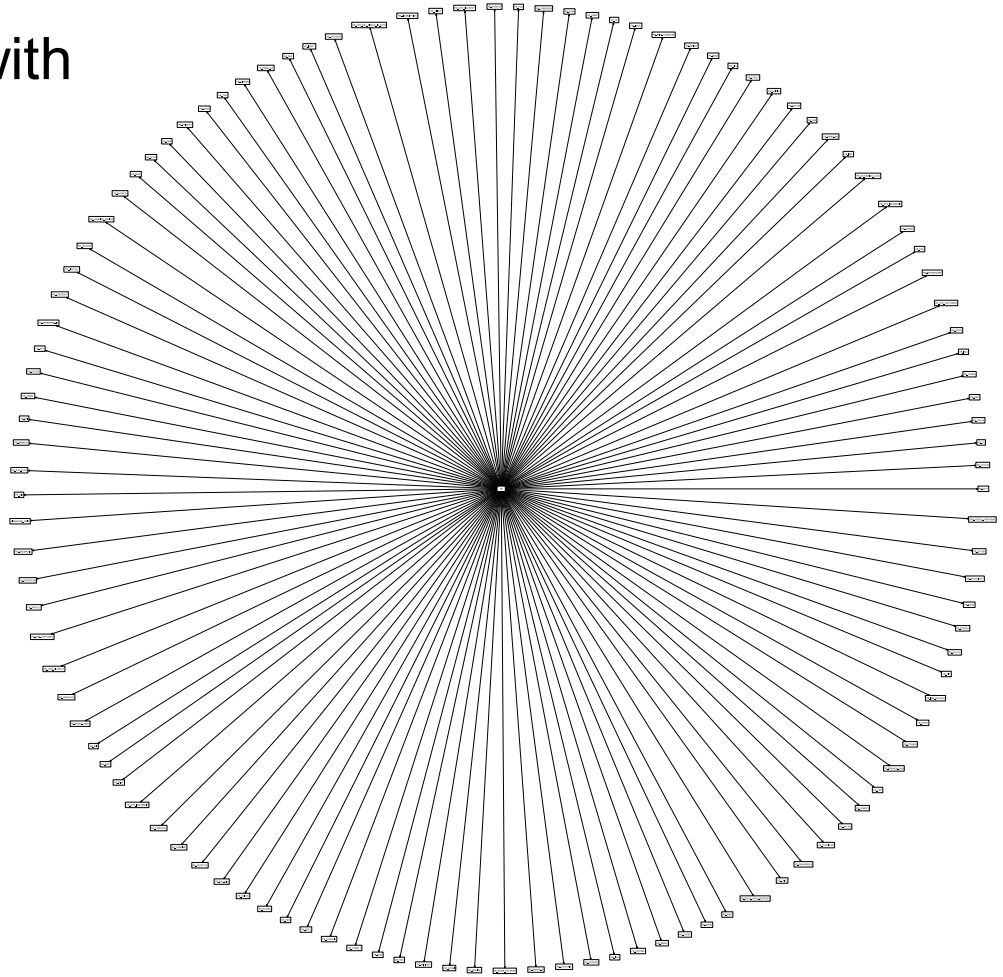

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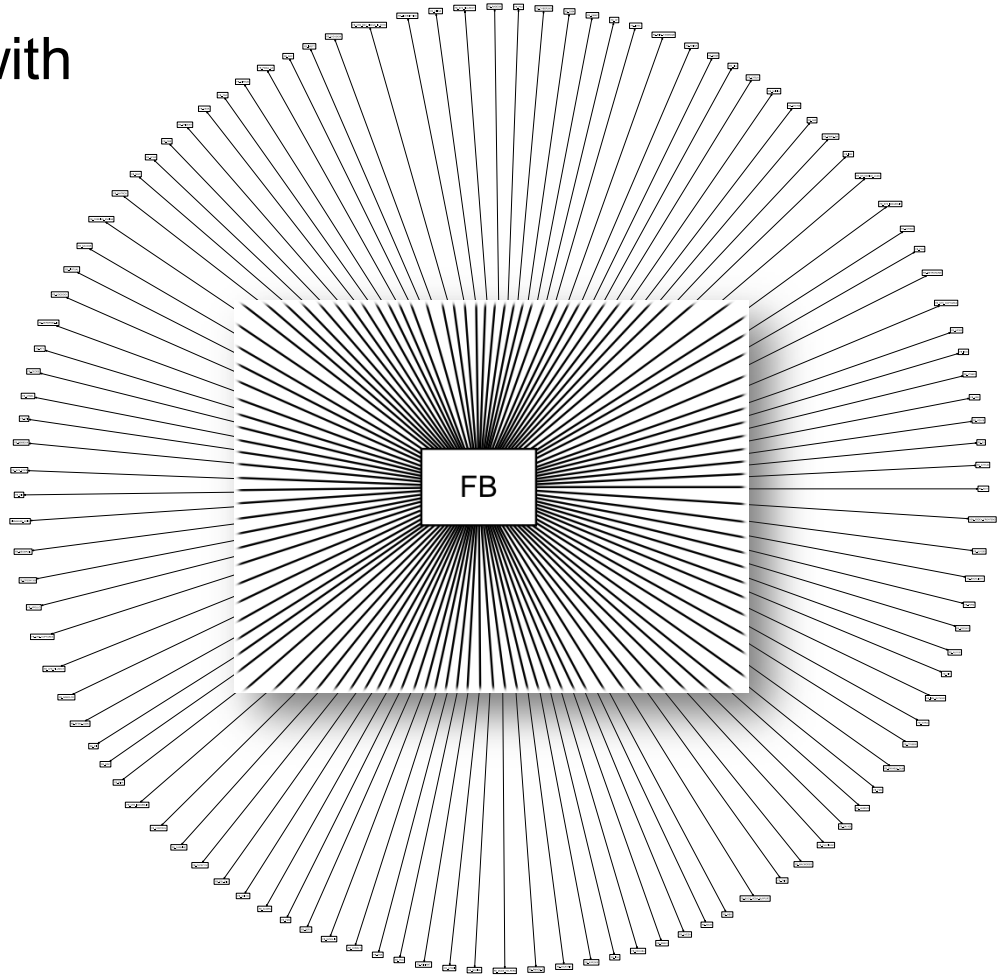


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- Many more details in the paper!

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- In studying the models in-depth, our findings have confirmed – and refuted – previous knowledge about variability languages and models.
- Understanding languages and extracting these models that were evolved over 10 years kept us PhD students and the professors busy for almost half a year!


# Variability Modeling in the Real: A Perspective from the Operating Systems Domain

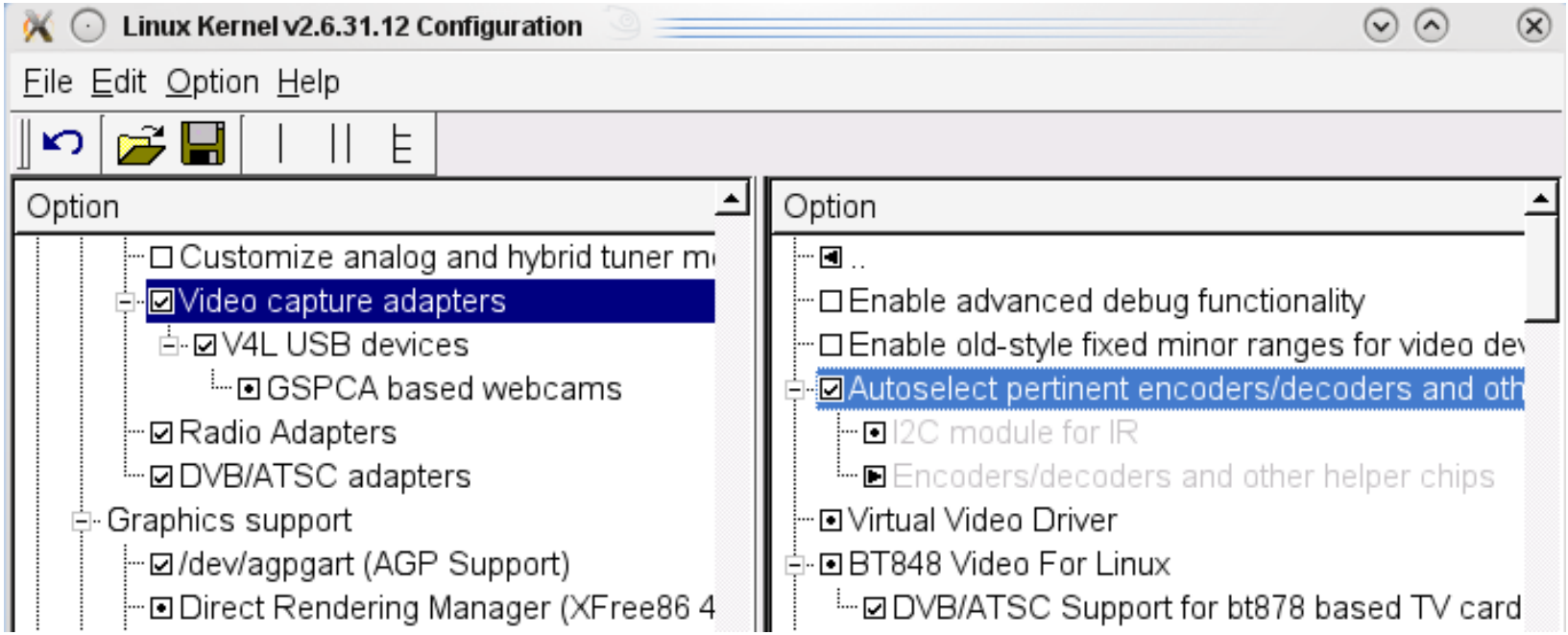
25th IEEE/ACM International Conference on Automated Software Engineering
ASE 2010
Antwerp, Belgium, Sept. 22nd, 2010

Thorsten Berger, Steven She, Rafael Lotufo,
Andrzej Wasowski, Krzysztof Czarnecki

# APPENDIX

# EXAMPLES

- Children can exclude their parent



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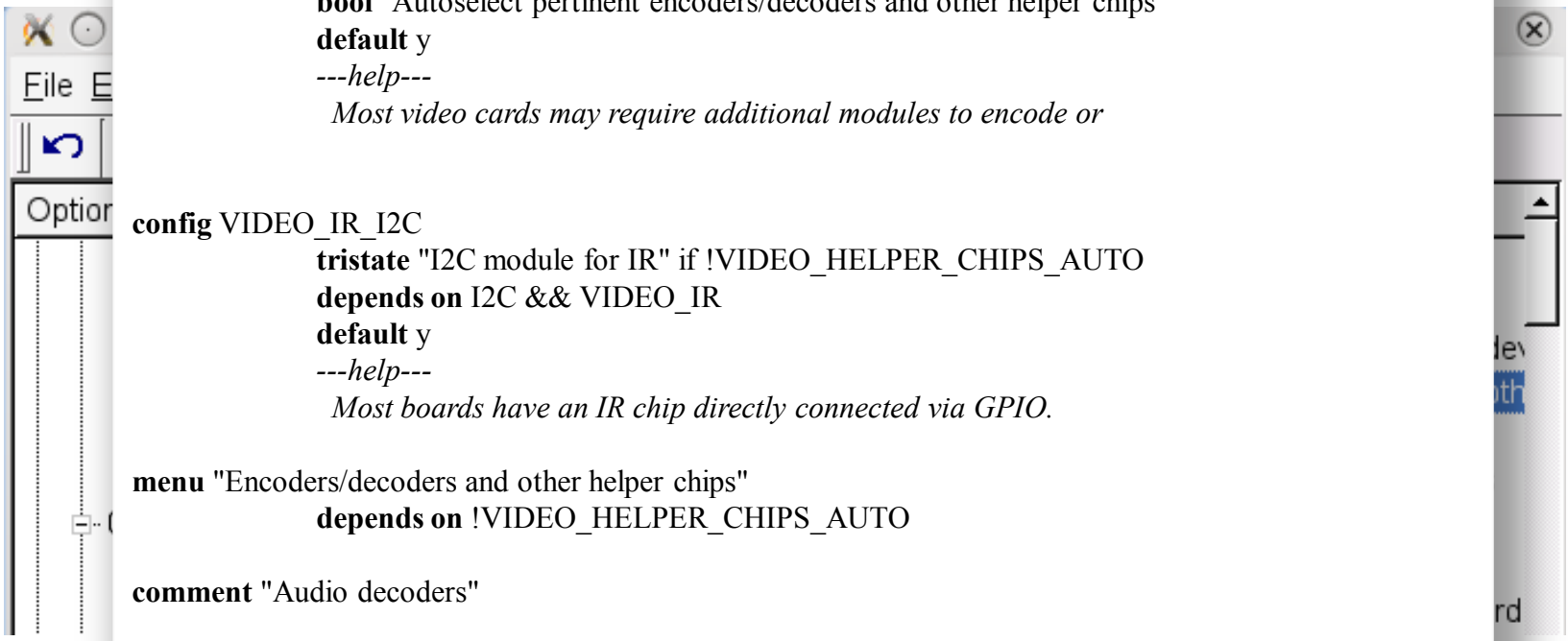



```
config VIDEO_HELPER_CHIPS_AUTO
        bool "Autoselect pertinent encoders/decoders and other helper chips"
        default y
        ---help---
          Most video cards may require additional modules to encode or


config VIDEO_IR_I2C
        tristate "I2C module for IR" if !VIDEO_HELPER_CHIPS_AUTO
        depends on I2C && VIDEO_IR
        default y
        ---help---
          Most boards have an IR chip directly connected via GPIO.

menu "Encoders/decoders and other helper chips"
        depends on !VIDEO_HELPER_CHIPS_AUTO

comment "Audio decoders"

config VIDEO_TVAUDIO
        tristate "Simple audio decoder chips"
        depends on VIDEO_V4L2 && I2C
        ---help---
          Support for several audio decoder chips found on some bt8xx boards:
```

- Defaults can impose constraints in Kconfig

```
config DW_DMAC
        tristate "Synopsys DesignWare AHB DMA support"
        depends on AVR32
        select DMA_ENGINE
        default y if CPU_AT32AP7000
        ---help---
          Support the Synopsys DesignWare AHB DMA controller.  This
          can be integrated in chips such as the Atmel AT32ap7000.
```

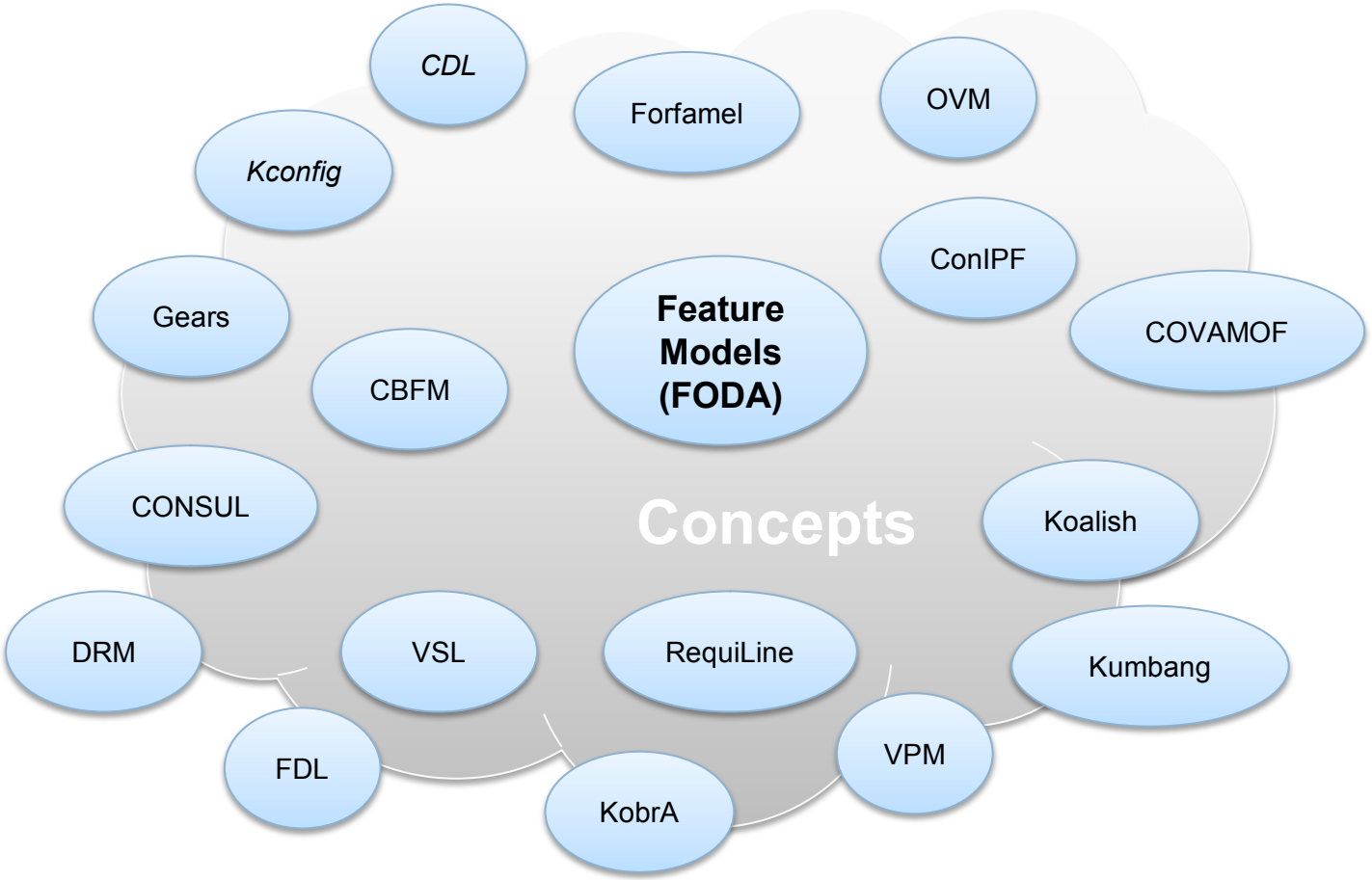
- We thought just
  - DW_DMAC ⟶ DMA_Engine Λ AVR32
- But instead also
  - !AVR32 Λ CPU_AT32AP7000 → DW_DMAC Λ DMA_ENGINE

- Computation of test cases

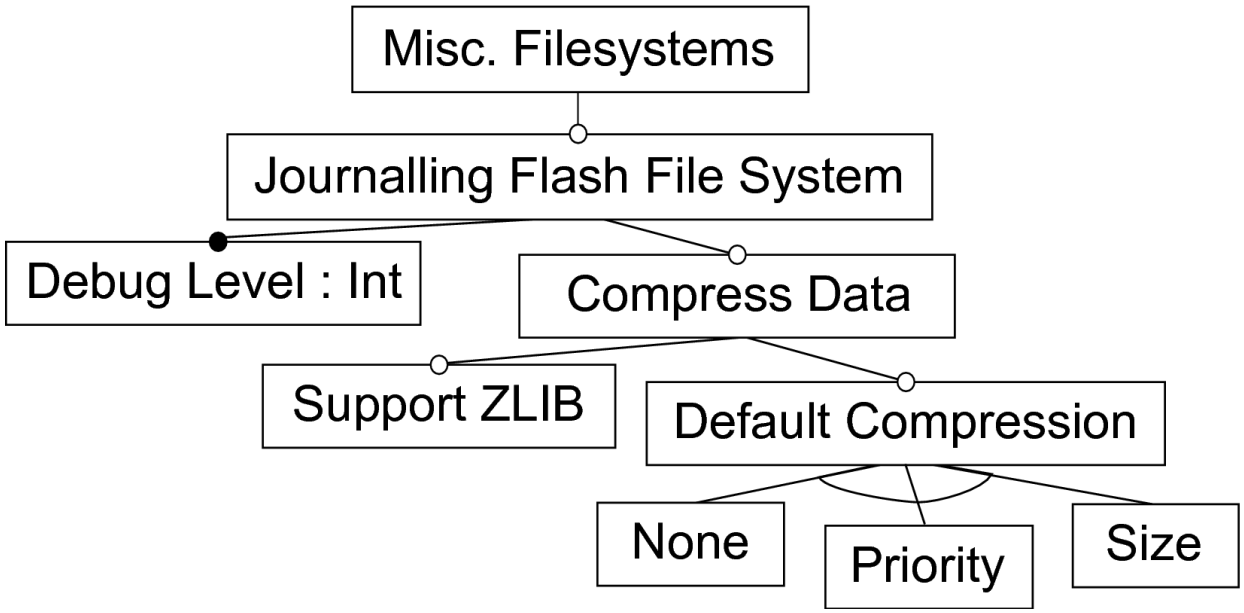
```
cdl_component CYGPKG_HAL_TESTS {
        display "Common HAL tests"
        flavor  data
        no_define
        calculated {  "tests/context tests/basic,,
                        . ((!CYGINT_HAL_TESTS_NO_CACHES) ? " tests/cache" : "")
                        . ((CYGPKG_HAL_BUILD_COMPILER_TESTS) ? " tests/cpp1 tests/vaargs" : "")
                        . ((!CYGVAR_KERNEL_COUNTERS_CLOCK) ?   " tests/intr" : "") }
        description   "
                        This option specifies the set of tests for the common HAL."
```

# VARIABILITY MODELING APPROACHES

# Variability Modeling Techniques



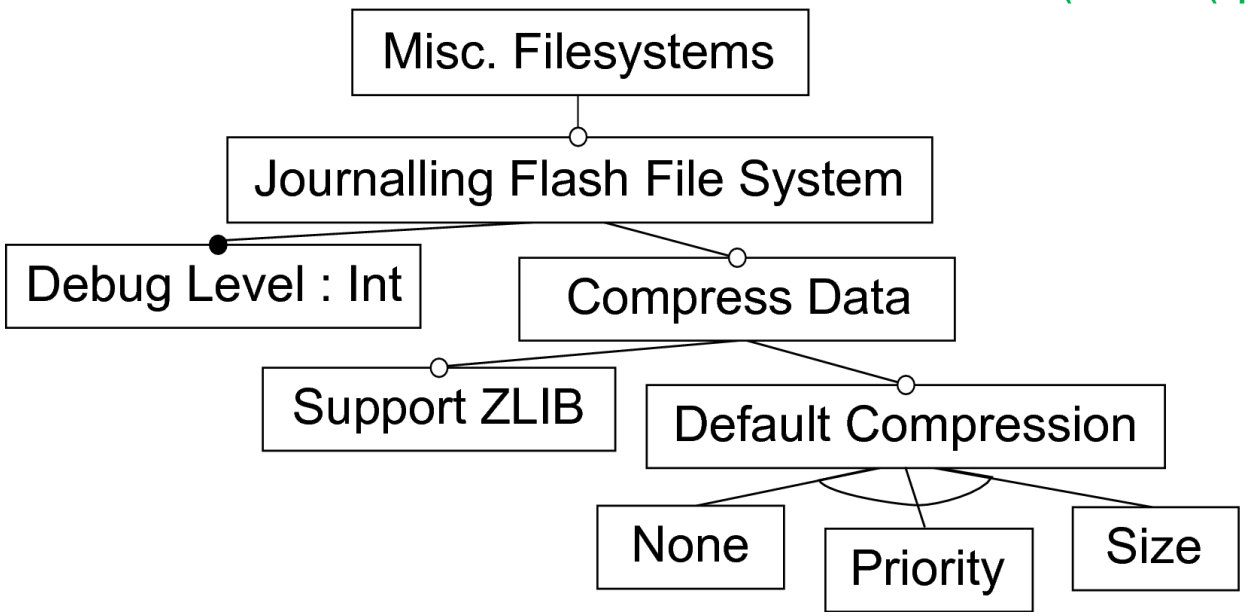
- JFFS2 filesystem




$$\text{Support ZLIB} \rightarrow \text{ZLIB Inflate}$$
$$\text{JFFS2} \rightarrow \text{CRC} \wedge \text{MTD}$$
$$0 \leq \text{Debug Level} \leq 2$$

- JFFS2 filesystem

**Features**
(Boolean (optional), String, Int)

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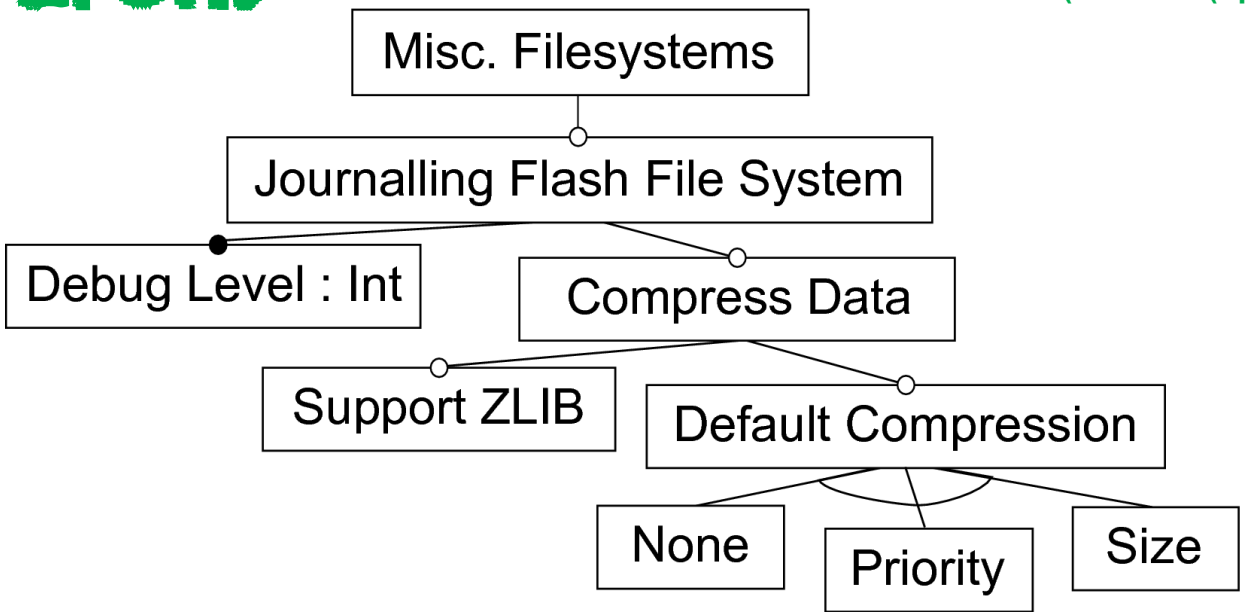


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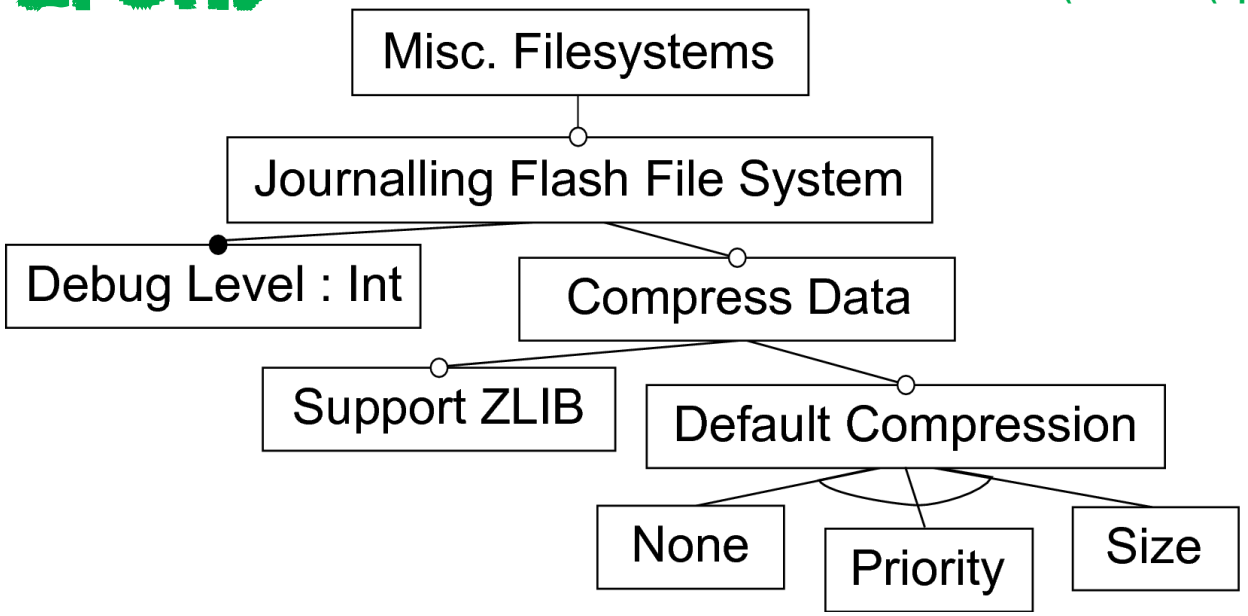


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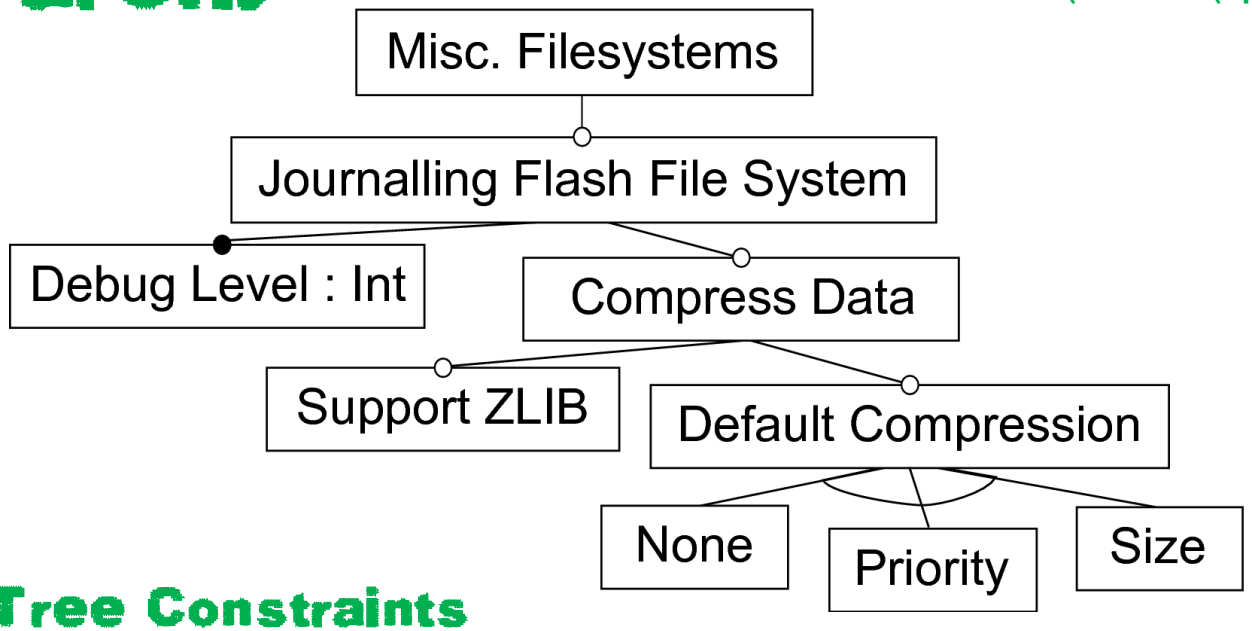


**Cross-Tree Constraints**

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