On the Relationship Between Object-Oriented Metrics and Software Evolution

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Introduction

- Want to find the relationship between metrics and SW evolution
- Introduce the LoD metric
- Look at the change in metrics over releases of systems
- Analyze change with correlation and regressions

What Do We Expect?

- Coupling, inheritance, and size will relate to releases
- Cohesion will be inversely related to releases
- LoD and releases???
- LoD will be inversely related to coupling
- LoD will be directly related to cohesion and size

The Metrics

- Five categories
  1. Coupling
  2. Cohesion
  3. Inheritance
  4. Size
  5. LoD
- Commonly-used, "off-the-shelf"
- All try to quantify one category

Coupling Metrics

- CBO and CBO' - Coupling between objects
- DAC and DAC' - Data-abstraction coupling
- ICP - Information-based flow coupling
- Briand *et al.*'s measures

Category	**Possibilities**
Relationship	Ancestor, Descendent, Friend, Inverse Friend, Other
Type	Class-Attribute, Class-Method, Method-Method
Impact	Import Coupling, Export Coupling

Examples: FMMEC, OCAIC, IFCMIC, ...

Cohesion Metrics

- $\text{LCOM}_{\#}$: Lack of cohesion $\#$
  - LCOM_1: number of methods not using attrributes in common
  - LCOM_2: LCOM_1 minus those that do
  - LCOM_3: connected commponents by common attributes
  - LCOM_4: LCOM_3 with invocations
  - LCOM_5: $\frac{1}{a}(\sum_{j=1}^{a} \mu(A_j) - m)/(1 - m)$
- Coh - Briand $et\ al.$'s cohesiveness: $\sum_{j=1}^{a} \mu(A_j)/(m - a)$
- ICH - Information-flow based cohesion

Inheritance Metrics

- DIT and NOA - Depth of inheritance tree & number of ancestors
- CLD - Class-to-leaf depth
- NOC and NOD - Number of children & descendents
- NMO and NMA - Number of methods overriden & added
- NMINH and NAINH - Number of methods & attributes inherited
- SIX - Specialization index

$$SIX = \frac{NMO \times DIT}{NMO + NMA + DIT} \tag{1}$$

Size Metrics

- NMINH and NAINH (again) - Number of methods & attributes inherited
- NMIMP and NAINH - Number of methods & attributes implemented
- NUMPAR - Number of parameters
- LOC - Lines of code
- NC - Number of classes

The Law of Demeter

- A rule of programming that restricts the coupling between classes
- The idea: Objects can only send messages to *closely-related* objects
- Two forms for an instance i of class C sending a message in method M

Class form	**Object form**
instance variables of C	immediate parts of i
argument classes to M	arguments objects to M
classes of objects created in M	objects created in M
classes of global variables	objects in global variables

- Violations are messages not abiding by these rules
- The metric is $|Violations|/|PossibleViolations|$

Example LoD Violation and the Metric

Listing 1: Simple LoD Violation

```
1 class A { void nothing() {} }
2 class B { A a; a() { return a; } }
3 class C {          // Violation! *********
4   void violation(B b) { b.a().nothing(); }}
5 }
```

- The object on which `nothing()` is called is:
  - not an instance variable
  - not an argument to `violation(B)`
  - not an object created in `violation(B)`
  - not a global (`static`) variable
- So this is a **violation!**

Another Example LoD Violation

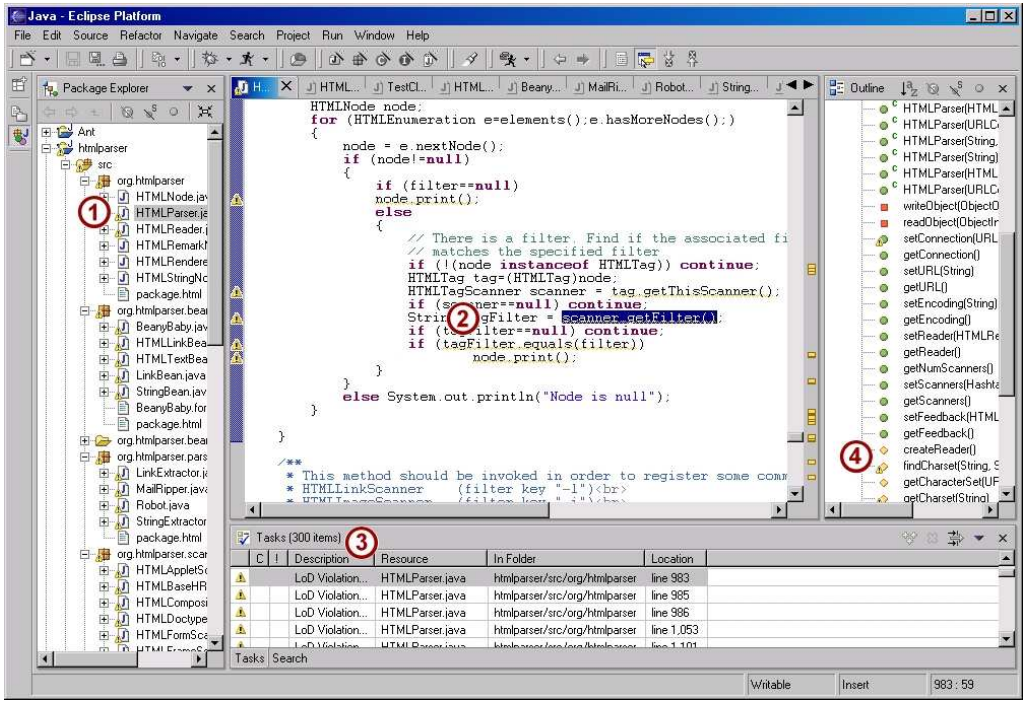
Listing 2: A violation due to assignment

```
1  class A { void nothing() {} }
2  class B { A a; a() { return a; } }
3  class C {
4    void violation(B t, boolean b) {
5      Object o;
6      if (b) o=``s'';          // String->toString: OK
7      else   o=t.a();          // B->A->toString:   No
8      String s=o.toString(); //          VIOLATION!!!!
9    }
10 }
```

- One violation on a path to a site $\Longrightarrow$ violation
- Need to do some flow analysis to find these

Collecting the Metrics

- All, but LoD , with `JavaPalm` from `http://javapalm.sourceforge.net`
- LoD with `DemeterCop` from `http://demetercop.sourceforge.net`



Systems

Who?	What?	Which Ones?
`htmlparser`	HTML parser	0.9, 1.0, 1.1, 1.2
`ant`	Build tool similar to `make`	1.1, 1.2, 1.3, 1.4
`tomcat`	Servlet container	3.2.3, 3.3.1, 4.0.6, 4.1.18
`xalan`	XSLT processor for XML	1.2.1, 2.0.0, 2.1.0, 2.2.0

Analysis Methods

- Pearson Correlation
  - ρ, p
  - for confidence $|\rho| \geq 0.5$ and $p \leq 0.05$
- Regression
  - linear ($y = mx + b$) and logarithmic ($y = bx^m$)
  - m, p
  - for confidence $p \leq 0.05$
- Two sets were taken
  1. releases/metric
  2. LoD/metric

Analysis Methods (con't)

- We need a view of a metric change over all releases
- View 1: Change in metric sum over all classes, for every release

$$\tau_{1_M} = \tau \left(\sum_{c \in C} M_1(c) \cdots \sum_{c \in C} M_n(c) \right) \tag{2}$$

- Two problems
  1. Summing at every release hid much of the change
  2. All classes $c \in C$ were weighted the same in $\sum_{c \in C} M_i(c)$

Analysis Methods (con't)

- Two solutions
  1. Take the average value of all the individual changes, over all the classes
     - Equation 2 becomes Equation 3

$$\tau_M = \frac{\sum_{c \in C} \tau\left(M_1(c) \cdots M_n(c)\right)}{n} = \frac{\sum_{c \in C} \tau_c}{n} \tag{3}$$

  2. Introduce a weighting term $\omega_c = \mathrm{IMP}$ into the summation for above
     - Each term τ_c in Equation 3 becomes $\tau'_c = \omega_c \times \tau_c$

- View 2: Combine Equation 3 and τ'_c to obtain Equation 4

$$\tau_{2_M} = \frac{\sum_{c \in C} \omega_c \times \tau\left(M_1(c) \cdots M_n(c)\right)}{\sum_{c \in C} \omega_c} = \frac{\sum_{c \in C} \tau'_c}{\sum_{c \in C} \omega_c} \tag{4}$$

Analysis Methods (con't)

- Replace τ'_c with ρ'_c and m'_c in Equation 4 for new correlation/regressions
- Vectors for release/metric stats are

$$\vec{R} = (1 \ \cdots \ n)$$
$$\vec{M}_c = (M_1(c) \ \cdots \ M_n(c))$$

- Vectors for LoD/metric are

$$\vec{M}_{LoD_c} = (M_{LoD_{\theta(1)}}(c) \ \cdots \ M_{LoD_{\theta(n)}}(c))$$
$$\vec{M}_{q_c} = (M_{q_{\theta(1)}}(c) \ \cdots \ M_{q_{\theta(n)}}(c))$$

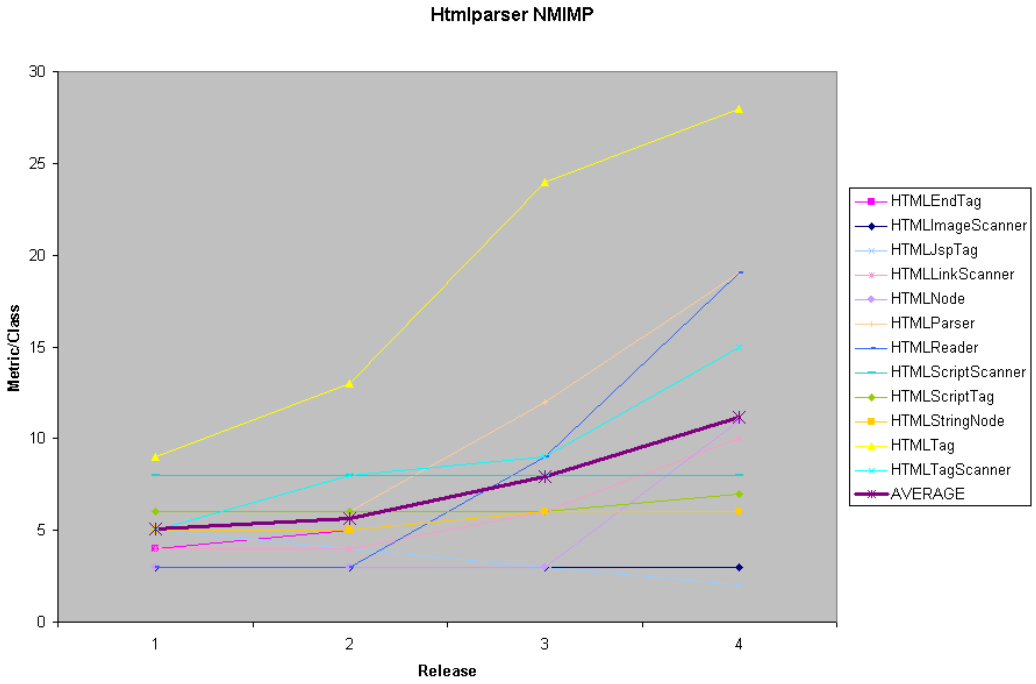
- where

$$\begin{array}{rcl} & \forall\, 1 \leq j < i & . \quad M_{LoD_{\theta(i)}} \geq M_{LoD_{\theta(j)}} \\ \bigwedge & \forall\, i < k \leq n & . \quad M_{LoD_{\theta(i)}} \leq M_{LoD_{\theta(k)}} \end{array} \tag{5}$$

Results I: Correlation to releases

Metric		*Correlation* Min	Max	Std	Diff.	ρ_{rel}	p	*Systems* A	H	T	X
		Coupling									
CBO	◁	-0.119	0.943	0.503	1.062	0.565	0.001	◁			◁
CBO'	◁	-0.065	0.959	0.491	1.024	0.572	0.005	◁			◁
OCAEC	◁	0.765	0.964	0.098	0.199	0.817	0.008	◁	◁	◁	◁
OCMEC	◁	0.566	0.775	0.099	0.209	0.634	0.030	◁	◁	◁	◁
RFC_1	◁	0.260	0.989	0.350	0.729	0.778	0.001			◁	◁
		Size									
LOC	◁	0.571	0.970	0.188	0.398	0.843	0.000	◁	◁	◁	◁
NC	◁	0.881	0.954	0.036	0.072	0.935	0.002	◁	◁	◁	◁
		LoD									
LoD	◁	-0.843	-0.180	0.322	0.663	-0.663	0.005			◁	◁

Example Discrepency



	Releases				*Pearson*	
Metric	**0.8**	**0.9**	**1.0**	**1.1**	ρ_{rel}	**p**
NMIMP	4.000	2.000	2.000	6.217	0.427	0.206

Example Discrepency (con't)

Increasing (22)						*Constant (6)*						*Decreasing (5)*					
Class	ω_C	**0.9**	**1.0**	**1.1**	**1.2**	**Class**	ω_C	**0.9**	**1.0**	**1.1**	**1.2**	**Class**	ω_C	**0.9**	**1.0**	**1.1**	**1.2**
HTMLNode	40	3	3	3	11	HTMLAppletScanner	4	–	9	9	9	HTMLDoctypeTag	4	*0*	*4*	*3*	*2*
HTMLMetaTagScanner	3	–	–	2	2	HTMLDoctypeScanner	4	–	5	5	5	HTMLJspTag	4	*5*	*4*	*3*	*2*
HTMLParser	13	6	6	12	19	HTMLScriptScanner	4	8	8	8	8	HTMLJspTag	4	*5*	*4*	*3*	*2*
HTMLAppletTag	5	–	13	13	14	HTMLStyleScanner	3	–	2	2	2	HTMLLinkProcessor	8	*0*	*7*	*7*	*5*
HTMLReader	21	3	3	9	19	HTMLImageNode	3	2	2	–	–	HTMLMetaTag	5	*0*	*0*	*8*	*7*
HTMLRemarkNode	4	–	5	5	6	MailRipper	2	–	2	2	2						
HTMLRemarkTag	2	5	5	–	–												
HTMLEndTag	7	4	5	6	6												
HTMLScriptTag	5	6	6	6	7												
HTMLStringNode	9	5	5	6	6												
HTMLStyleTag	5	–	2	2	3												
HTMLTag	46	9	13	24	28												
HTMLImageScanner	4	3	3	3	3												
HTMLImageTag	5	–	2	2	5												
HTMLTagScanner	22	5	8	9	15												
HTMLJspScanner	4	–	5	5	6												
HTMLTitleScanner	3	–	–	2	3												
HTMLTitleTag	5	–	–	4	5												
HTMLLinkNode	4	4	8	–	–												
HTMLLinkScanner	4	4	4	6	10												
HTMLLinkTag	9	–	9	9	22												
Robot	2	–	3	3	3												

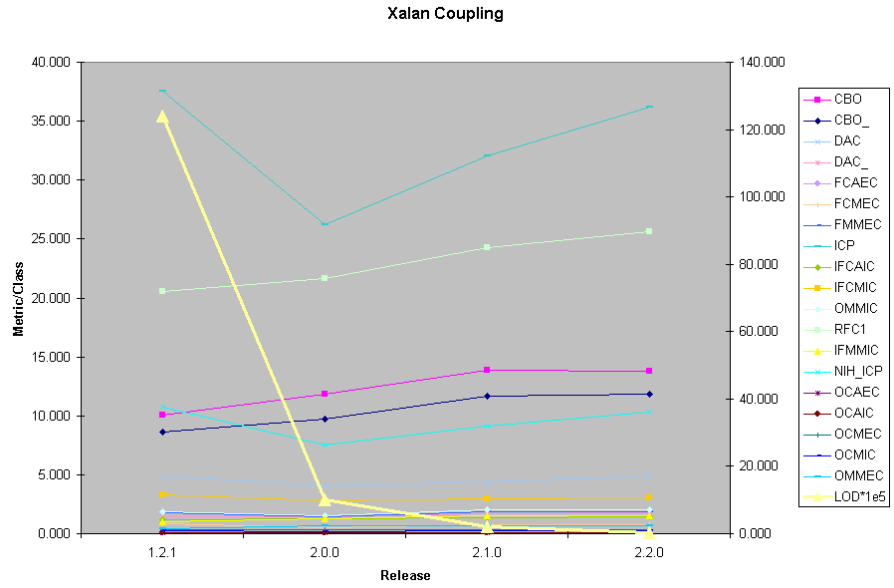
Results I: Correlation to LoD

Metric		*Correlation* Min	Max	Std	Diff.	ρ_{LoD}	p	*Systems* A	H	T	X
		Coupling									
CBO	◁	-0.884	-0.170	0.337	0.714	-0.639	0.000	◁	◁		◁
CBO'	◁	-0.831	-0.222	0.288	0.609	-0.620	0.001	◁	◁		◁
DAC'	◁	-0.926	-0.723	0.105	0.202	-0.813	0.015	◁		◁	◁
IFCAIC	◁	-0.966	-0.837	0.069	0.129	-0.897	0.014	◁		◁	◁
IFMMIC	◁	-0.899	-0.605	0.148	0.294	-0.774	0.008	◁	◁	◁	◁
OCAEC	◁	-0.956	-0.482	0.225	0.474	-0.810	0.038	◁		◁	◁
OMMEC	◁	-0.987	-0.170	0.400	0.817	-0.662	0.017	◁			◁
RFC_1	◁	-0.921	-0.403	0.219	0.518	-0.711	0.001	◁		◁	◁
		Cohesion									
Coh	◁	-0.843	0.182	0.495	1.025	-0.559	0.023	◁			◁
$LCOM_3$	◁	-0.980	0.220	0.597	1.201	-0.676	0.014				◁
		Inheritance									
NMO	◁	-0.949	0.137	0.515	1.087	-0.561	0.000	◁			◁
		Size									
LOC	◁	-0.855	-0.647	0.119	0.208	-0.752	0.000		◁	◁	◁
NC	◁	-0.901	-0.610	0.145	0.292	-0.781	0.002		◁	◁	◁

Results I: Correlation to LoD (con't)

	Release				*Pearson Coefficients*		
System	**1**	**2**	**3**	**4**	ρ_{LoD}	**p**	
ant	2.471	3.254	2.839	2.829	0.943	0.000	$\lhd$
htmlparser	1.500	2.000	2.000	3.233	-0.503	0.001	$\lhd$
tomcat	3.359	4.010	3.626	3.725	-0.725	0.000	$\lhd$
xalan	3.259	2.815	2.952	3.013	0.861	0.000	$\lhd$

- Much variation in IFCMIC



	Releases				*Pearson*	
Metric	**1.2.1**	**2.0.0**	**2.1.0**	**2.2.0**	ρ_{LoD}	
CBO	10.104	11.818	13.863	13.808	-0.884	◁
CBO'	8.656	9.748	11.668	11.816	-0.831	◁
DAC	4.901	4.029	4.368	4.891	0.500	◁
DAC'	1.425	1.478	1.689	1.758	-0.723	◁
FCAEC	0.192	0.172	0.287	0.277	-0.519	◁
FCMEC	0.870	0.497	0.770	0.759	0.555	◁
FMMEC	1.755	1.449	1.887	1.872	-0.024	
ICP	37.575	26.218	32.081	36.180	0.540	◁
IFCAIC	1.200	1.294	1.387	1.461	-0.837	◁
IFCMIC	3.259	2.815	2.952	3.013	0.861	◁
IFMMIC	3.454	4.403	5.359	5.420	-0.899	◁
OCAEC	0.304	0.383	0.363	0.385	-0.956	◁
OCAIC	0.225	0.184	0.301	0.297	-0.374	
OCMEC	1.203	1.173	1.257	1.227	-0.290	
OCMIC	0.873	0.512	0.784	0.764	0.545	◁
OMMEC	1.403	2.349	2.238	2.306	-0.987	◁
OMMIC	1.845	1.536	2.002	2.031	-0.096	
RFC_1	20.513	21.665	24.287	25.661	-0.759	◁

Results I: Regressions

- None of the regressions were condfident

Results II: Descriptive

Metric	Min	Max	Mean	Med	Std	Mean′	% Diff
NAIMP	0.427	1.003	0.647	0.580	0.270	4.050	-84.02
NAINH	0.164	0.300	0.216	0.201	0.061	2.296	-90.58
LOC	10.058	28.861	18.311	17.163	8.810	108.119	-83.06
NC	17.363	28.327	23.541	24.237	5.092	435.813	-94.60
NMINH	1.737	3.438	2.439	2.290	0.769	25.000	-90.24
NMIMP	1.010	1.882	1.402	1.357	0.424	8.081	-82.66
NUMPAR	0.856	2.113	1.329	1.174	0.601	7.910	-83.19

- Results I are shown in green
- Results II are shown in blue
- Percent differences (% Diff) are shown in magenta
- This was the case for all metric categories

Results II: Correlation to Releases

Metric		*Previous*			*Current*										*Systems*			
		ρ_{rel}		p	ρ_{rel}	Min	Max	Med	Std	p	Min	Max	Med	Std	A	H	T	X
		Coupling																
CBO	◁	◁	0.565	0.001	0.554	0.225	0.879	0.556	0.296	0.016	0.006	0.025	0.016	0.008	◁	◁		
CBO'	◁	◁	0.572	0.005	0.529	0.210	0.845	0.530	0.280	0.025	0.008	0.044	0.024	0.015	◁	◁		
IFCAIC	◁		0.788	0.130	0.525	0.310	0.716	0.537	0.216	0.048	0.043	0.060	0.044	0.008	◁	◁		
IFCMIC	◁		0.104	0.217	0.500	0.020	0.823	0.579	0.370	0.041	0.033	0.047	0.041	0.006	◁	◁		
RFC_1	◁	◁	0.778	0.001	0.575	0.441	0.734	0.563	0.142	0.015	0.006	0.018	0.017	0.006	◁	◁		
		Inheritance																
NMA			0.263	0.114	0.594	0.475	0.754	0.573	0.121	0.064	0.026	0.112	0.060	0.038	◁		◁	
NAINH	◁		0.276	0.349	0.848	0.788	0.928	0.838	0.058	0.040	0.030	0.048	0.040	0.008	◁	◁	◁	◁
NMINH	◁		0.418	0.000	0.715	0.581	0.870	0.704	0.120	0.042	0.004	0.094	0.035	0.041	◁			◁
NOC			0.026	0.011	0.640	0.016	0.911	0.817	0.424	0.080	0.042	0.172	0.054	0.062	◁	◁		
		Size																
NAIMP	◁		0.353	0.022	0.621	0.433	0.832	0.610	0.167	0.047	0.035	0.053	0.050	0.008	◁		◁	
NAINH	◁		0.276	0.349	0.848	0.788	0.928	0.838	0.058	0.040	0.030	0.048	0.040	0.008	◁	◁	◁	◁
LOC	◁	◁	0.843	0.000	0.574	0.494	0.757	0.522	0.125	0.020	0.004	0.032	0.022	0.014	◁	◁		
NMIMP			0.722	0.051	0.648	0.520	0.816	0.627	0.123	0.053	0.020	0.079	0.057	0.030	◁		◁	
NMINH	◁		0.418	0.000	0.715	0.581	0.870	0.704	0.120	0.042	0.004	0.094	0.035	0.041	◁			◁

Results II: Correlation to LoD

- No strong, confident correlations were found
- Many metrics showed erratic numbers; take NMINH

Metric	ρ_{LoD}	Min	Max	Med	Std	p	Min	Max	Med	Std
ant	0.445	-23.133	46.739	0.000	4.307	0.002	0.000	0.961	0.000	0.071
htmlparser ◁	0.629	-7.045	17.778	2.545	3.912	0.023	0.000	2.742	0.001	0.483
tomcat ◁	-0.735	-48.000	5.000	0.000	2.916	0.050	0.000	10.288	0.000	0.516
xalan ◁	-0.871	-1.000	1.000	0.000	0.405	0.012	0.000	0.132	0.000	0.009

- Positive ρ_{LoD}s in blue, negatives in red

Results II: Regression to Releases

	Regression Measures							*Systems*			
Metric	**m**	**SE**	$\mathbf{R^2}$	$\mathbf{SS_{reg}}$	$\mathbf{SS_{rid}}$	$\mathbf{SE_y}$	**p**	**A**	**H**	**T**	**X**
	Coupling										
CBO ◁	4.681	0.939	0.850	496.159	21.373	1.761	0.048	◁	◁	◁	
CBO' ◁	4.619	0.926	0.847	507.331	20.511	1.734	0.050	◁	◁	◁	
IFCAIC ◁	0.772	0.282	0.812	6.597	1.081	0.523	0.041	◁	◁	◁	◁
OCAIC	0.223	0.187	0.662	1.758	0.409	0.360	0.051		◁	◁	◁
OCMIC	0.085	0.235	0.667	1.124	0.534	0.426	0.061		◁	◁	◁
OMMIC ◁	0.361	0.265	0.796	4.703	1.236	0.476	0.046	◁	◁	◁	◁
	Inheritance										
CLD	0.032	0.315	0.777	2.871	1.180	0.590	0.051			◁	
NMA	1.460	0.809	0.842	64.305	11.727	1.418	0.055			◁	◁
NAINH ◁	1.181	0.187	0.835	4.101	0.986	0.334	0.035			◁	◁
NMINH ◁	1.789	0.893	0.875	112.382	42.281	1.488	0.047			◁	◁
NMO	0.530	0.342	0.820	7.819	2.063	0.599	0.063		◁		◁
NOA ◁	0.636	0.193	0.789	0.724	0.273	0.321	0.046			◁	◁
NOC ◁	0.303	0.511	0.829	143.882	3.935	1.047	0.045	◁	◁	◁	
NOD ◁	0.309	0.933	0.824	490.809	17.041	1.898	0.047	◁	◁	◁	
	Size										
NAIMP ◁	1.110	0.422	0.824	56.230	4.498	0.748	0.048		◁	◁	◁
NAINH ◁	1.181	0.187	0.835	4.101	0.986	0.334	0.035			◁	◁
LOC	28.779	4.959	0.846	10294.384	747.741	9.586	0.055	◁		◁	
NMIMP ◁	1.520	0.699	0.875	64.914	11.070	1.203	0.034	◁	◁	◁	◁
NMINH ◁	2.158	0.893	0.875	112.382	42.281	1.488	0.047			◁	◁

Results II: Other Regressions

- No confident logarithmic regressions to releases
- No confident linear/logarithmic regressions to LoD

Analysis

- No metrics showed relationships to LoD
- No metrics showed logarithmic fits to releases or LoD
  $\Longrightarrow$ we only look at linear relationships
- We relax the $p \leq 0.05$ rule in some cases

Analysis: Coupling

- ACAIC, ACMIC, and AMMIC:
  - all zeros
  - ancestors do not use descendents members
- DCAEC and DCMEC:
  - all zeros
  - converses of A**IC
- CBO and CBO':
  - strong metric
  - confident correlation and linear regression
  - $\Longrightarrow$ linear relationship, good!

Analysis: Coupling (con't)

- DAC and DAC':
  - correlation p-values were slightly too high
  - expected to increase over time along with NAIMP
- ICP:
  - no linear relationship
  - this metric has problems: parameters are always references in Java
- FCAEC. FCMEC, and FMMEC:
  - high correlation p-values, $near$ linear regressions
  - very few friend classes compared to all others

Analysis: Coupling (con't)

- IFCAIC, IFCMIC, and IFMMIC:
  - confident moderate correlations, confident regression for IFCAIC (others were just over)
  - many inverse friends (opposite of FC**EC)
  - have a linear relationship
- OCAEC, OMMEC, and OCMEC:
  - low correlations and no regressions
  - as time passes additional references are outside system

Analysis: Coupling (con't)

- OCMIC, OCAIC, and OMMIC:
  - only OMMIC had a valid regression
  - very close to IF**IC
- RFC_1:
  - confident correlation, no confident regression
- Conclusion:
  - many metrics showed linear relationships
  - this is good sign

Analysis: Cohesion

- Overall: No confident correlations or linear regressions
- $LCOM_1$: not correlated enough
- $LCOM_2$: always smaller than $LCOM_1$
- $LCOM_3$: similar behavior to $LCOM_1$ & $LCOM_2$, very different slope
- $LCOM_4$: similar to $LCOM_3$
- $LCOM_5$: smallest slope and correlation, constant over time

Analysis: Cohesion (con't)

- Coh: variant of $LCOM_5$
- ICH: suffered from same problems as ICP
- Conclusion: no confident correlations & regressions
  $\Longrightarrow$ no linear relationship

Analysis: Inheritance

- DIT and NOA:
  - confident high correlation, *slightly* high regression p-value
  - mostly stays constant, but changes on occasion

	DIT Difference				
System	**0**	**1**	**2**	**3**	**4**
`ant`	117	99	3	0	0
`htmlparser`	18	12	2	0	0
`tomcat`	417	108	0	0	0
`xalan`	673	116	12	1	1

  - most probably has a linear relationship

Analysis: Inheritance (con't)

- CLD:
  - confident correlation, $p = 0.051$, we accept that p-value
  - similar situation to DIT

	CLD Difference							
System	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
`ant`	202	7	6	0	3	1	0	0
`htmlparser`	30	1	1	0	0	0	0	0
`tomcat`	517	3	3	0	1	1	0	0
`xalan`	751	14	19	7	6	4	2	0

  - small slope of $0.032 \Longrightarrow$ slight increase over time

Analysis: Inheritance (con't)

- NOC:
  - *nearly* confident correlation, confident regression
  - small subset of classes keep adding children

	ant*Release*			
Category	**1.1**	**1.2**	**1.3**	**1.4**
# >= 60	0	0	0	1
# >= 50	0	0	1	0
# >= 40	0	1	0	1
# >= 30	0	0	1	0
# >= 20	1	1	1	2
# >= 10	1	1	1	0
# >= 4	2	1	7	10
# >= 3	1	2	1	0
# >= 2	2	1	11	14
# >= 1	4	13	13	10
# >= 0	63	111	206	209

  - there is a linear relationship

Analysis: Inheritance (con't)

- NOD:
  - similar to NOC
  - actually NOC+ indirect children

	Release			
Category	**1.1**	**1.2**	**1.3**	**1.4**
# >= 60	0	1	1	1
# >= 50	0	0	0	0
# >= 40	1	1	1	1
# >= 30	0	0	0	0
# >= 20	1	2	2	2
# >= 10	1	0	1	1
# >= 4	2	2	7	9
# >= 3	1	1	2	3
# >= 2	2	5	13	13
# >= 1	4	9	11	11
# >= 0	63	115	208	208

  - there is a linear relationship

Analysis: Inheritance (con't)

- NMO:
  - high correlation and regression p-values
  - could not find a connection to releases
- NMINH:
  - confident correlation and regression
  - related to NMIMP and DIT
  - slightly higher sloper than NMIMP
  - has a linear relationship

Analysis: Inheritance (con't)

- NAINH:
  - confident correlation and regression
  - related to NAIMP and DIT
  - slightly higher sloper than NAIMP
  - has a linear relationship
- NMA:
  - high correlation and regression p-values
  - no linear relationship

Analysis: Inheritance (con't)

- SIX:
  - high correlation and regression p-values
  - no linear relationship
- Conclusion:
  - five metrics showed linear relationships, two groups
    - members: NAINH and NMINH
    - family: NOA, NOC, and NOD
  - many $close$ relationships
  - yes, there is a linear relationship
  - though these metrics increase, it's only linear

Analysis: Size

- NMIMP:
  - confident correlation, *slightly* high regression p-value
  - a linear relationship
- NAIMP:
  - confident correlaton and regression
  - a linear regression
- NUMPAR:
  - neither confident correlation or regression
  - no linear relationship

Analysis: Size (con't)

- LOC:
  - confident correlation and regression
  - linear relationship (as expected for young projects)
- NC:
  - confident correlation, no confident regression
  - no linear relationship
- Conclusions:
  - three metrics with confident correlations and regressions
  - also NAINH and NMINH
  - there is a linear relationship

Analysis: LoD

- No confident correlation or regresion
- No linear relationship

Conclusions

- No logarithmic relationships
- Coupling, inheritance, and size were linearly related to releases
  - upheld our hypothesis
- No inverse relationship between cohesion and releases
  - rejected our hypothesis
- No relationship between any metrics and LoD
  - rejected our hypothesis on coupling
  - rejected our hypothesis on inheritance and size
  - cannot say whether or not LoD is a worthwhile programming idea

Conclusions (con't)

- Additional contributions
  - `DemeterCop`
  - `JavaPalm` metric finders

Future Work

- Different regression functions
- Different core units (other than classes)
- Use metrics from different categories
  - maintainability
  - complexity
- Try to quantify the *quality* of systems

Thanks.