

Defects Density

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Lecture #18 out of 24
80 minutes

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MICHAEL FAGAN

“Feedback of results from inspections must be counted for the programmer’s use and benefit: they should not under any circumstances be used for programmer performance appraisal.”

— Michael Fagan. Design and Code Inspections to Reduce Errors in Program Development. *IBM Systems Journal*, (3), 1976

Figure 8 Example of most error-prone modules based on I_1 and I_2

<i>Module name</i>	<i>Number of errors</i>	<i>Lines of code</i>	<i>Error density, Errors/K. Loc</i>
Echo	4	128	31
Zulu	10	323	31
Foxtrot	3	71	28
Alpha	7	264	27 ← Average
Lima	2	106	19 Error
Delta	3	195	15 Rate
⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮
	<u>67</u>		

Source: Michael Fagan. Design and Code Inspections to Reduce Errors in Program Development. *IBM Systems Journal*, (3), 1976

TABLE IX. Complexity and Error Rate for Errored Modules

Module Size	Average Cyclomatic Complexity	Errors/1000 Executable Lines
50	6.2	65.0
100	19.6	33.3
150	27.5	24.6
200	56.7	13.4
>200	77.5	9.7

“One surprising result was that module size did not account for error proneness. In fact, it was quite the contrary—the larger the module, the less error prone it was. This was true even though the larger modules were more complex.”

Source: Victor R. Basili and Barry T. Perricone. Software Errors and Complexity: An Empirical Investigation. *Communications of the ACM*, 27(1): 42–52, 1984



“A defect is a product anomaly. Examples include such things as 1) omissions and imperfections found during early life cycle phases and 2) faults contained in software sufficiently mature for test or operation.”

— IEEE Standards Board. IEEE Std 982.2-1988: Guide for the Use of IEEE Standard Dictionary of Measures to Produce Reliable Software, 1989

$$\begin{aligned} I &= 7 \\ KSLOD &= 8 \end{aligned}$$

Then,

$$\sum_{i=1}^7 D_i = 78 \text{ (total defects found)}$$

$$DD = \frac{78}{8} = 9.8 \text{ (estimated defect density)}$$

Source: IEEE Standards Board. IEEE Std 982.2-1988:
Guide for the Use of IEEE Standard Dictionary of
Measures to Produce Reliable Software, 1989

“This measure has a degree of indeterminism. For example, a low value may indicate either a good process and a good product or it may indicate a bad process. If the value is low compared to similar past projects, the inspection process should be examined. If the inspection process is found to be adequate, it should then be concluded that the development process has resulted in a relatively defect-free product.”

Measures (Experience)	Product Measures						Process Measures		
	Errors, Faults, Failures	Mean Time to Failure; Failure Rate	Reliability Growth & Projection	Remaining Product Faults	Completeness & Consistency	Complexity	Management Control	Coverage	Risk, Benefit, Cost Evaluation
1. Fault density (2)	X								
2. Defect density (3)	X								
3. Cumulative failure profile (1)	X								
4. Fault-days number (0)	X						X		
5. Functional or modular test coverage (1)					X			X	X
6. Cause and effect graphing (2)					X			X	
7. Requirements traceability (3)	X				X			X	
8. Defect indices (1)	X						X		
9. Error distribution(s) (1)							X		
10. Software maturity index (1)			X						X
11. Man hours per major defect detected (2)							X		X
12. Number of conflicting requirements (2)	X				X			X	
13. Number of entries/exists per module (1)					X	X			
14. Software science measures (3)				X		X			
15. Graph-theoretic complexity for architecture (1)						X			
16. Cyclomatic complexity (3)					X	X			
17. Minimal unit test case determination (2)					X	X			
18. Run reliability (2)			X						
19. Design structure (1)						X			
20. Mean time to discover the next K faults (3)									X
21. Software purity level (1)			X						
22. Estimated number of faults remaining (seeding) (2)				X					
23. Requirements compliance (1)	X				X			X	
24. Test coverage (2)					X			X	
25. Data or information flow complexity (1)						X			
26. Reliability growth function (2)			X						
27. Residual fault count (1)				X					
28. Failure analysis using elapsed time (3)			X	X					
29. Testing sufficiency (0)			X					X	
30. Mean-time-to-failure (3)		X	X						
31. Failure rate (3)		X							
32. Software documentation & source listings (2)					X				
33. RELY - (Required Software Reliability) (1)								X	X
34. Software release readiness (0)									X
35. Completeness (2)					X				
36. Test accuracy (1)				X	X			X	
37. System performance reliability (2)			X						
38. Independent process reliability (0)			X						
39. Combined HW/SW system operational availability (0)			X						

Table 4.1-1 — Measure Classification Matrix

Source: IEEE Standards Board. IEEE Std 982.2-1988: Guide for the Use of IEEE Standard Dictionary of Measures to Produce Reliable Software, 1989

39 Measures for Reliable Software

- | | | |
|--|---|---|
| 1. Fault Density | 14. Software Science Measures | 27. Residual Fault Count |
| 2. Defect Density | 15. Graph-Theoretic Complexity for Arch. | 28. Failure Analysis Using Elapsed Time |
| 3. Cumulative Failure Profile | 16. Cyclomatic Complexity | 29. Testing Sufficiency |
| 4. Fault-Days Number | 17. Minimal Unit Test Case Determination | 30. Mean Time to Failure |
| 5. Functional or Modular Test Coverage | 18. Run Reliability | 31. Failure Rate |
| 6. Cause and Effect Graphing | 19. Design Structure | 32. Software Docmnt and Source Listings |
| 7. Requirements Traceability | 20. Mean Time to Discover the Next K Faults | 33. RELY-Required Software Reliability |
| 8. Defect Indices | 21. Software Purity Level | 34. Software Release Readiness |
| 9. Error Distribution(s) | 22. Estimated Num. of Faults Remaining | 35. Completeness |
| 10. Software Maturity Index | 23. Requirements Compliance | 36. Test Accuracy |
| 11. Manhours per Major Defect Detected | 24. Test Coverage | 37. System Performance Reliability |
| 12. Number of Conflicting Requirements | 25. Data or Information Flow Complexity | 38. Independent Process Reliability |
| 13. Number of Entries and Exits per Module | 26. Reliability Growth Function | 39. Combined H&S Operational Availability |

Source: IEEE Standards Board. IEEE Std 982.2-1988: Guide for the Use of IEEE Standard Dictionary of Measures to Produce Reliable Software, 1989



HARLAN D. MILLS

“While our experience in applying statistical quality-control techniques to software development is limited, initial experience indicates that five fixes per thousand lines of code can be tolerated without invalidating the application of statistics to estimate MTTF. This failure rate is low compared to normal development practices, where 20 to 60 fixes per thousand lines of code is not atypical.”

— Richard H. Cobb and Harlan D. Mills. Engineering Software under Statistical Quality Control. *IEEE software*, 7(6):45–54, 1990



JOSEPH SHERIF

“The analysis showed a significantly higher density of defects during requirements inspections. It was also observed, that the defect densities found decreased exponentially as the work products approached the coding phase.”

— John C. Kelly, Joseph S. Sherif, and Jonathan Hops. An Analysis of Defect Densities Found During Software Inspections. *Journal of Systems and Software*, 17(2):111–117, 1992



VICTOR R. BASILI

“Five out of the six object-oriented metrics presented by Chidamber and Kemerer [1994] appear to be useful to predict class fault-proneness during the high- and low-level design phases of the life-cycle.”

— Victor R. Basili, Lionel C. Briand, and Walcélío L. Melo. A Validation of Object-Oriented Design Metrics as Quality Indicators. *IEEE Transactions on Software Engineering*, 22(10):751–761, 1996



NORMAN FENTON

“Our critical review of state-of-the-art of models for predicting software defects has shown that many methodological and theoretical mistakes have been made... We recommend holistic models for software defect prediction, using Bayesian Belief Networks, as alternative approaches to the single-issue models used at present.”

— Norman E. Fenton and Martin Neil. A Critique of Software Defect Prediction Models. *IEEE Transactions on Software Engineering*, 25(5):675–689, 1999

TABLE 4
DEFECTS DENSITY (F/KLOC) vs. MTTF

F/KLOC	MTTF
> 30	1 min
20–30	4-5 min
5–10	1 hr
2–5	several hours
1–2	24 hr
0.5–1	1 month

“This means we should be very wary of attempts to equate fault densities with failure rates, as proposed for example by Jones [1996]. Although highly attractive in principle, such a model does not stand up to empirical validation.”

Source: Norman E. Fenton and Martin Neil. A Critique of Software Defect Prediction Models. *IEEE Transactions on Software Engineering*, 25(5):675–689, 1999

TABLE 1
DEFECTS PER LIFE-CYCLE PHASE PREDICTION
USING TESTING METRICS

Defect Origins	Defects per Function Point
Requirements	1.00
Design	1.25
Coding	1.75
Documentation	0.60
Bad fixes	0.40
Total	5.00

“We already see defect density defined in terms of defects per function point, and empirical studies are emerging that seem likely to be the basis for predictive models. For example, Jones [1991] reports the following bench-marking study, reportedly based on large amounts of data from different commercial sources.”

Source: Norman E. Fenton and Martin Neil. A Critique of Software Defect Prediction Models. *IEEE Transactions on Software Engineering*, 25(5):675–689, 1999



STEVE McCONNELL

“Industry average experience is about 1-25 errors per 1000 lines of code for delivered software. Cases that have one-tenth as many errors as this are rare; cases that have 10 times more tend not to be reported. (They probably aren’t ever completed!) Microsoft experiences about 10–20 defects per 1000 lines of code during in-house testing and 0.5 defects per 1000 lines of code in released product.”

— Steve McConnell. *Code Complete*. Pearson Education, 2004



PARASTOO MOHAGHEGHI

“The analysis showed that reused components have lower defect-density than non-reused ones. Reused components have more defects with highest severity than the total distribution, but less defects after delivery.”

— Parastoo Mohagheghi, Reidar Conradi, Ole M. Killi, and Henrik Schwarz. An Empirical Study of Software Reuse vs. Defect-Density and Stability. In *Proceedings of the 26th International Conference on Software Engineering*, pages 282–291. IEEE, 2004



NACHIAPPAN NAGAPPAN

“A case study performed on Windows Server 2003 indicates the validity of the relative code churn measures as early indicators of system defect density. Our code churn metric suite is able to discriminate between fault and not fault-prone binaries with an accuracy of 89%.”

— Nachiappan Nagappan and Thomas Ball. Use of Relative Code Churn Measures to Predict System Defect Density. In *Proceedings of the 27th International Conference on Software Engineering*, pages 284–292, 2005b



THOMAS BALL

“Our results show that the static analysis defect density is correlated at statistically significant levels to the pre-release defect density determined by various testing activities. Further, the static analysis defect density can be used to predict the pre-release defect density with a high degree of sensitivity.”

— Nachiappan Nagappan and Thomas Ball. Static Analysis Tools as Early Indicators of Pre-release Defect Density. In *Proceedings of the 27th International Conference on Software Engineering*, pages 580–586, 2005a



A GÜNEŞ KORU

“We studied four large-scale object-oriented products, Mozilla, Cn3d, JBoss, and Eclipse. We observed that defect proneness increased as class size increased, but at a slower rate; smaller classes were proportionally more problematic than larger classes.”

— A Güneş Koru, Dongsong Zhang, Khaled El Emam, and Hongfang Liu. An Investigation into the Functional Form of the Size-Defect Relationship for Software Modules. *IEEE Transactions on Software Engineering*, 35(2):293–304, 2008



KAZUHIRO YAMASHITA

“Although we found some support for findings in recent literature that smaller files have higher defects density, we found further evidence that very large or complex files have lower defect densities and in some cases even lower defect proneness. Our findings have immediate practical implications: the redistribution of Java code into smaller and less complex files may be counterproductive.”

— Kazuhiro Yamashita, Changyun Huang, Meiyappan Nagappan, Yasutaka Kamei, Audris Mockus, Ahmed E. Hassan, and Naoyasu Ubayashi. Thresholds for Size and Complexity Metrics: A Case Study from the Perspective of Defect Density. In *Proceedings of the International Conference on Software Quality, Reliability and Security (QRS)*, pages 191–201. IEEE, 2016

100+ Metrics that Predict Faults

- | | | | | |
|---|--|-------------------------------------|--|--|
| 1. AHF Attribute Hiding Factor | 11. DAM Data Access Metric | 20. TCC Tight class cohesion | 38. OMMEC | 51. NOC Number of children |
| 2. AIF Attribute Inheritance Factor | 12. DCC Direct Class Coupling | 21. ACAIC | 39. OMMIC | 52. NTM Number of trivial methods |
| 3. COF Coupling Factor | 13. DSC Design size in classes | 22. ACMIC | 40. ATTRIB Attributes | 53. RFC Response for a class |
| 4. MHF Method Hiding Factor | 14. MFA Measure of Functional Abstraction | 23. AMMIC | 41. DELS Deletes | 54. WMC Weighted methods per class |
| 5. MIF Method Interface Factor | 15. MOA Measure of Aggregation | 24. Coh A variation on LCOM5 | 42. EVNT Events | 55. AMC Average method complexity |
| 6. POF Polymorphism Factor | 16. NOH Number of hierarchies | 25. DCAEC | 43. READS Reads | 56. Past faults Number of past faults |
| 7. SCC Similarity-based Class Cohesion | 17. NOM Number of Methods | 26. DCMEC | 44. RWD Read/write/deletes | 57. Changes Number of times a module has been changed |
| 8. ANA Average Number of Ancestors | 18. NOP Number of polymorphic methods | 27. DMMEC | 45. STATES States | 58. Age Age of a module |
| 9. CAM Cohesion Among Methods | 19. LCC Loose class cohesion | 28. FCAEC | 46. WRITES Writes | 59. Changeset Number of modules changed |
| 10. CIS Class Interface Size | | 29. FCMEC | 47. CBO Coupling between object classes | 60. N_1 Total number of operators |
| | | 30. FMMEC | 48. DIT Depth of inheritance tree | |
| | | 31. IFCAIC | 49. LCOM Lack of cohesion in methods | |
| | | 32. IFCMIC | 50. LCOM2 Lack of cohesion in methods | |
| | | 33. IFMMIC | | |
| | | 34. OCAEC | | |
| | | 35. OCAIC | | |
| | | 36. OCMEC | | |
| | | 37. OCMIC | | |

61. N_2 Total number of operands	70. ICH Information-flow-based cohesion	passing	86. NMI Number of methods inherited	94. SIX Specialization index
62. g_1 Number of unique operators	71. ICP Information-flow-based coupling	77. NAC Number of ancestor	87. NMO Number of methods overridden	95. C3 Conceptual cohesion of Classes
63. g_2 Number of unique operands	72. IH-ICP Information-flow-based inheritance coupling	78. NDC Number of descendent	88. NOA Number of attributes	96. McCabe Cyclomatic Complexity
64. AID Average inheritance depth of a class	73. NIH-ICP Information-flow-based non-inheritance coupling	79. NLM Number of local methods	89. NOAM Number of added methods	97. Delta Code delta
65. LCOM1 Lack of cohesion in methods	74. CMC Class method complexity	80. DAC Data abstraction coupling	90. NOO Number of operations	98. Churn Code churn
66. LCOM5 Lack of cohesion in methods	75. CTA Coupling through abstract data type	81. DAC1 Data abstraction coupling	91. NOOM Number of overridden methods	99. Devs Number of developers
67. Co Connectivity	76. CTM Coupling through message	82. MPC Message passing coupling	92. NOP Number of parents	100. CLD Class-to-leaf depth
68. LCOM3 Lack of cohesion in methods		83. NCM Number of class methods	93. NPAVG Average number of parameters per method	101. NOA Number of ancestors
69. LCOM4 Lack of cohesion in methods		84. NIM Number of instance methods		102. NOD Number of descendants
		85. NMA Number of methods added		103. LOC Lines of Code

Source: Danijel Radjenović, Marjan Heričko, Richard Torkar, and Aleš Živkovič. Software Fault Prediction Metrics: A Systematic Literature Review. *Information and Software Technology*, 55(8):1397–1418, 2013



XIAO YU

“The problem of predicting the precise number of defects via regression algorithms is far from being solved.”

— Xiao Yu, Jacky Keung, Yan Xiao, Shuo Feng, Fuyang Li, and Heng Dai.
Predicting the Precise Number of Software Defects: Are We There Yet?
Information and Software Technology, 146:106847, 2022

Table 1 The literature overview of the studies for predicting the numbers of defect.			
Study	Corpus/Number	Regression algorithms ^a	Performance measures
Ostrand [18] 2005	ISS/12	Negative Binomial Regression (NBR)	PoB
James [19] 2006	ISS/5	Poisson Regression (PR), NBR, Zero-Inflated Negative Binomial Regression (ZINBR)	Alberg diagrams
Gao [20] 2007	ISS/1	PR, Zero-Inflated Poisson Regression (ZIPR), NBR, ZINBR, Hurdle Poisson Regression (HPR)	AAE, ARE
Afzal [21] 2008	ISS/3	Genetic Programming (GP)	Pred(I), MMRE, Spearman
Yu [22] 2012	PROMISE/5	NBR	Accuracy, Precision, Recall
Wang [15] 2012	Bugzilla and Jira/6	BugStates	Absolute Error (AE), Mean Absolute Error (MAE)
Rathore [23] 2015	PROMISE/10	Neural Network Regression (NNR), Genetic Programming (GP)	ARE, Recall, Completeness
Rathore [24] 2015	PROMISE/10	GP	ARE, Recall, Completeness
Chen [25] 2015	PROMISE/26	Linear Regression (LR), Bayesian Ridge Regression (BRR), Support Vector Regression (SVR), Nearest Neighbors Regression (NNR), Decision Tree Regression (DTR), Gradient Boosting Regression (GBR)	Precision, RMSE
Rathore [26] 2016	PROMISE/18	DTR	AAE, ARE, Pred(I)
Rathore [27] 2016	Eclipse/3	(Bagging/Boosting/Random subspace/Rotation Forest/Stacking)+(LR/Multilayer Perceptron Regression (MPR)/DTR)	AAE, ARE
Rathore [28] 2017	Firefox/3	NBR, ZIPR, MPR, GP, DTR, LR	AAE, ARE, Pred(I), Completeness
Rathore [29] 2017	PROMISE/11	Linear Regression based Combination Rule (LBCR), Gradient Boosting based Combination Rule (GBCR), MPR, GP, LR, NBR, ZIPR	AAE, ARE, Pred(I), Completeness
Rathore [30] 2017	PROMISE and Eclipse/17	Error Rate based Weighted Average (ERWA) combination rule, Linear Regression based Weighted Average (LRWA) combination rule, Decision Tree Forest based (DTF) ensemble method, Gradient Boosting Regression (GBR) based ensemble method, LR, MPR, DTR, GP, NBR, ZIPR	AAE, ARE, Pred(I), Completeness
Yu [31] 2017	PROMISE/22	(SMOTER/RUS/AdaBoost.R2)+(DTR/BRR/LR), SmoteNDBoost, RusNDBoost	FPA, Kendall
Zhang [14] 2018	Firefox/7	Sample entropy-Support Vector Regression (SSVR), Auto-Regressive Integrated Moving Average (ARIMA) model, X12-ARIMA model, NNR	Magnitude of Relative Error (MRE), MMRE
Wu [32] 2018	PROMISE/31	BRR, DTR, GBR, LR, NNR, MPR, and SVR	FPA
Rathore [33] 2019	PROMISE and Eclipse/19	A dynamic selection algorithm (DynSelection), LR, MPR, DTR, GP, NBR, ZIPR	AAE, ARE, Pred(I), Precision, Recall, F-measure
Chen [34] 2019	PROMISE/24	(SMOTER/SMOTUNED/AdaBoost.R2)+(DTR/BRR/LR)	FPA, Kendall
Huang [35] 2019	PROMISE/30	Multi-Project Regression (MPR), LR, NNR, SVR, DTR, BRR, GBR	AAE, ARE
Nevendra [36] 2019	PROMISE/15	AdaBoost.R2+(Extra Tree Regression (ETR)/Random Forest Regression (RFR)/Extreme Gradient Boosting Regression (EGBR)/GBR)	MAE, MRE
Qiao [17] 2020	PROMISE and ISS/2	Deep Learning Neural Network (DPNN), SVR, DTR, Fuzzy Support Vector Regression (FSVR), RFR	Mean Squared Error (MSE), R ²
Bai [37] 2020	PROMISE/26	Weighted Regularization Extreme Learning Machine (WR-ELM), Weighted Extreme Learning Machine (WELM), ELM, SmoteR+(ELM/SVR/NBR)	AAE, ARE, Pred(I)
Tong [38] 2021	PROMISE/27	Subspace Hybrid Sampling Ensemble (SHSE), SmoteR, SmoteRDE, DynSelection, SmoteNDBoost, RusNDBoost	FPA, Kendall, RMSE

^a(Bagging/Boosting/Random subspace/Rotation Forest/Stacking)+(LR/MPR/DTR) represents that the five ensemble learning methods (Bagging, Boosting, Random subspace, Rotation Forest, and Stacking) use LR, MPR, and DTR as the base learners. It is the same below.

Source: Xiao Yu, Jacky Keung, Yan Xiao, Shuo Feng, Fuyang Li, and Heng Dai. Predicting the Precise Number of Software Defects: Are We There Yet? *Information and Software Technology*, 146:106847, 2022

“Software testers want to not only know which software modules should be inspected first, but also evaluate the reliability and maintenance effort of each module. Therefore, they can first employ the historical data to construct a Defect Number Prediction (DNP) model, then use the two trained models to predict the defective-proneness or the number of defects.”

My Own Statistics (2 Feb 2024)

Github Repository	Stack	KLoC	Issues	I/KLoC
zerocracy/farm	Java	58	2343	40.4
objectionary/eo	Java	49	2837	57.9
yegor256/cactoos	Java	34	1707	50.2
yegor256/takes	Java	27	1227	45.4
zold-io/zold	Ruby	12	810	67.5
yegor256/tacit	CSS	1	227	227.0

All repositories are open source.

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