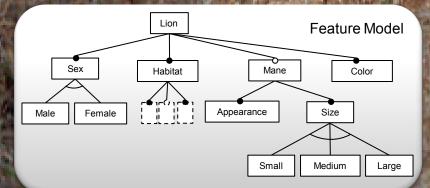


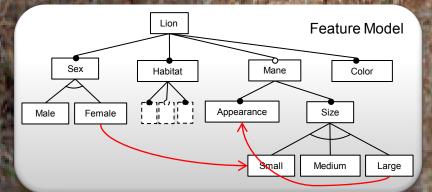
Variability Modeling in the Real: A Perspective from the Operating Systems Domain

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

> <u>Thorsten Berger</u>, Steven She, Rafael Lotufo, Andrzej Wasowski, Krzysztof Czarnecki

Thorsten Berger























Variability Model (15810 possible configurations)

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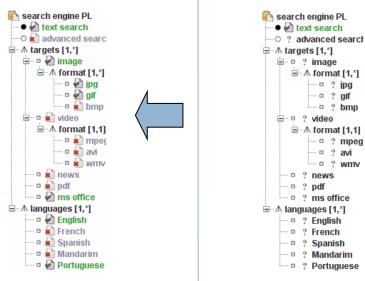








Configuration #1



Variability Model (15810 possible configurations)



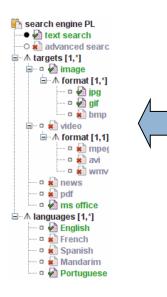




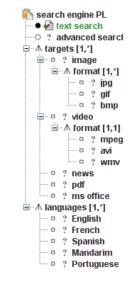




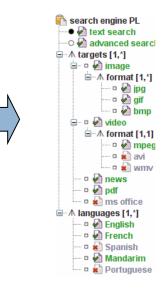
Configuration #1



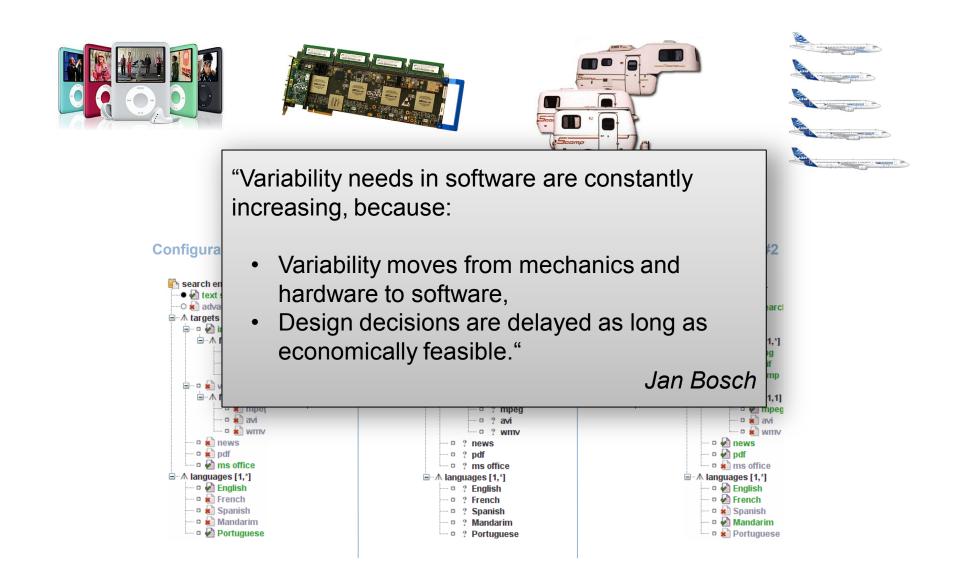




Configuration #2













Other Domains





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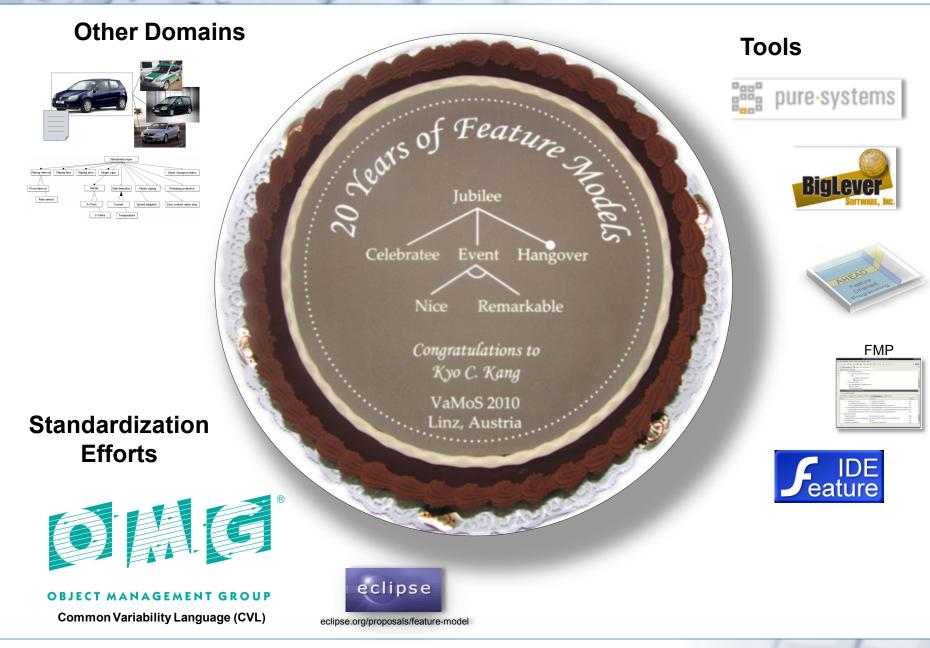




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NOW, WHAT'S THE PROBLEM?

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• A lot of research on variability, but not on real models!

• A lot of research on variability, but not on real models!

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Some **industry reports** available, but **not** the models!

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- **Assumptions** of real models used for **synthetic** examples!

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Literature studies:

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- Literature studies:
 - Hubaux et al. [VAMOS10]:
 - Only 2% of reviewed papers (8 of 415) discuss applications of Feature Models in practice
 - Few details about their **usage** given

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- Literature studies:
 - Hubaux et al. [VAMOS10]:
 - Only 2% of reviewed papers (8 of 415) discuss applications of Feature Models in practice
 - 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

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OUR STUDY...

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

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2. Are additional concepts needed?

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We study CONCEPTS, SEMANTICS AND USAGE OF...

Kconfig and CDL



Kconfig language



Linux Kernel 2.6.32

(22 hardware architectures, 6.4 mio. SLOC)

6320 Features (X86)

CDL language



eCos 3.0 (embedded RTOS, 116 architectures, ~1 mio. SLOC)

1244 Features (I386)

Kconfig and CDL



Kconfig language



Linux Kernel 2.6.32

(22 hardware architectures, 6.4 mio. SLOC)

6320 Features (X86)

Eile <u>E</u> dit <u>O</u> ption <u>H</u> elp			
Option	Name	Value	^
HAVE_ARCH_EARLY_PFN_TO_NID	HAVE_ARCH_EARLY_PFN_TO_NID	N	1
 Power management and ACPI options 			
ARCH_HIBERNATION_HEADER	ARCH_HIBERNATION_HEADER	N	
> 🗹 Power Management support	PM	Υ	
PM_TRACE	PM_TRACE	Υ	
Suspend/resume event tracing	PM_TRACE_RTC	Υ	
PM_SLEEP_SMP	PM_SLEEP_SMP	Υ	
PM_SLEEP	PM_SLEEP	Υ	
Suspend to RAM and standby	SUSPEND	Υ	
➤ ☑ Hibernation (aka 'suspend to disk')	HIBERNATION	Υ	
Advanced Power Management Emulation	APM_EMULATION	N	
> 🗹 ACPI (Advanced Configuration and Power Interface) Support	ACPI	Υ	
□X86_APM_BOOT	X86_APM_BOOT	N	=
> 🗆 APM (Advanced Power Management) BIOS support	APM	N	
 CPU Frequency scaling 			
► I CPU idle PM support	CPU_IDLE	Y	
 Memory power savings 			
 Bus options (PCI etc.) 			
Power Management support (DM)			Ì

Power Management support (PM)

type: boolean prompt: <u>Power Management support</u> dep: <u>!X86_VOYAGER</u> && !<u>IA64_HP_SIM</u>

defined at kernel/power/Kconfig:1

"Power Management" means that parts of your computer are shut off or put into a power conserving "sleep" mode if they are not being used. There are two competing standards for doing this: APM and ACPI. If you want to use either one, say Y here and then also to the requisite support below.

TOOD)

atures

Kconfig and CDL



📫 💽 untitled1 - eCos Configuration Tool

<u>F</u>ile <u>E</u>dit <u>V</u>iew <u>B</u>uild <u>T</u>ools <u>H</u>elp

D 😅 🖬 🐰 🖻 🛍 🖌 🛍 🕺 🤋

▷ 😫 ROM filesystem	v3_0
	v3_0
▽ 🗖 Support garbage-collection background thread	
📷 jffs2 gc thread priority	30
ତ jffs2 gc stackstack size	8192
🌉 ticks between each garbage collect	100
Include write support for JFFS2	
Support for NAND flash	
颼 Debug level	0
✓ I Compress data	
Compress data using zlib	
Compress data using rtime	
Compress data using rubin	
📑 Set the default compression mode	PRIORITY
💩 Memory pool size	0
Additional compiler flags	-D_ECOS
Suppressed compiler flags	
Support for fileio's struct dirent d_type field	
jFFS2 FS tests	tests/jffs2_1 tests/jffs2_2
▽ 😫 Linux compatibility layer	v3_0
武 Define page size	12
マ	v3_0
Should deflate() produce 'gzip' compatible output	

•	ltem	Conflict	Proj
	CYGPKG_POSIX_CLOCKS	Unsatisfied	Req
	CYGPKG_DEVS_FLASH_FRV_F	Unsatisfied	Req
	CYGPKG_FILEIO_FNMATCH	Unsatisfied	Req
	CYGPKG_DEVS_FLASH_AMD_A	Unsatisfied	Req

~

 \odot

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<>

4 conflicts

< <u> </u>	
Property	Value
URL	ref/fileio.html
Macro	CYGOPT_FS_JFFS2_COMPRESS
File	/home/berger/workspace/ecos/build/ur
Enabled	True
Flavor	bool
DefaultValue	1
Define	JFFS2_COMPRESSION

Compression and decompression are entirely handled by the file system and are fully transparent to applications. However, selecting this option increases the amount of RAM required and slows down read and write operations considerably if you have a slow CPU.

CDL language



eCos 3.0 (embedded RTOS, 116 architectures, ~1 mio. SLOC)

244 Features (I386)

Ready



Kconfig language

-53



	k-1	menuconfig MISC_FILESYSTEMS	c-1	cdl_component MISC_FILESYSTEMS {
	k-2	bool "Miscellaneous filesystems"	c-2	display "Miscellaneous filesystems"
	k-3		c-3	flavor none
	k-4	if MISC FILESYSTEMS	c-4	}
	k-5	-	c-5	-
	k-6	config JFFS2 FS	c-6	cdl_package CYGPKG FS JFFS2 {
	k-7	tristate "Journalling Flash File System" if MTD	c-7	display "Journalling Flash File System"
	k-8	select CRC32 if MTD	c-8	requires CYGPKG CRC
	k-9		c-9	implements CYGINT IO FILEIO
	k-10		c-10	parent MISC FILESYSTEMS
	k-11		c-11	active_if MTD
	k-12		c-12	
	k-13	config JFFS2 FS DEBUG	c-13	cdl_option CYGOPT FS JFFS2 DEBUG {
	k-14	int "JFFS2 Debug level (0=quiet, 2=noisy)"	c-14	display "Debug level"
	k-15	depends on JFFS2 FS	c-15	
	k-16	default 0	c-16	default_value 0
	k-17	range 0 2	c-17	legal_values 0 to 2
	k-18	help	c-18	define CONFIG JFFS2 FS DEBUG
	k-19	Debug verbosity of	c-19	description "Debug verbosity of"
	k-20	being (cibobie) of the	c-20	}
	k-21		0-21	,
	k-22	config JFFS2_FS_WRITEBUFFER	c-22	cdl_option CYGOPT FS JFFS2 NAND {
	k-23	bool	c-23	flavor bool
	k-24	depends on JFFS2 FS	c-24	define CONFIG JFFS2 FS WRITEBUFFER
	k-25	default HAS IOMEM	c-25	calculated HAS IOMEM
	k-26		c-26	3
	k-27		c-27	,
	k-28	config JFFS2 COMPRESS	c-28	cdl_component CYGOPT FS JFFS2 COMPRESS {
	k-29	bool "Advanced compression options for JFFS2"	c-29	display "Compress data"
	k-30	depends on JFFS2 FS	c-30	default_value 1
INIX KE	k-31		c-31	
	k-32	config JFFS2 ZLIB	c-32	cdl_option CYGOPT FS JFFS2 COMPRESS ZLIB {
	k-33	bool "Compress w/zlib" if JFFS2 COMPRESS	c-33	display "Compress data using zlib" requires CYGPKG COMPRESS ZLIB RTOS,
(22 hardwi	k-34	depends on JFFS2 FS	c-34	requires CYGPKG COMPRESS ZLIB
(22 hardwa	k-35	select ZLIB_INFLATE	c-35	
	k-36	default y	c-36	³ ctures,
6.4 (k-37		c-37	ccurco,
	k-38	choice	c-38	cdl_option CYGOPT_FS_JFFS2_COMPRESS_CMODE {
	k-39	<pre>prompt "Default compression" if JFFS2 COMPRESS</pre>	c-39	cdl_option CYGOPT_FS_JFFS2_COMPRESS_CMODE { display "Set the default compression mode"
	k-40	default JFFS2_CMODE_PRIORITY	c-40	flavor data
	k-41	depends on JFFS2 FS	c-41	default_value { "PRIORITY" }
	k-42	config JFFS2 CMODE NONE	c-42	legal_values { "NONE" "PRIORITY" "SIZE" }
	k-43	bool "no compression"	c-43	}
	k-44	config JFFS2 CMODE PRIORITY	c-44	}
	k-45	bool "priority"	c-45	,
	k-46	config JFFS2_CMODE_SIZE	c-46	·
	k-47	bool "size (EXPERIMENTAL)"	c-47	
りろノリ ト	k-48	endchoice	c-48	res (13
55201	k-49	endif	c-49	

Linux

(I386)



What do we mean by variability model

SEMANTICS?

Thorsten Berger

Variability Model Semantics



Configuration Space Semantics

Variability Model Semantics



Configuration Space Semantics

Kconfig Model

menuconfig MISC_FILESYSTEMS bool "Miscellaneous filesystems"

if MISC_FILESYSTEMS

config JFFS2_FS tristate "Journalling Flash FS" 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 ... $[\![\cdot]\!]_{\mathsf{kconfig}} \colon \mathsf{Kconfig} \to \mathcal{P}(\mathsf{Confs})$

C₁={(JFFS2,y),(JFFS2_DEBUG,2),...}

C₂={(JFFS2,m),(JFFS2_DEBUG,0),...}

C_n={(JFFS2,n),(JFFS2_DEBUG,0),...}



METHODOLOGY

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Methodology - Design Space



Reverse-engineered formal semantics (denotational style)

Methodology - Design Space



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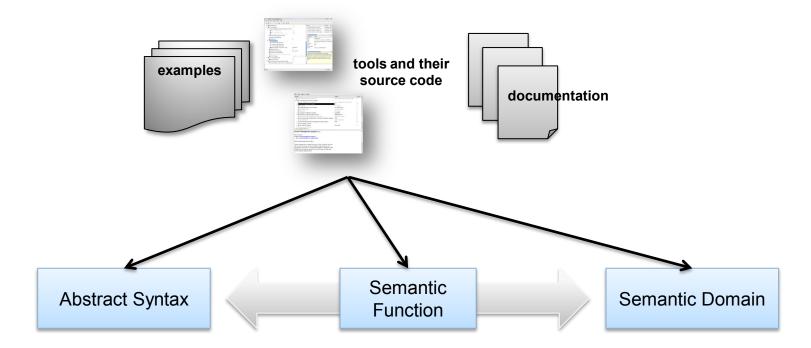


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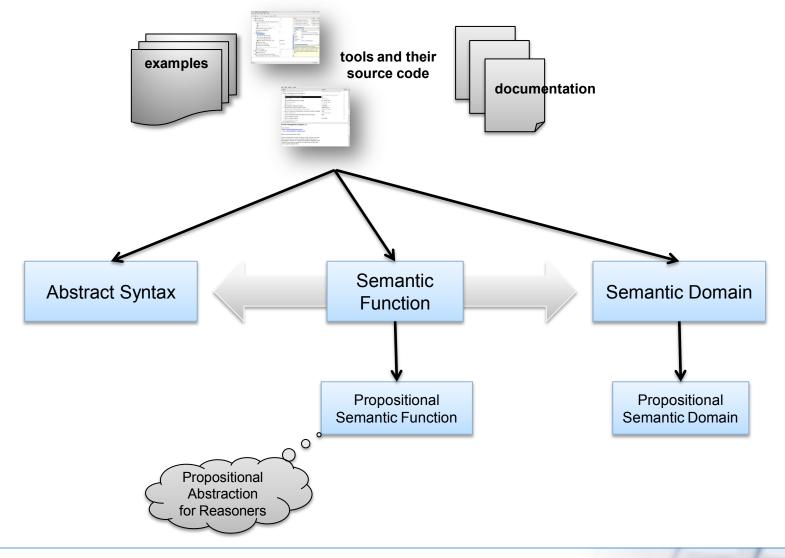
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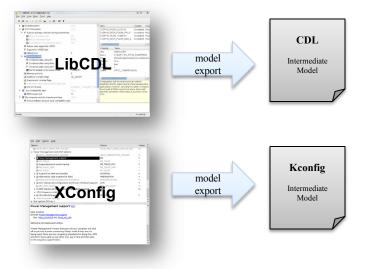
extension of configurators

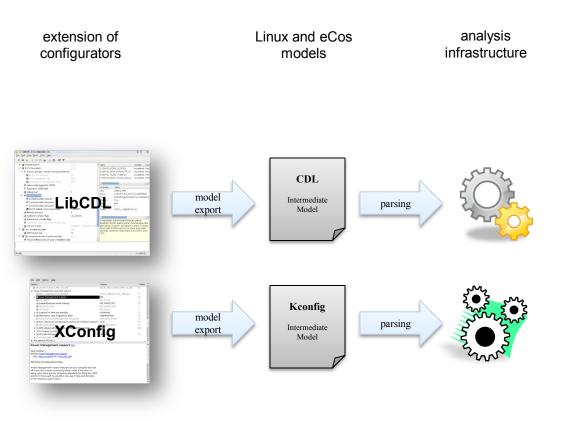




extension of configurators

Linux and eCos models

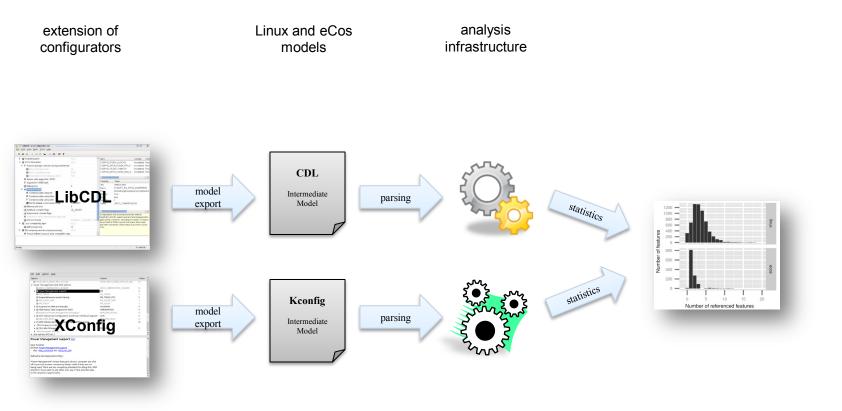




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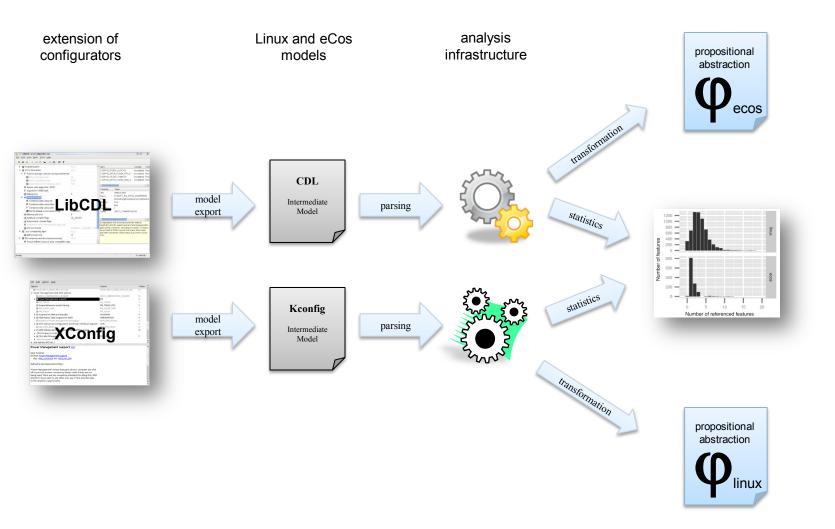


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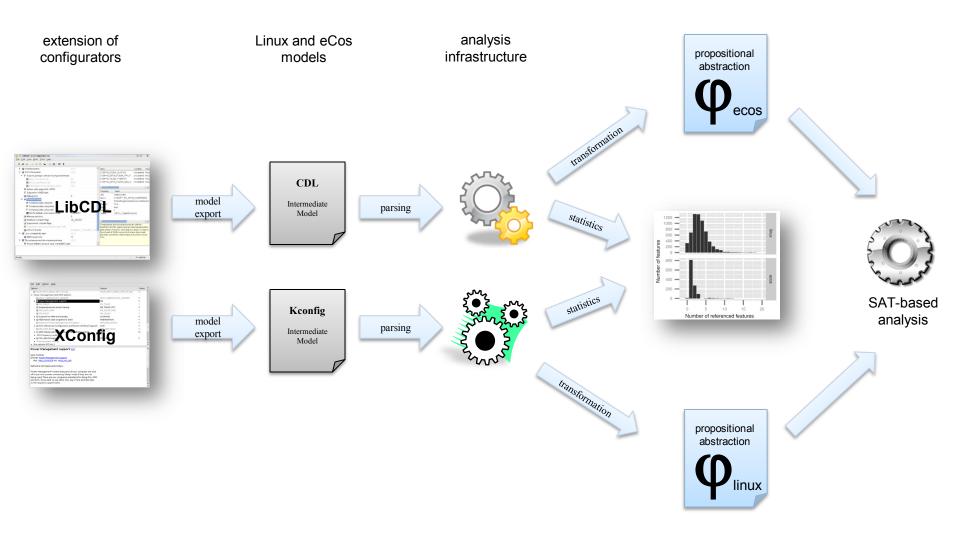
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RESULTS

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

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2. Are additional concepts needed?

3. Are the assumptions about real models in the literature correct?



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

2. Are additional concepts needed?

3. Are the assumptions about real models in the literature correct?



- Concepts:
 - Boolean (optional), Integer and String features (attributes)
 - 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

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

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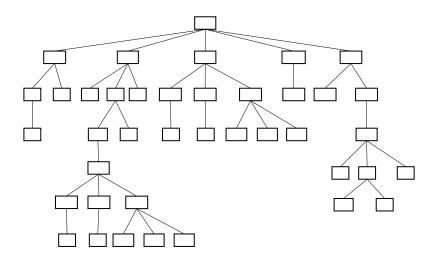
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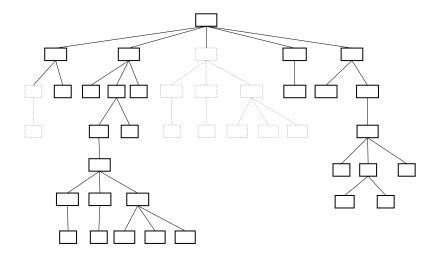


Concepts for scalability



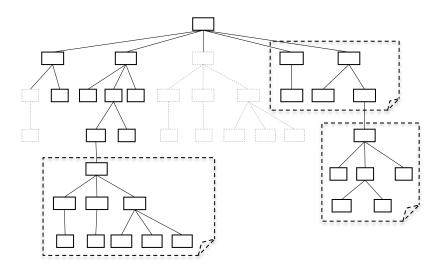


- Concepts for scalability
 - Visibility



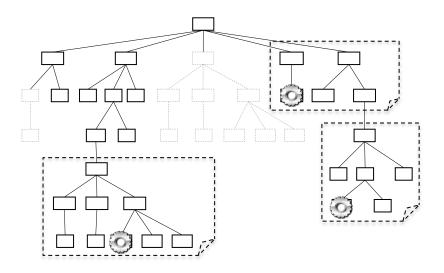


- Concepts for scalability
 - Visibility
 - Modularization





- Concepts for scalability
 - Visibility
 - Modularization
 - Derived defaults / derived features

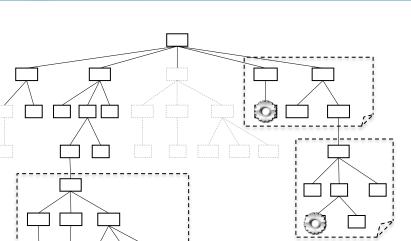




- Visibility
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- Derived defaults / derived features



- Kconfig: Three-state logic (follows Kleene's rules)
- CDL: Comparison, arithmetic and String operators



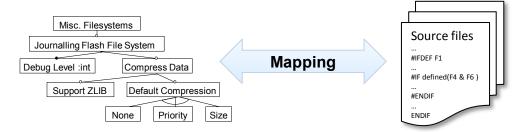
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- Visibility
- Modularization
- Derived defaults / derived features
- Expressive constraints
 - Kconfig: Three-state logic (follows Kleene's rules)
 - CDL: Comparison, arithmetic and String operators
- Code mappings / build specifications



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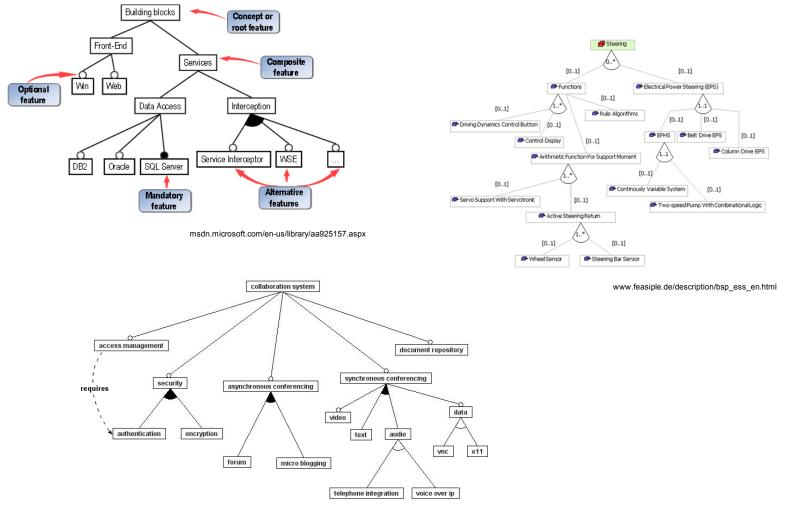
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• We always see nicely balanced trees...



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





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But Linux and eCos models are very shallow!

	Avg. depth	Max. depth	Max. branching	No. of leaves
Linux	4	8	158	5316 (84%)
eCos	3	6	29	947 (76%)





But Linux and eCos models are very shallow!

eCos model

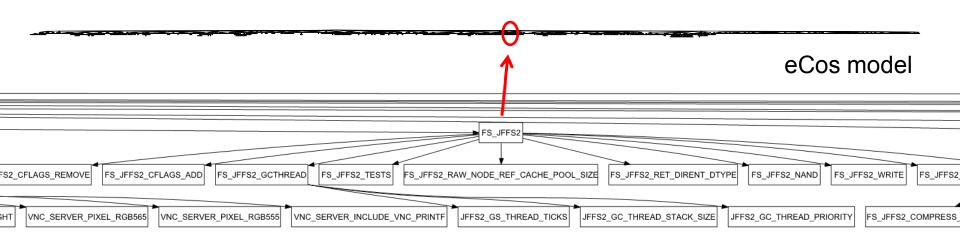
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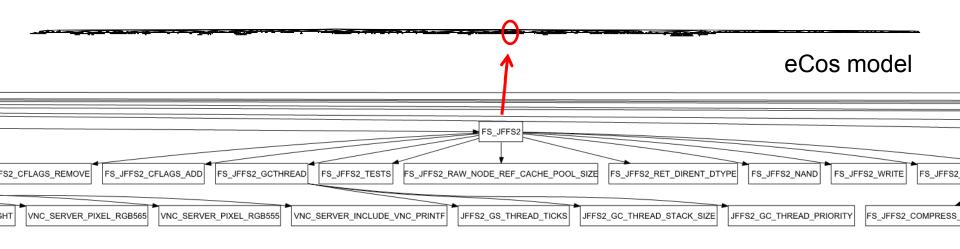
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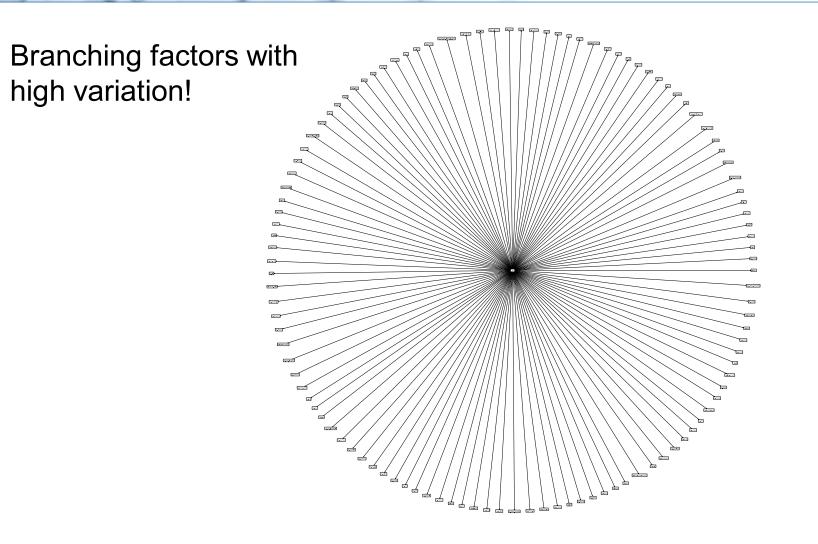




 Branching factors with high variation!

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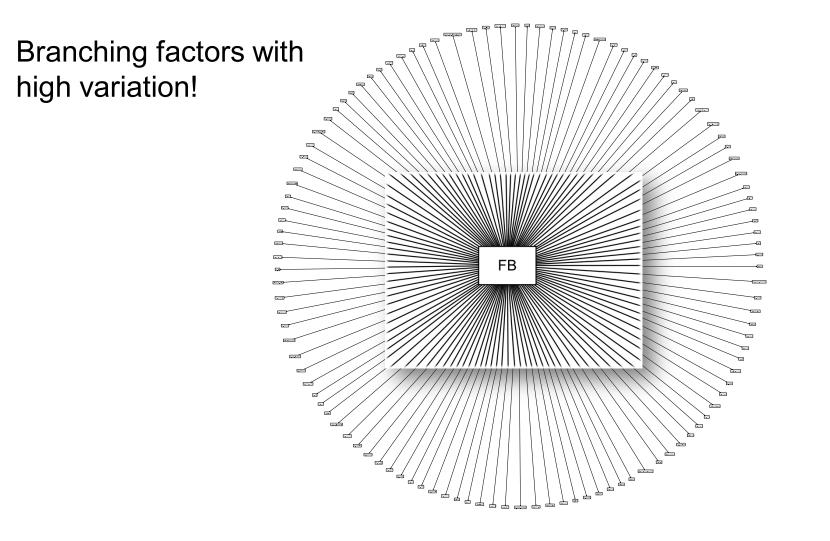




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Assumptions



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Some More Findings

- Cross-Tree Constraints ratio
 - Literature: 30-40%
 - Our models: 86%

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Very few group constraints (OR, XOR, MUTEX)

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 - Configuration process is *Re-Configuration*!
 - Limited or no reasoning support
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- Many more details in the paper!

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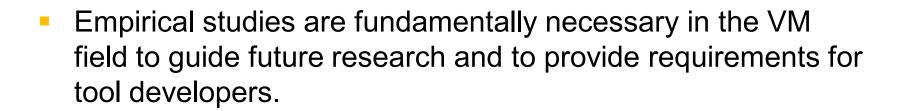
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CONCLUSIONS

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- Empirical studies are fundamentally necessary in the VM field to guide future research and to provide requirements for tool developers.
- The more ways we look at how real languages are designed and how models look like, the more confidence we have that we understand Software Product Lines.

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- Empirical studies are fundamentally necessary in the VM field to guide future research and to provide requirements for tool developers.
- The more ways we look at how real languages are designed and how models look like, the more confidence we have that we understand Software Product Lines.
- In studying the models in-depth, our findings have confirmed – and refuted – previous knowledge about variability languages and models.

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- Empirical studies are fundamentally necessary in the VM field to guide future research and to provide requirements for tool developers.
- The more ways we look at how real languages are designed and how models look like, the more confidence we have that we understand Software Product Lines.
- 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!

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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

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APPENDIX

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EXAMPLES

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Children can exclude their parent

🔀 🕞 Linux Kernel v2.6.31.12 Configuration 📄	\odot \odot \otimes
<u>File</u> <u>E</u> dit <u>O</u> ption <u>H</u> elp	
] 🖍 🔁 🔚 📋 🗉 E	
Option 🔺	Option 🔺
Customize analog and hybrid tuner m	
⊡ <mark>I</mark> Video capture adapters	□Enable advanced debug functionality
⊡- ⁄⊒ V4L USB devices	□Enable old-style fixed minor ranges for video dev
GSPCA based webcams	Autoselect pertinent encoders/decoders and oth
⊡Radio Adapters	■ I2C module for IR
☑ DVB/ATSC adapters	Encoders/decoders and other helper chips
- Graphics support	™ • Virtual Video Driver
	⊜- • BT848 Video For Linux
	ⁱ ☑ DVB/ATSC Support for bt878 based TV card

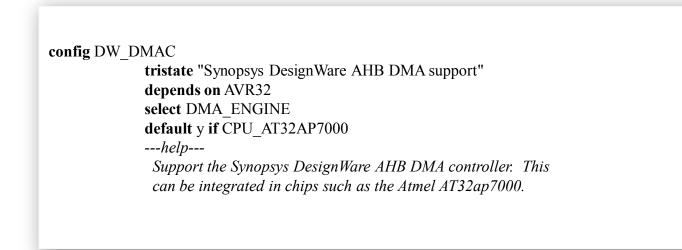


Children can exclude their parent

	config VIDEO_HELPER_CHIPS_AUTO	
XO	bool "Autoselect pertinent encoders/decoders and other helper chips" default y	6
<u>F</u> ile <u>E</u>	<i>help</i>	
	Most video cards may require additional modules to encode or	
Optior	config VIDEO_IR_I2C	-
	tristate "I2C module for IR" if !VIDEO_HELPER_CHIPS_AUTO depends on I2C && VIDEO_IR	
	default y	lev
	<i>help</i>	
	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"	rd
	config VIDEO TVAUDIO	- 84
	tristate "Simple audio decoder chips"	
	depends on VIDEO_V4L2 && I2C	
	<i>help</i>	
	Support for several audio decoder chips found on some bt8xx boards:	
		_



Defaults can impose constraints in Kconfig



- We thought just
 - DW_DMAC \rightarrow DMA_Engine \land AVR32
- But instead also
 - $!AVR32 \land CPU_AT32AP7000 \rightarrow DW_DMAC \land DMA_ENGINE$

Computed features



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."
1 1 5 5 5

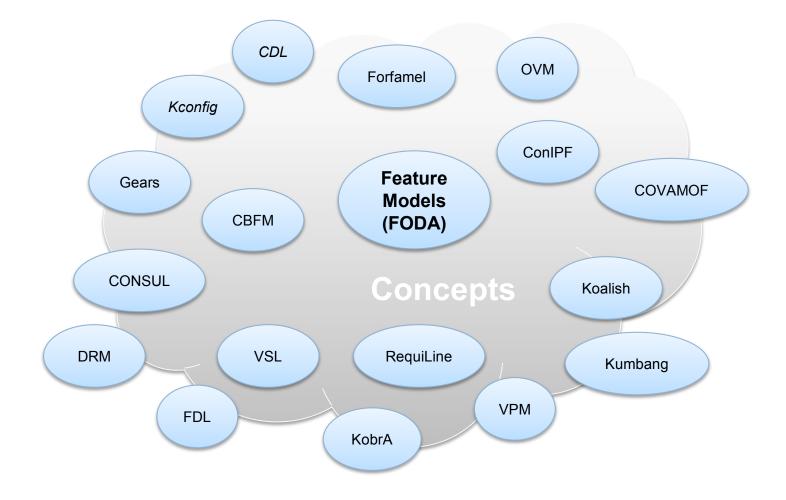


VARIABILITY MODELING APPROACHES

Thorsten Berger

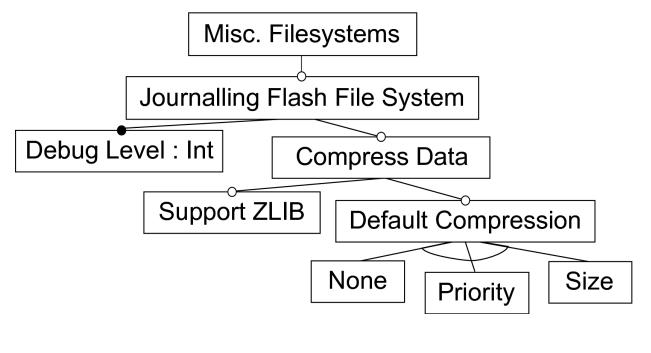
Variability Modeling Techniques







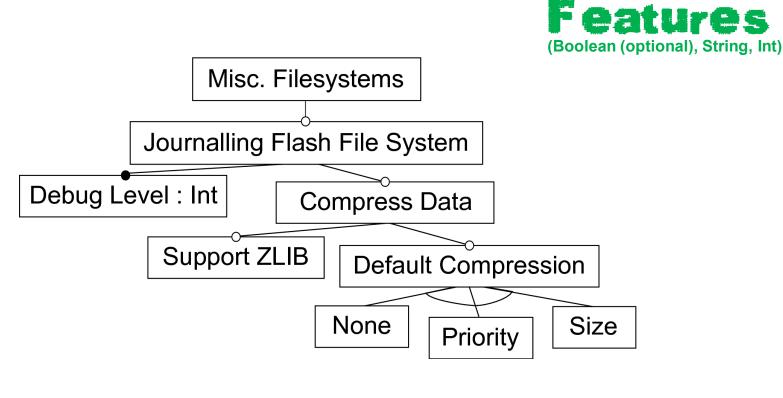
JFFS2 filesystem



 $\begin{array}{l} \text{Support ZLIB} \rightarrow \text{ZLIB Inflate} \\ \text{JFFS2} \rightarrow \text{CRC} \land \text{MTD} \\ 0 \leq \text{Debug Level} \leq 2 \end{array}$



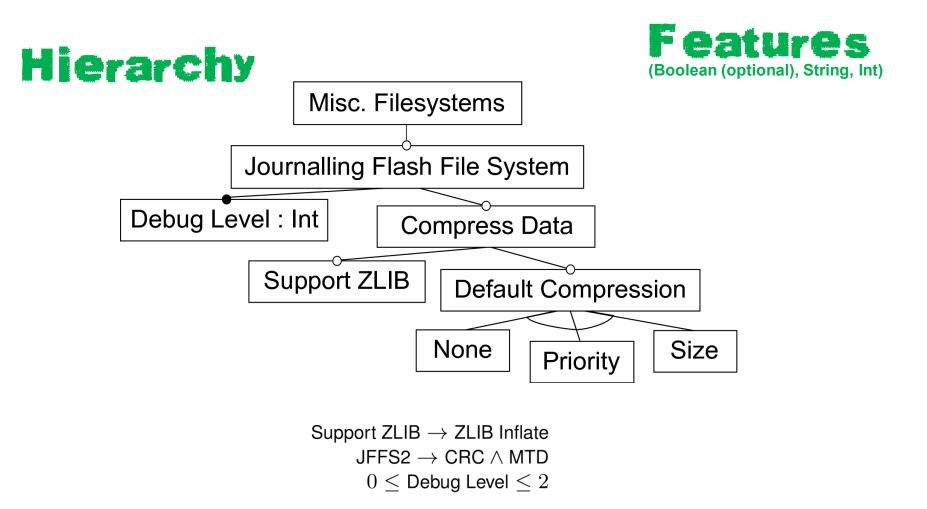
JFFS2 filesystem



Support ZLIB \rightarrow ZLIB Inflate JFFS2 \rightarrow CRC \land MTD 0 < Debug Level < 2

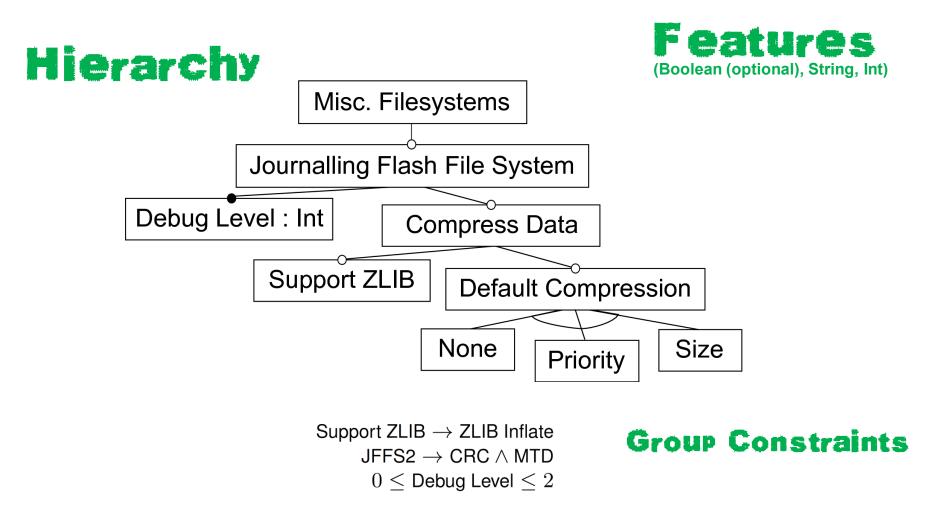
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JFFS2 filesystem



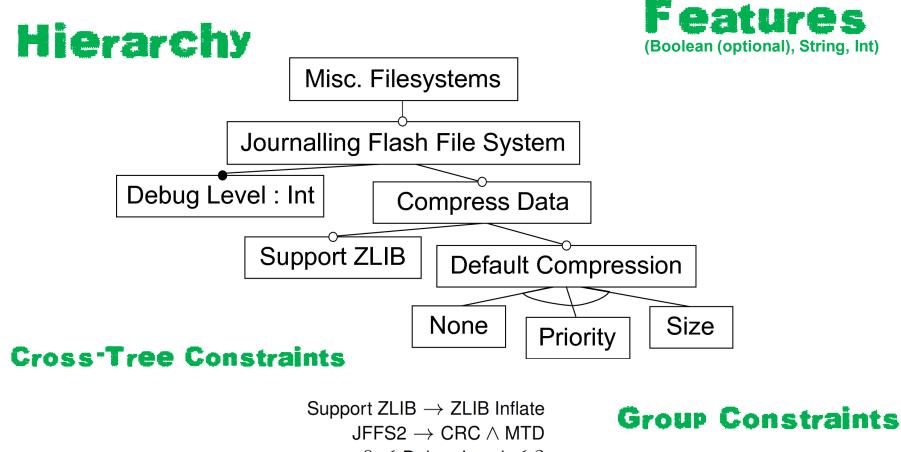


JFFS2 filesystem





JFFS2 filesystem



 $0 \leq \text{Debug Level} \leq 2$