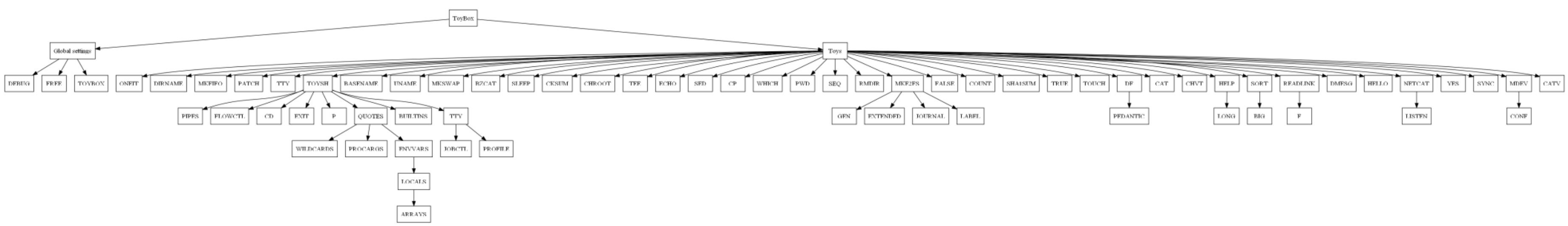
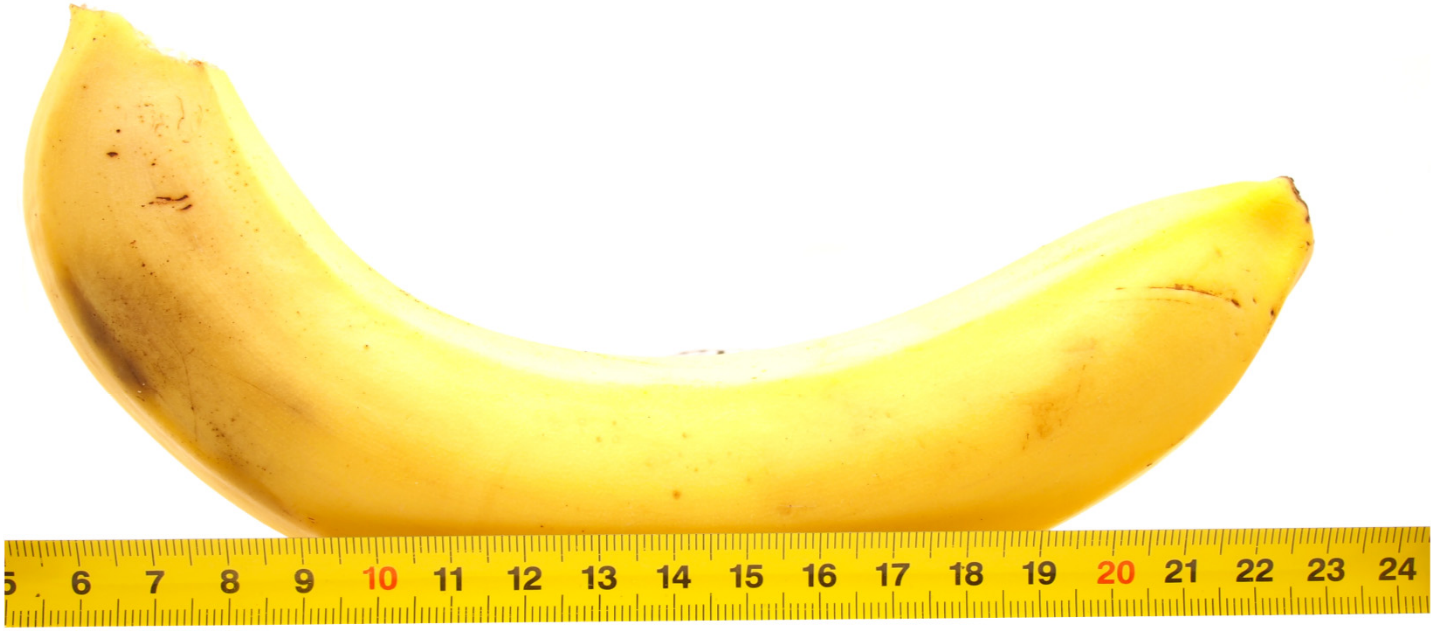
research-in-progress report



towards system analysis with variability model metrics

thorsten berger, jianmei guo

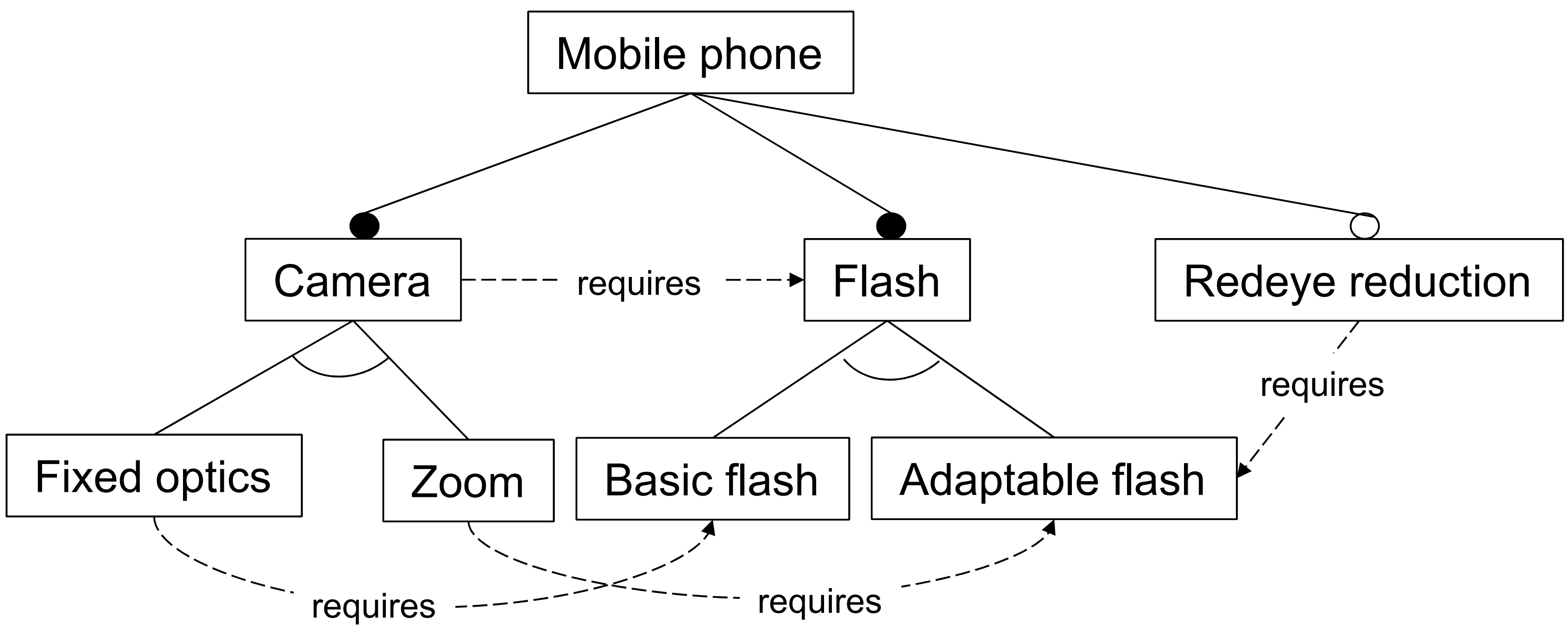


how big is my system?

thorsten berger, jianmei guo

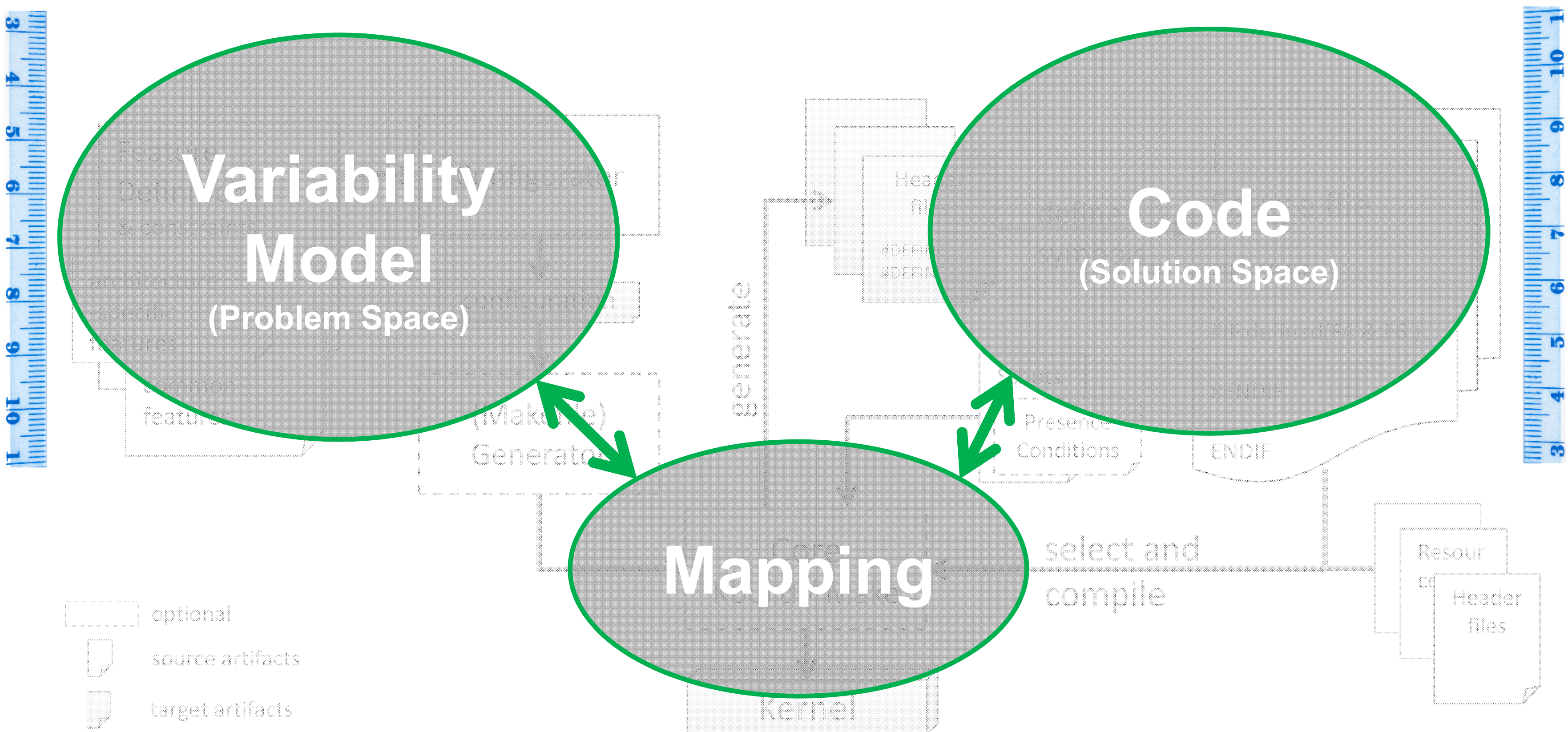
simple systems

simple model / simple feature modeling language



model adapted from
keynote of J. Savolainen

systems software



a systems software model

eCos ARM AT91
1297 features

```
cdl_component POSIX_SIGNALS {
  display "POSIX signals configuration“
  flavor  bool
  default_value 1
  requires KERNEL_EXCEPTIONS
  requires POSIX_PTHREAD
  requires POSIX_TIMERS
  implements POSIX_REALTIME_SIGNALS
  implements ISO_SIGSETJMP
  requires { ISO_SIGSETJMP_HEADER == "<cyg/posix/sigsetjmp.h>" }
  implements ISO_SIGNAL_NUMBERS
  implements ISO_SIGNAL_IMPL
  requires { ISO_SIGNAL_NUMBERS_HEADER == "<cyg/posix/signal.h>" }
  requires { CYGBLD_ISO_SIGNAL_IMPL_HEADER == "<cyg/posix/signal.h>" }
  description "This component provides configuration controls for the POSIX
                    signals.“
  compile signal.cxx except.cxx
}
```

```
cdl_op
  displa
  flavor
  legal_
  calcul

  descri
}
```

```
    descriptor space is saved, as well as no longer requiring POSIX
    realtime signal support.“
  }
```

scalability concepts

- derived features
- ranges
- expressive constraint languages
- visibility conditions
- defaults (als computed)
- capabilities
- binding modes
- hierarchy manipulation
- ...

feature modeling concepts

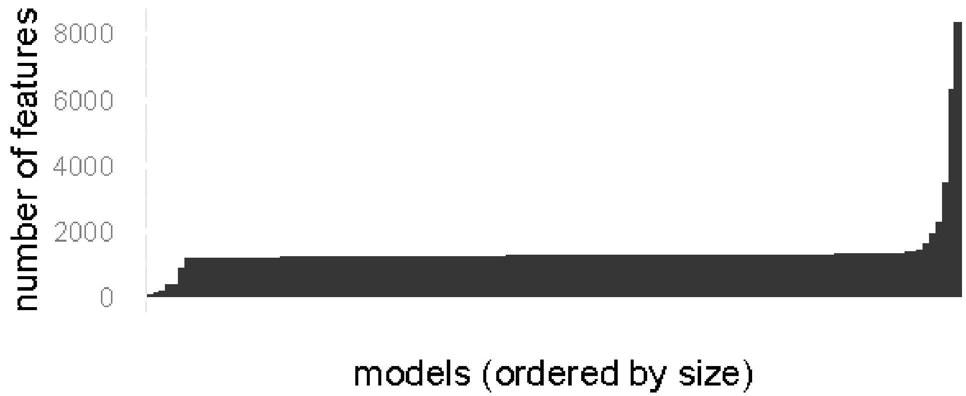
- hierarchy
- Boolean, integer, string features
- feature groups
- cross-tree constraints

Berger, She, Lotufo, Czarnecki, Wasowski: A Study of Variability Models and Languages in the Systems Software Domain. IEEE Transactions on Software Engineering, 2013

more systems software models

129 models

- 108 – 8355 features
- languages: CDL and Kconfig
- system: 26K – 10.2M LOC



analysis tools

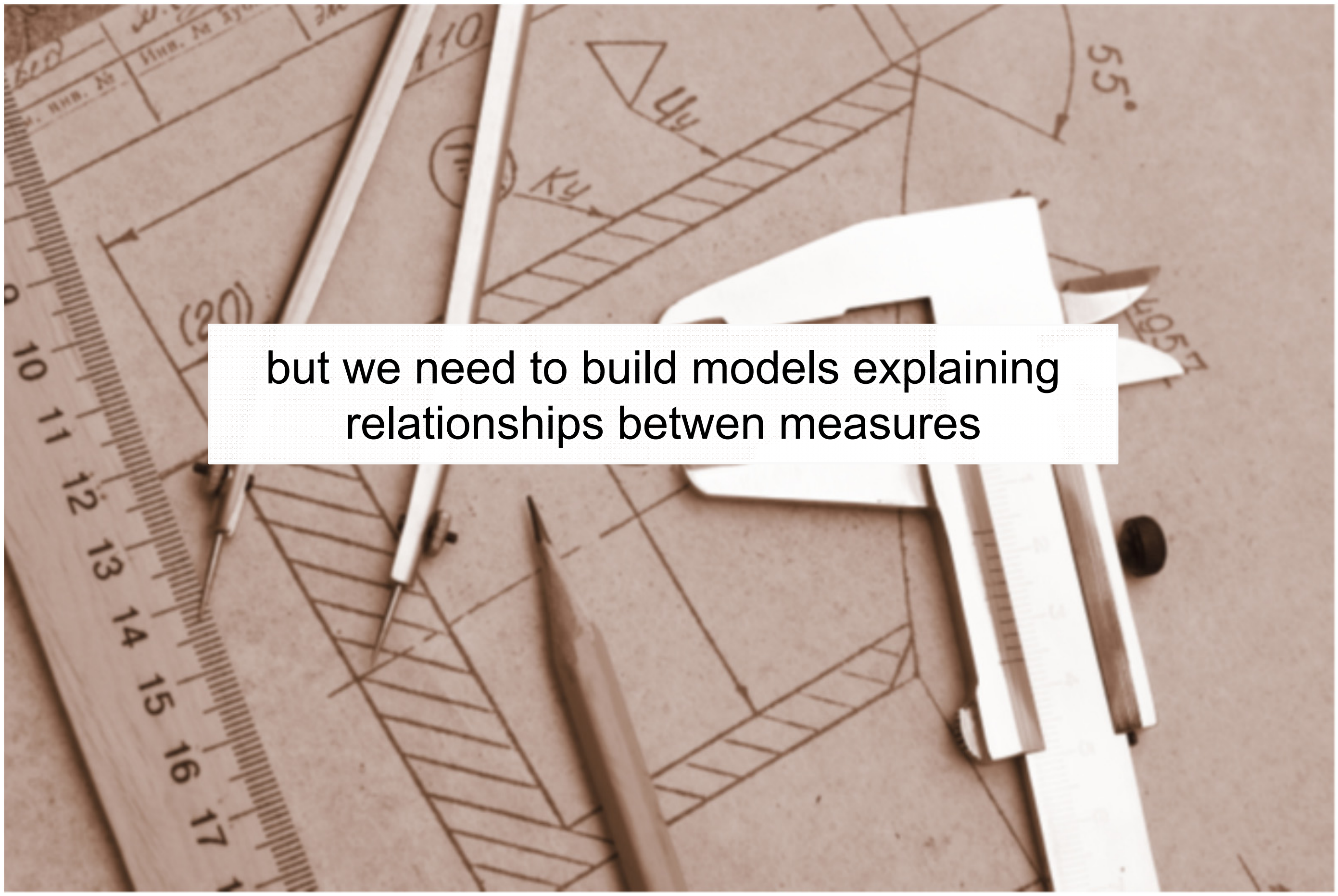
- CDLTools
- LVAT (credits: S. She)

abstractions

- configuration space in propositional logic (DIMACS)
- hierarchy plots

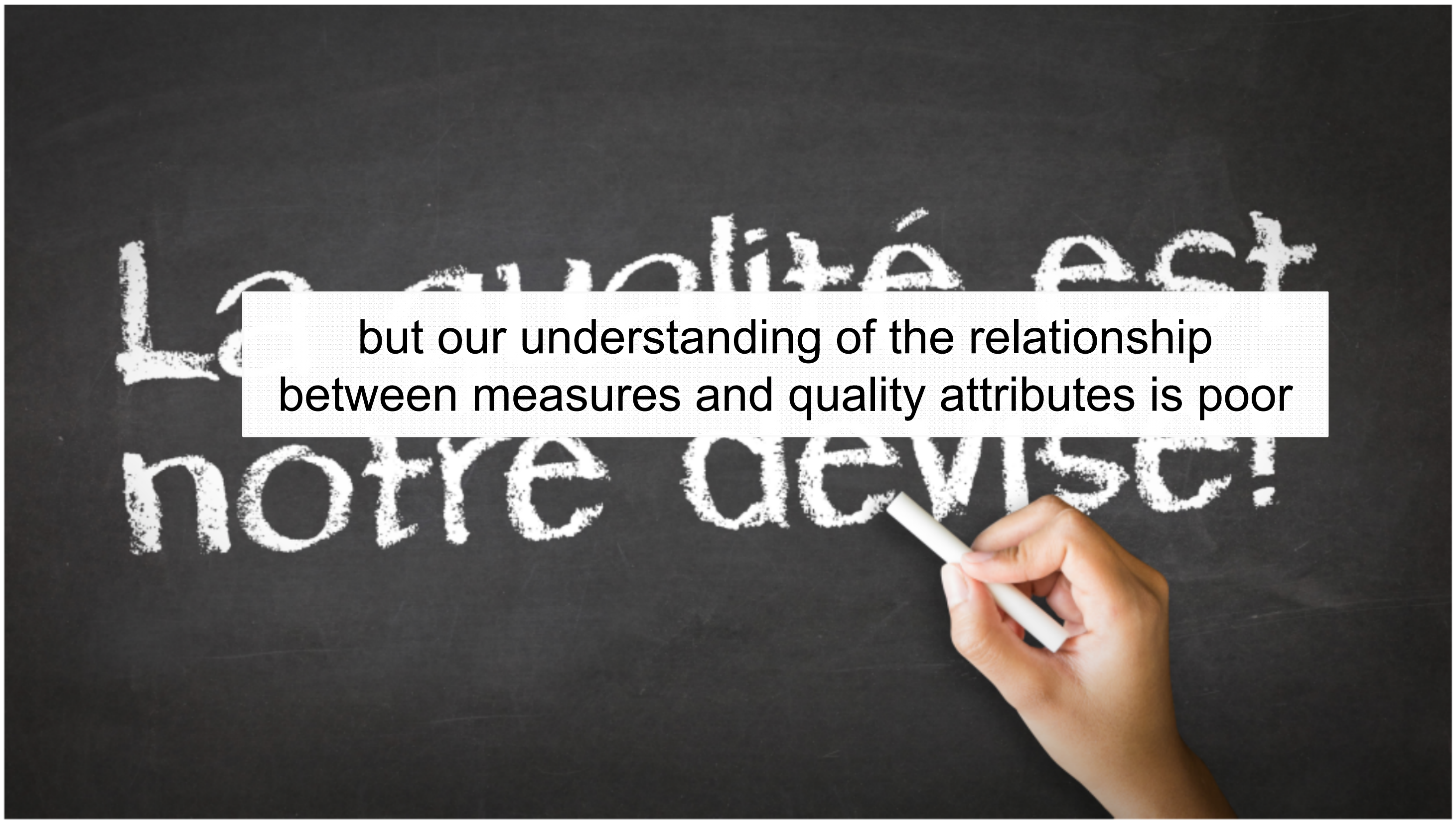
WHY TO MEASURE?

quantifying model properties



but we need to build models explaining
relationships betwen measures

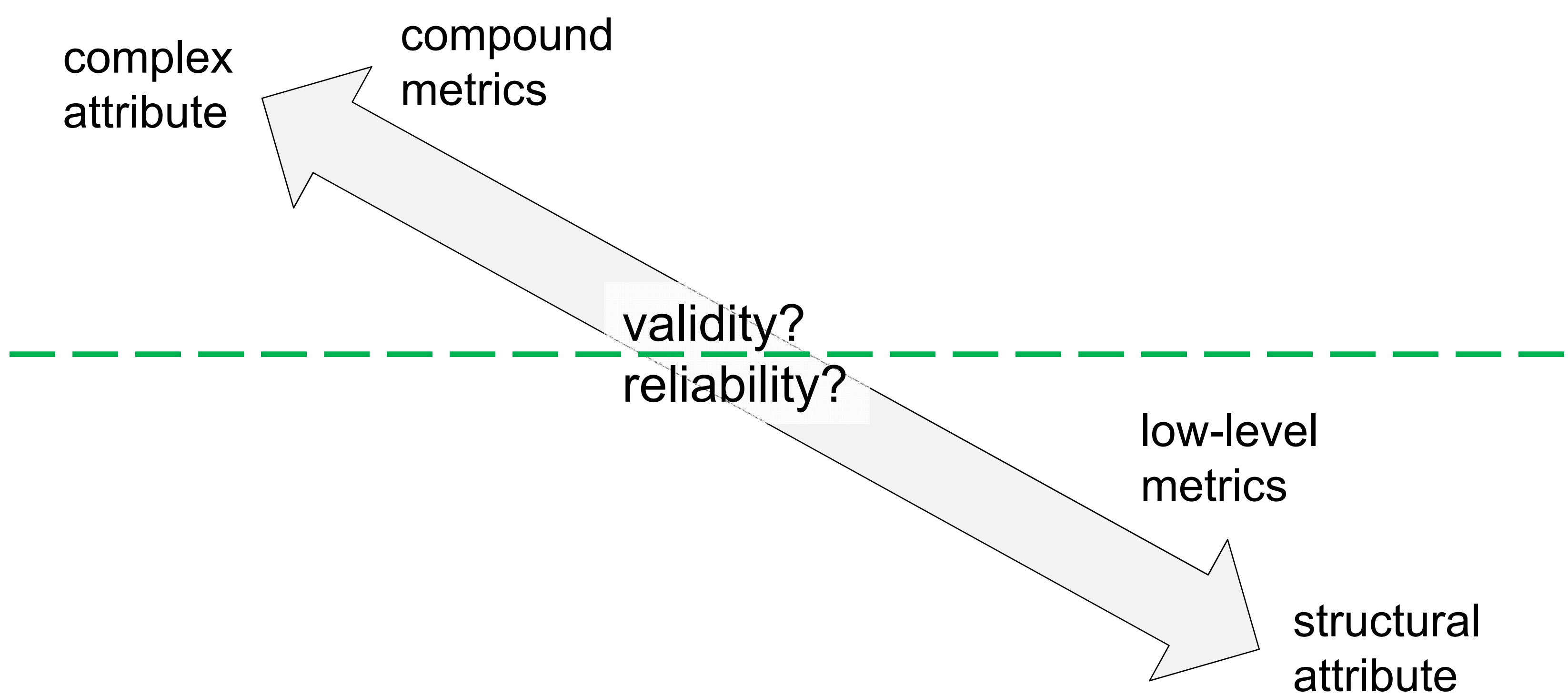
assure quality attributes



but our understanding of the relationship between measures and quality attributes is poor

HOW TO MEASURE?

measurement using metrics



understanding of low-level attributes of variability models is low!

metrics definition

goal: define metrics for low-level characteristics

9 structural metrics

- reflect size, shape, hierarchy, grouping

7 feature representation metrics

- reflect data types (switch, none, number, string), value domain restrictions (e.g., ratio of open value domain features), capabilities

10 feature constraint metrics

- constrained features, ratio of constraint types (e.g., derived, visibility, default)

3 dependency metrics

- CTCR, density, connectivity

prospective metrics

- hierarchy specifics, feature descriptions, feature-to-code mapping

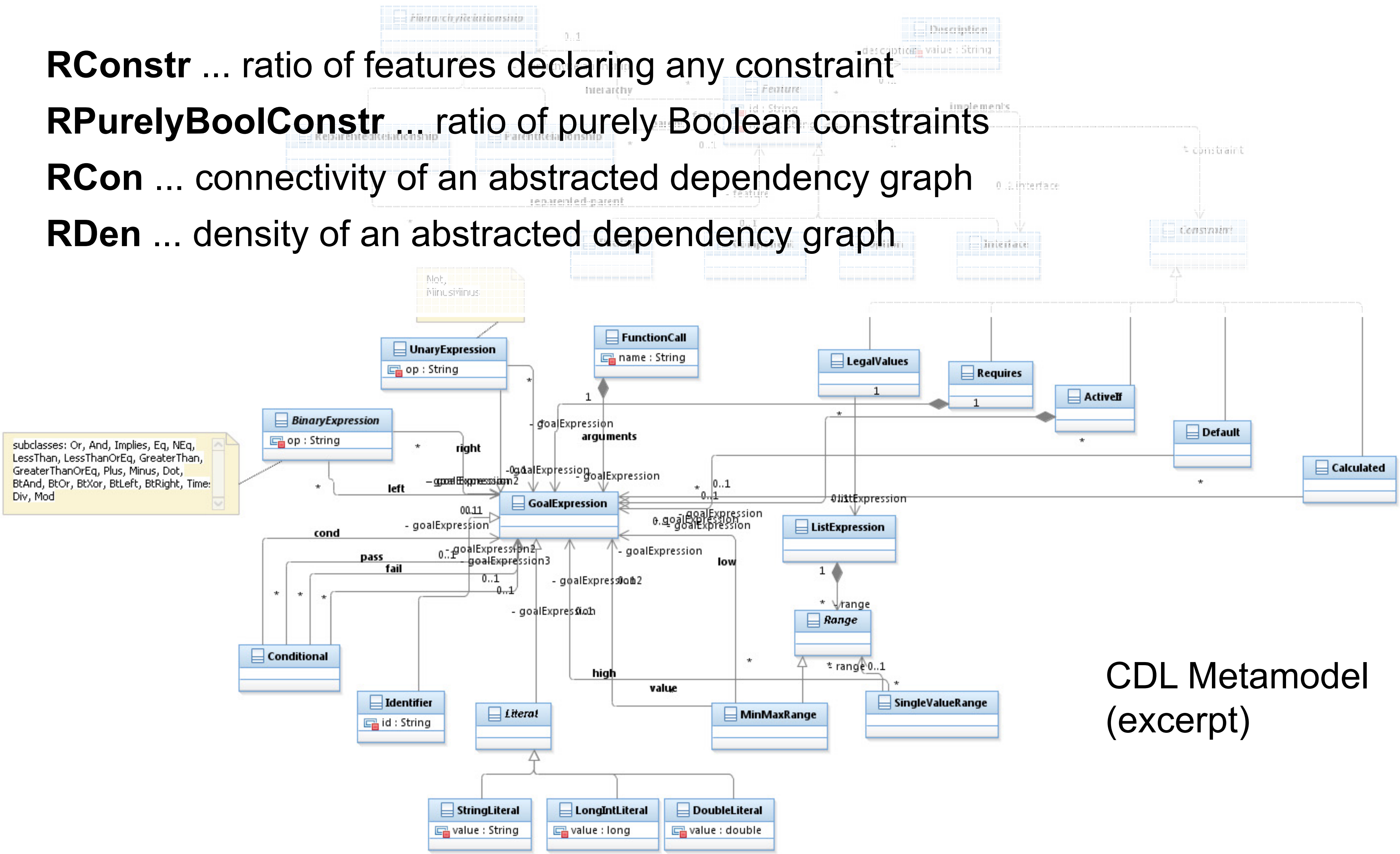
examples

RConstr ... ratio of features declaring any constraint

RPurelyBoolConstr ... ratio of purely Boolean constraints

RCon ... connectivity of an abstracted dependency graph

RDen ... density of an abstracted dependency graph



CDL Metamodel (excerpt)

preliminary experiment

ANALYSES USING METRICS

possible analysis techniques

interest in co-variance:

association (correlation) analysis

interest in prediction:

classification and regression

interest in outliers:

clustering and anomaly detection

preliminary experiment

CORRELATION ANALYSIS

methodology

model	version	features	LOC
ToyBox	0.1.0	191	26K
axTLS	1.4.9	114	21.4K
Fiasco	2013091917	213	140K
BusyBox	1.21.0	921	195K
eCos i386PC	3.0	1256	301K
uClibc	0.9.31	367	320K
CoreBoot	4.0-nov2013.git	4118	1.5M
Linux x86	3.4	8355	10.2M

eight real-world systems with models and proper (C-based) codebases

correlation test criteria (limitations)

- model metrics have no normal distribution
- low sample size compared to the number of variables (34 model metrics, 23 code metrics)

Spearman correlation test

- significant level: p-value < 0.05
- Spearman is non-parametric and can detect non-linear relationships, to account for limitations of our dataset

qualitative inspection of correlations

selection of preliminary

RESULTS

model metric correlation test

goal: identify inherent model characteristics

	NF	NGF	NTop	LD_median	NLeaf	LD_mean	BF_mean	BF_max	LD_max	BF_median	RSwitch	RData	RData_num	RNone	RData_strin	RCap	RDataOpen
NF	+++++	0.731	0.952	—	1	—	—	—	—	—	—	—	—	—	—	—	—
NGF	0.04	+++++	0.755	—	0.731	0.731	—	—	—	—	—	—	—	—	—	—	—
NTop	0.001	0.031	+++++	—	0.952	—	—	—	—	—	—	—	—	—	—	—	—
LD_median	—	—	—	+++++	—	0.913	—	—	—	—	—	—	—	—	—	—	—
NLeaf	<0.001	0.04	0.001	—	+++++	—	—	—	—	—	—	—	—	—	—	—	—
LD_mean	—	0.04	—	0.002	—	+++++	-0.762	—	—	—	—	—	—	—	—	—	—
BF_mean	—	—	—	—	—	0.037	+++++	—	-0.724	—	—	—	—	—	—	—	—
BF_max	—	—	—	—	—	—	—	+++++	—	—	—	—	—	-0.786	—	—	—
LD_max	—	—	—	—	—	—	0.042	—	+++++	-0.745	—	—	—	—	—	—	—
BF_median	—	—	—	—	—	—	—	—	0.034	+++++	-0.771	0.771	—	—	—	—	0.771
RSwitch	—	—	—	—	—	—	—	—	—	0.025	+++++	-1	-0.833	—	-0.929	—	-1
RData	—	—	—	—	—	—	—	—	—	0.025	<0.001	+++++	0.833	—	0.929	—	1
RData_num	—	—	—	—	—	—	—	—	—	—	0.015	0.015	+++++	—	0.762	—	0.833
RNone	—	—	—	—	—	—	—	0.028	—	—	—	—	—	+++++	—	—	—
RData_string	—	—	—	—	—	—	—	—	—	—	0.002	0.002	0.037	—	+++++	—	0.929
RCap	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+++++	—
RDataOpen	—	—	—	—	—	—	—	—	—	0.025	<0.001	<0.001	0.015	—	0.002	—	+++++
RDerived	—	—	—	—	—	—	—	—	—	—	—	—	—	0.015	—	—	—
RDataRes	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RConstr	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RDefault	—	—	—	—	—	—	—	—	—	—	—	—	—	0.037	—	—	—
RDerived_lit	—	—	—	—	—	—	—	—	—	—	—	—	—	0.015	—	—	—
RVisibility	—	—	—	—	—	—	—	—	—	—	—	—	0.037	—	—	—	—
RDefault_lit	—	—	—	—	—	—	—	—	—	—	—	—	—	0.037	—	—	—
NOr	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RConfVis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
NXor	0.037	—	0.037	—	0.037	—	—	—	—	—	—	—	—	0.011	—	—	—
NMutex	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	<0.001	—
ROr	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RMutex	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	<0.001	—
RXor	—	—	—	—	—	—	—	—	0.037	0.009	—	—	—	—	—	—	—
CTCR	—	—	—	—	—	—	—	—	0.021	0.022	—	—	—	—	—	—	—
RDen	—	—	—	—	—	—	—	—	0.01	0.025	—	—	—	—	—	—	—
RCon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

	RDerived	RDataRes	RConstr	RDefault	RDerived_lit	RVisibility	RDefault_lit	NOr	RConfVis	NXor	NMutex	ROr	RMutex	RXor	CTCR	RDen	RCon
NF	—	—	—	—	—	—	—	—	—	0.762	—	—	—	—	—	—	—
NGF	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
NTop	—	—	—	—	—	—	—	—	—	0.762	—	—	—	—	—	—	—
LD_median	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
NLeaf	—	—	—	—	—	—	—	—	—	0.762	—	—	—	—	—	—	—
LD_mean	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
BF_mean	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
BF_max	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LD_max	—	—	—	—	—	—	—	—	—	—	—	—	—	-0.737	-0.786	-0.835	—
BF_median	—	—	—	—	—	—	—	—	—	—	—	—	—	0.843	0.783	0.771	—
RSwitch	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RData	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RData_num	—	—	—	—	—	0.762	—	—	—	—	—	—	—	—	—	—	—
RNone	-0.833	—	—	0.762	-0.833	—	0.762	—	—	-0.857	—	—	—	—	—	—	—
RData_string	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RCap	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—
RDataOpen	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RDerived	+++++	—	—	-0.81	1	—	-0.81	—	0.857	0.833	—	—	—	—	—	—	—
RDataRes	—	+++++	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RConstr	—	—	+++++	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RDefault	0.022	—	—	+++++	-0.81	—	1	—	—	-0.857	—	—	—	—	—	-0.738	—
RDerived_lit	<0.001	—	—	0.022	+++++	—	-0.81	—	0.857	0.833	—	—	—	—	—	—	—
RVisibility	—	—	—	—	—	+++++	—	—	—	—	—	—	—	—	—	—	—
RDefault_lit	0.022	—	—	<0.001	0.022	—	+++++	—	—	-0.857	—	—	—	—	—	-0.738	—
NOr	—	—	—	—	—	—	—	+++++	—	—	—	1	—	—	—	—	—
RConfVis	0.011	—	—	—	0.011	—	—	—	+++++	0.81	—	—	—	—	—	—	—
NXor	0.015	—	—	0.011	0.015	—	0.011	—	0.022	+++++	—	—	—	—	—	—	—
NMutex	—	—	—	—	—	—	—	—	—	—	+++++	—	1	—	—	—	—
ROr	—	—	—	—	—	—	—	<0.001	—	—	—	+++++	—	—	—	—	—
RMutex	—	—	—	—	—	—	—	—	—	—	<0.001	—	+++++	—	—	—	—
RXor	—	—	—	—	—	—	—	—	—	—	—	—	—	+++++	—	0.786	—
CTCR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+++++	0.929	0.929
RDen	—	—	—	0.046	—	—	0.046	—	—	—	—	—	—	0.028	0.002	+++++	0.929
RCon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.002	0.002	+++++

correlations and insights

model size and shape

number features, number top-level features and leaf features

-> equal growth at both levels; with other findings: shapes remain when models grow

ratio of abstract features strongly negatively correlated with branching, but strongly correlated with defaults

-> domain modeling does not produce wide trees, and the more manual effort goes into domain modeling, the more defaults are modeled

mean and median branching not correlated

-> many outliers (we knew before), median is the better measure

correlations and insights

feature constraints

- CTCR correlated strongly with branching and strongly negatively with maximum depth
- -> wider and less-deep trees have less opportunities to encode constraints in hierarchy
- CTCR, connectivity and density of dependency graph highly correlate
- -> more investigation required, but early indicator of regular, non-skewed structures

model and code relationship

code metrics from [Liebig et al. 2010]

adapted the cppstats tool,
and ran it on our codebases

metric	description
LOC	lines of code
NOFC	number of feature constants (features referenced in source code)
LOFC	lines of feature code
ND	average (**AND**) and maximal (**NDMAX**) nesting of conditional compilation directives (#IF*)
SD	scattering degree: average and standard deviation of the number of occurrences of features in different expressions of conditional compilation directives
TD	tangling degree: average and standard deviation of the number of features in expressions of conditional compilation directives
GRAN	number of #IFDEFS occurring at a certain kind of language granularity: global level (**GRANGL**), function or type level (**GRANFL**), block level (**GRANBL**), statement level (**GRANSL**), expression level (**GRANEL**), method signature level (**GRANML**)
TYPE	number of extensions under equivalent #IF* expressions: homogeneous extensions with duplicated code (**HOM**), heterogeneous extensions with varying code (**HET**), and mixed (**HOHE**).

Liebig, Apel, Lengauer, Kästner, Schulze: An analysis of the variability in forty preprocessor-based software product lines. In International Conference on Software Engineering, 2010

model and code relationship

goal: explore potential of predicting system characteristics

	NF	NGF	NTop	LD_median	NLeaf	LD_mean	BF_mean	BF_max	LD_max	BF_median	RSwitch	RData	RData_num	RNone	RData_string	RCap	RDataOpen	RDerived	RDataRes	RConstr	RDefault	RDerived_lit	RVisibility	RDefault_lit	NOr	RConfVis	NXor	NMutex	ROr	RMutex	RXor	CTCR	RDen	RCon
LOC	1	0.731	0.952	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.762	—	—	—	—	—	—	—
NOFC	0.905	—	0.857	—	0.905	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.905	—	—	—	—	—	—	—
LOF	0.905	0.778	0.881	—	0.905	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.786	—	—	—	—	—	—	—
ANDAVG	—	—	—	—	—	—	—	—	—	—	-0.857	0.857	—	—	0.833	—	0.857	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ANDSTDEV	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.81	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
SDEGMEAN	—	—	—	—	—	—	—	—	—	—	-0.738	0.738	0.738	—	—	—	0.738	—	—	—	—	—	—	—	—	0.786	0.738	—	—	—	—	—	—	—
SDEGSTD	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	-0.786	—	—	—	—	—	0.762	0.857	—	—	—	—	—	—	—
TDEGMEAN	—	—	—	—	—	—	—	—	-0.773	0.843	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.833	—	—	—	—	0.762	0.762	0.762	—
TDEGSTD	—	—	—	—	—	—	—	—	—	0.723	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.857	—	—	—	—	—	—	—	—
HOM	0.952	0.755	1	—	0.952	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.762	—	—	—	—	—	—	—
HET	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
HOHE	0.976	0.79	0.976	—	0.976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.786	—	—	—	—	—	—	—
GRANGL	0.905	—	0.857	—	0.905	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.905	—	—	—	—	—	—	—
GRANFL	0.929	0.85	0.929	—	0.929	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
GRANBL	0.905	0.922	0.905	—	0.905	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
GRANSL	0.738	—	—	—	0.738	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
GRANEL	0.805	0.785	—	—	0.805	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
GRANML	0.85	—	0.802	—	0.85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
GRANERR	0.755	—	—	—	0.755	—	—	—	—	—	—	—	—	-0.79	—	—	—	—	—	—	—	—	—	—	—	—	0.85	—	—	—	—	—	—	—
NDMAX	—	—	—	—	—	—	—	—	—	0.758	-0.731	0.731	—	—	—	—	0.731	0.778	—	—	—	0.778	—	—	—	0.934	0.778	—	—	—	—	—	—	—
RDerived_expr	0.764	0.741	0.764	—	0.764	—	—	—	—	—	—	—	0.764	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RDefault_expr	—	0.768	—	—	—	0.733	—	—	—	—	—	—	—	—	—	0.756	—	—	—	—	—	—	—	—	—	—	—	0.756	—	0.756	—	—	—	—
RPurelyBoolConstr	-0.723	—	—	—	-0.723	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

correlations and insights

sizes

- model size metrics and code size metrics (LOC, NOFC, LOFC) very strongly correlated
- size metrics very strongly correlated with code extension metrics HOM, HOHE, but not with HET

granularity

- sizes strongly correlated with extension granularities (GRANGL, GRANFL, GRANBL, GRANSL, GRANEL, GRANML, and GRANERR)

-> identification of significant system characteristics

-> indications of system characteristics show that forward and reverse inference of model and code characteristics is possible

CONCLUSION

summary and conclusions

contributions: defined and implemented metrics on rich languages, a tool, quantitative datasets, qualitatively inspected correlations

model metrics provide insights

- analysis both confirms earlier findings and provides a complementary picture

model and code metric analysis *can potentially* provide insights

- for instance, for reverse-engineering techniques
- -> further analysis required, but needs better focus

outlook

evaluation of applicability of metrics to further languages and further real models

investigate prospective model metrics and feature metrics

connect to findings about computational and cognitive complexity

theoretical evaluation of the metrics regarding accepted properties (e.g., additivity, triangle inequality), for instance, using the DISTANCE framework

look at evolution?

and so?

models

https://bitbucket.org/tberger/variability-models

https://code.google.com/p/linux-variability-analysis-tools/source/browse/?repo=extracts

metrics and analysis tools

VMM https://bitbucket.org/tberger/vmm

LVAT (S. She) https://code.google.com/p/linux-variability-analysis-tools/

CDLTools https://bitbucket.org/tberger/cdltools

read on...

Berger, She, Lotufo, Czarnecki, Wasowski: A Study of Variability Models and Languages in the Systems Software Domain. IEEE Transactions on Software Engineering, 2013

She, Berger: Formal Semantics of the Kconfig Language. Technical Note, 2010

Berger, She: Formal Semantics of the CDL Language. Technical Note, 2010

thanks for listening!

towards system analysis
with variability model metrics
thorsten berger, jianmei guo