



Developing Fault Models for Space Mission Software

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Outline

- Goal
- Measurement Requirements
 - ◆ Measuring Structural Evolution
 - ◆ Identifying and Counting Faults
- Modeling Fault Content
- Current and Future Work
- Discussion and Conclusions
- References and Further Reading



Goal: Improve Understanding of Fault Generation Process

- Look for relationships between:
 - ◆ Measurements of a system's structure.
 - ◆ Number of faults inserted during development.
- Recent work
 - ◆ Classification Methods
 - Classification Trees [Ghok97]
 - Regression Trees [Khos01a]
 - ◆ Discriminant Functions
 - Boolean Discriminant Functions [Schn97]
 - Relative Critical Value Deviation [Schn01a]
 - ◆ Regression Modeling
 - Zero-inflated Poisson Regression [Khos01]
 - Logistic Regression [Schn01]
 - ◆ Limitation – these efforts look at the system at a particular moment in time
 - May limit validity of results at other points during development effort



Goal: Improve Understanding of Fault Generation Process (cont'd)

- Analyzing SW Evolution
 - ◆ Examines entire developmental history of a SW system
 - ◆ Conclusions valid over entire development interval analyzed
 - ◆ Measurement requirements
 - ✦ Quantifiable notion of software evolution
 - ✦ Quantitative definition of software fault



Required Measurement Characteristics

- Measurement mechanisms must have the following characteristics:
 - ◆ Satisfy representation condition [Fen97]
 - ◆ Produce accurate, repeatable, consistent measurements
 - ◆ Measurements of artifacts, fault counts, development process made at same level of detail
 - ◆ Perceived benefit of making measurements must exceed cost of making them



Measuring Structural Evolution

Measure change activity between successive versions of the system.

Granularity Issues

- ◆ Structural evolution is measured at the module level
- ◆ Every version of every module is measured.
- ◆ Changes between subsequent versions of a module are measured with respect to a chosen *baseline*.

Distinct sources of variation identified with Principal Components Analysis (PCA) [Dill84]

Measurements are performed automatically outside of the development environment

- ◆ Minimize impact of measurement activities on developers.
- ◆ Relies on read access to CM repository.
- ◆ Accomplished with Darwin network appliance [Cyla03].



Module Attributes

Metric	Definition
Exec	Number of executable statements
NonExec	Number of non-executable statements
N_1	Total operator count
η_1	Unique operator count
N_2	Total operand count
η_2	Unique operand count
Nodes	Number of nodes in the module control flow graph
Edges	Number of edges in the module control flow graph
Paths	Number of paths in the module control flow graph
MaxPath	The length of the path with the maximum edges
AvePath	The average length of the paths in the module control flow graph
Cycles	Total number of cycles in the module control flow graph

Standardized definitions were developed for each measurement – see [Cyla03] 7



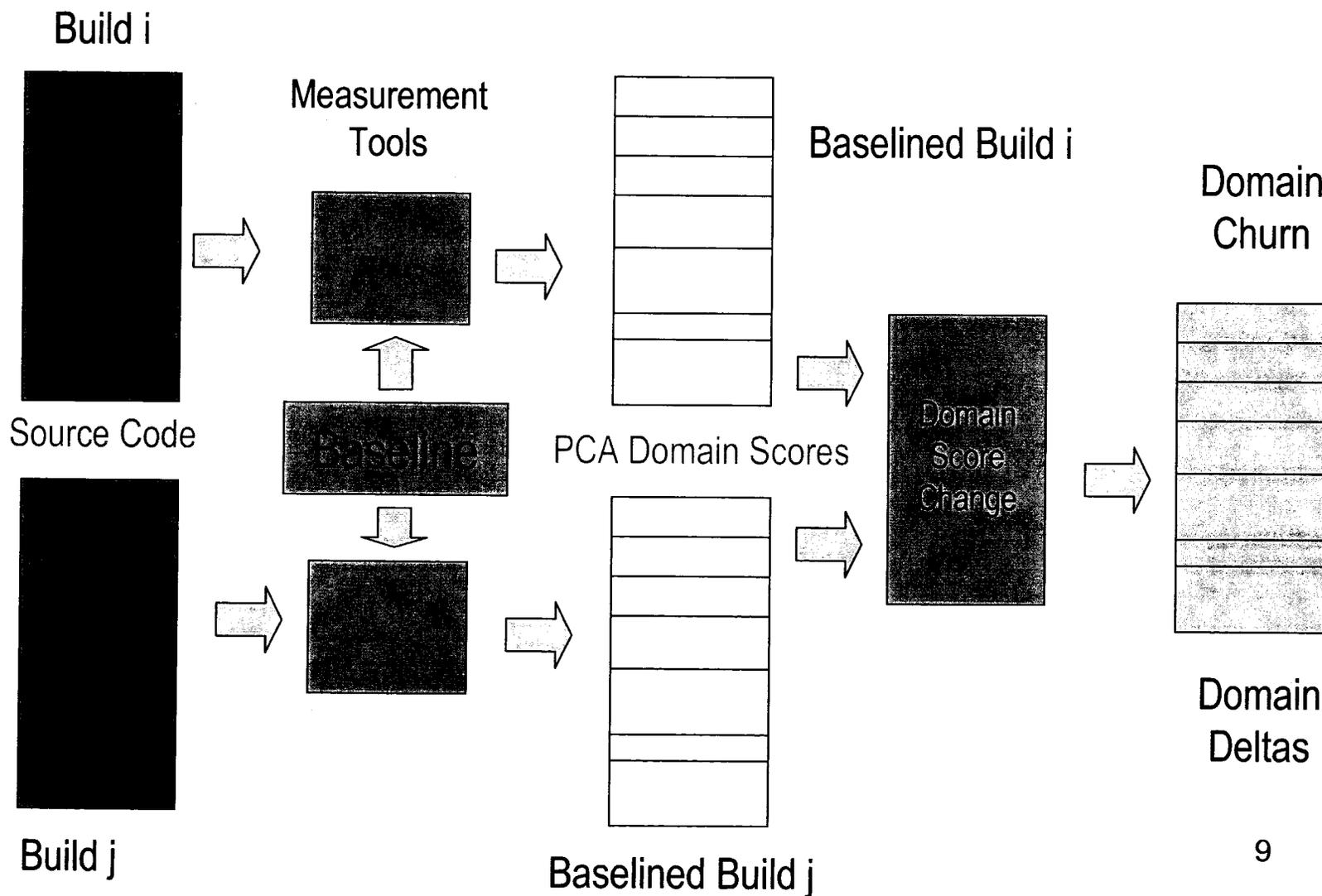
Principal Components of Raw Metrics

Metric	Domain		
	1	2	3
Exec	.60	.49	.47
NonExec	.64	.53	.18
N_1	.28	.64	.65
η_1	.49	.70	.07
N_2	.28	.64	.65
η_2	.35	.90	.04
Nodes	.87	.31	.27
Edges	.88	.31	.27
Paths	.17	-.10	.89
MaxPath	.87	.35	.29
AvePath	.86	.34	.33
Cycles	.67	.22	-.02
Eigenvalues	4.79	3.13	2.24

Measurement domains resulting from PCA

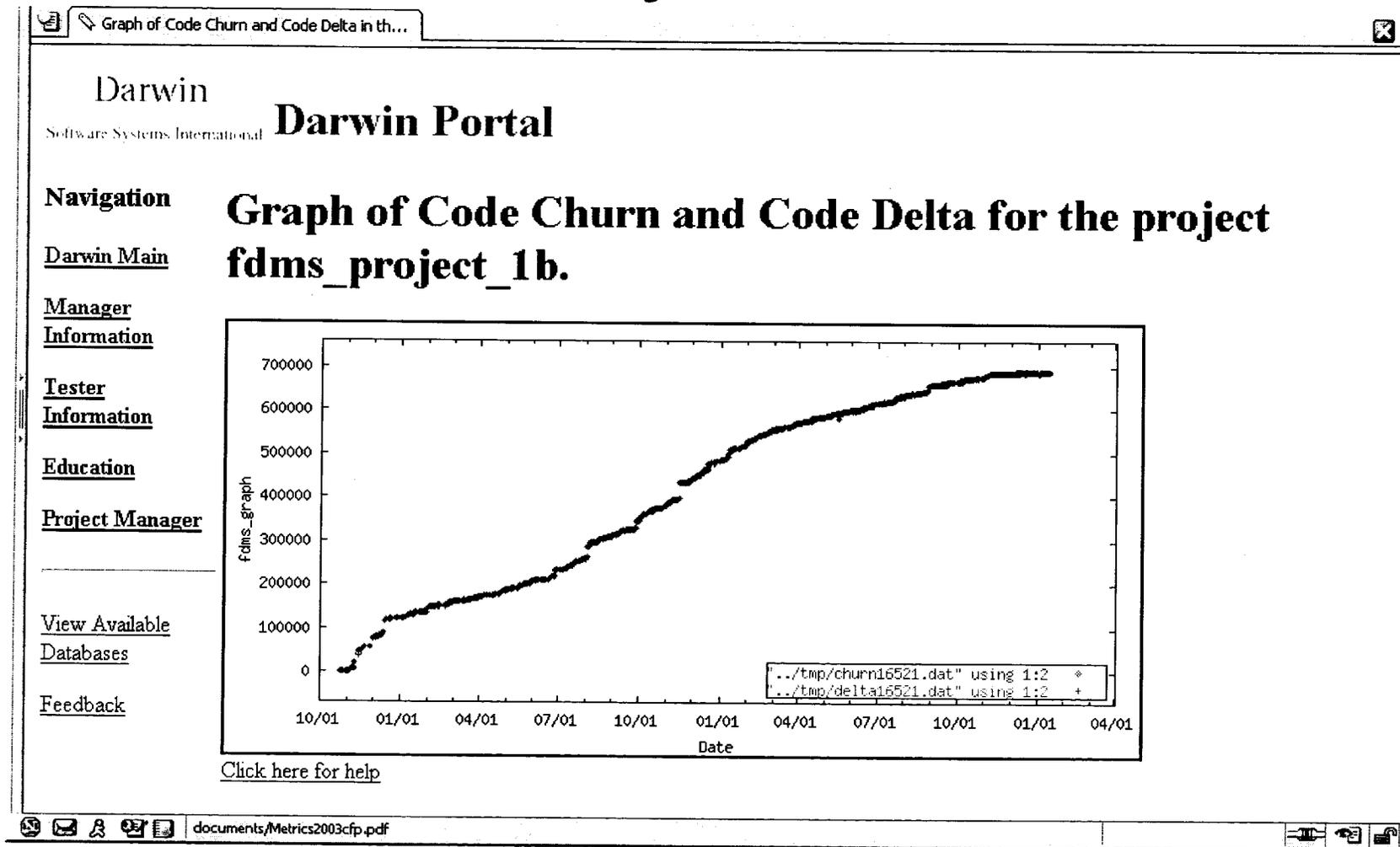


The Measurement Process





View of Structural Evolution at the System Level





View of Structural Evolution at the Module Level

(Non-zero) Modules for build 2001-11-02 of project project_1b, sorted by Churn since baseline.

Modulename	Churn From Baseline
doContent(XML_Parser parser, int startTagLevel, const ENCODING *enc, const char *s, const char *end, const char **nextPtr)	329.523165
doProlog(XML_Parser parser, const ENCODING *enc, const char *s, const char *end, int tok, const char *next, const char **nextPtr)	311.585820
examples()	309.099387
processMeasurementAndPredict(const Mds:Fw:Time:Tmgt:REepoch& current, const Mds:Fw:Time:Tmgt:REepoch& stop)	289.353008
test2s()	279.141671
TestDiscrete::TestDiscrete()	260.394345
TestIntervallc::TestIntervallc()	256.865234
storeAtts(XML_Parser parser, const ENCODING *enc, const char *attStr, TAG_NAME *tagNamePtr, BINDING **bindingsPtr)	240.951958
GreaseFilterTest(Dispatch& r, const std::string& key, const CGLArgs& args)	240.699311
doTest()	237.752957
PositionEstimateFunctionTest(Dispatch& r, const std::string& key, const CGLArgs& args)	223.900440
DirectedGraph::close()	214.416659
SimpleNormalPositionEstimatorTraits::Thread::updateStateVariables(const Mds:Fw:Time:Tmgt:REepoch& start, const Mds:Fw:Time:Tmgt:REepoch& stop, const Mds:Fw:Filter:Grease::GreaseBasis& state, const Mds:Fw:Filter:Grease::GreaseBasis& covariance, const Mds:Rd:Mars::Common::SimpleAirDragModel:AirDragModelParameterType& air_drag_model_para, double spacecraft_mass, double avg_engine_thrust)	204.313726
AirDragModelParameterEstimatorTraits::Thread::predictState()	203.781925
ParachuteEstimatorTraits::Thread::predictState()	195.118089
SimpleNormalPositionEstimatorTraits::Thread::changed(const Mds:Fw:Cmp:RefCountComponentInstance monitored_sv, Mds:Fw:Dm:Vhis::ConstItemVectorRef changedItems)	182.312589
PREFIX(prologTok)	175.659645
LengthTest(Dispatch& r, const std::string& key, const CGLArgs& args)	165.230353
vzmain(int ctor, const char* argList)	164.506422
GoalNetTestHarness::createXGoalNet(Dispatch& r, const std::string& key, const CGLArgs& args)	163.479793
vzmain_internal(const char* argList)	162.467209

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Identifying and Counting Faults

- Accurate software fault prediction depends on precise, measurable definition of a fault
- Until 2002, no definition of fault in measurable terms
 - ◆ IEEE Standards
 - ✦ IEEE Std 729-1983, “IEEE Standard Glossary of Software Engineering Terminology” [IEEE83]
 - ✦ IEEE Std 982.1-1988, “IEEE Standard Dictionary of Measures to Produce Reliable Software” [IEEE88]
 - ✦ IEEE Std 1044-1993, “IEEE Standard Classification for Software Anomalies” [IEEE99]
 - ◆ ODC [Chil92]
 - ◆ Previous work (Annual Oregon Workshop on Software Metrics, May 11-13, 1997) [Niko97]



Fault Enumeration

- Examine changes made in response to reported failures
- Base recognition/enumeration of software faults on the grammar of the software system's language
- Fault measurement granularity in terms of tokens that have changed [Muns02]



Fault Enumeration (cont'd)

- Consider each line of text in each version of the program as a bag of tokens
 - ◆ If a change spans multiple lines of code, all lines for the change are included in the same bag
- Number of faults based on bag differences between
 - ◆ Version of program exhibiting failures
 - ◆ Version of program modified in response to failures
- Use version control system to distinguish between
 - ◆ Changes due to repair and
 - ◆ Changes due to functionality enhancements and other non-repair changes



Fault Enumeration: Example

Example 1

- ◆ Original statement: $a = b + c;$
 - ◆ $B_1 = \{ \langle a \rangle, \langle = \rangle, \langle b \rangle, \langle + \rangle, \langle c \rangle \}$
- ◆ Modified statement: $a = b - c;$
 - ◆ $B_2 = \{ \langle a \rangle, \langle = \rangle, \langle b \rangle, \langle - \rangle, \langle c \rangle \}$
- ◆ $B_1 - B_2 = \{ \langle + \rangle, \langle - \rangle \}$
- ◆ $|B_1| = |B_2|, |B_1 - B_2| = 2$
- ◆ One token has changed \Rightarrow 1 fault



Fault Enumeration: Example

Example 2

- ◆ Original statement: $a = b - c$;
 $B_3 = \{ \langle a \rangle, \langle = \rangle, \langle c \rangle, \langle - \rangle, \langle b \rangle \}$
- ◆ Modified statement: $a = 1 + c - b$;
 $B_4 = \{ \langle a \rangle, \langle = \rangle, \langle 1 \rangle, \langle + \rangle, \langle c \rangle, \langle - \rangle, \langle b \rangle \}$
- ◆ $B_3 - B_4 = \{ \langle 1 \rangle, \langle + \rangle \}$
- ◆ $|B_3| = 6$, $|B_4| = 8$, $|B_4| - |B_3| = 2$
- ◆ 2 new tokens representing 2 faults



Modeling Fault Content

- Fault models developed from:
 - ◆ Measured structural evolution (cumulative amount of change for each module).
 - ◆ Number of faults repaired for each module.
- Analysis indicates that the amount of structural evolution is related to the number of faults repaired [Niko03].



Modeling Results

Regression ANOVA

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	10091546	3	3363848	293	P<.01
Residual	6430656	560	11483		
Total	16522203	563			

Regression Model

Model	Coefficients	t	Sig.
(Constant)	18.24	3.5	P<.01
Domain 1 Churn	21.63	17.3	P<.01
Domain 2 Churn	-.59	-.3	p>.01
Domain 3 Churn	.93	.7	p>.01

Quality of the Regression Model

	R	R Square	Adjusted R Square	Std. Error of the Estimate
Model Summary	.782	.611	.609	107.16024



Current and Future Work

- Determine whether the fault insertion rate changes over time
- Identify which types of faults correspond to which types of change.
- Expand the number of projects to obtain larger measurement baseline.
 - ◆ Collaborating with GSFC SATC to infuse measurement techniques
- Enlarge the set of structural measurements taken by network appliance (e.g., include CDK OO measures [Chid94]).
- Include effect of measurable development process characteristics in fault models
- Integrate measurement of system execution profile to estimate
 - ◆ Test effectiveness
 - ◆ Risk of exposure to residual faults



Current and Future Work (cont'd)

- Estimate amount of noise in fault counts
 - ◆ Not all changes associated with a PR may actually be repairs
 - ◆ “Pocket PRs”
 - Not a significant issue for this development effort because of how CM is set up and discipline of development team
 - May be issue for other efforts
 - ◆ Unequal test coverage – some components may be more heavily tested, finding more faults



Current and Future Work (cont'd)

- Resolve known fault counting inaccuracies
 - ◆ Example 1 – adding operators/operands
 - Original faulty statement: $a = b + c$;
 - Repaired statement: $a = b - c + d$;
 - Bag difference: $\{<->, <d>\}$
 - 3 tokens added or changed, however
 - ◆ Example 2 – token reordering
 - Original faulty statement: $a = b - c$;
 - Repaired statement: $a = c - b$;
 - Bag difference: $\{\}$
 - Number of reordered tokens cannot be accurately determined
- Develop training materials for practitioners
 - ◆ Measurement user's guide
 - ◆ Measurement tutorials



Discussion and Conclusions

- At least for the data with which we have worked, a software component's fault burden is related to the measured amount of change during its development.
- Practical techniques for measuring structural evolution and the number of repaired faults have been developed and are available for use on "real" development efforts.
 - ◆ Allows development of fault models that can provide additional information to help decide where to deploy fault identification and repair resources (e.g., test staff, additional inspections).



References and Further Reading

- [Chil92] R. Chillarege, I. Bhandari, J. Chaar, M. Halliday, D. Moebus, B. Ray, M.-Y. Wong, "Orthogonal Defect Classification - A Concept for In-Process Measurement", IEEE Transactions on Software Engineering, November, 1992, pp. 943-946.
- [Cede93] Per Cederqvist, "Version Management with CVS for CVS 1.11.1p1", available at <http://www.cvshome.org/docs/manual/>
- [Chid94] S. Chidamber, C. Kemerer, "A Metrics Suite for Object Oriented Design", IEEE Transactions on Software Engineering, vol. 20, no. 6, June, 1994, pp. 476-493.
- [Cyla03] "The Darwin Software Engineering Measurement Appliance", Cylant, <http://www.cylant.com/>
- [Dill84] William R. Dillon, Matthew Goldstein, Multivariate Analysis: Methods and Applications, Wiley-Interscience, August 1984, ISBN: 0471083178
- [Dvo99] D. Dvorak, R. Rasmussen, G. Reeves, A. Sacks, "Software Architecture Themes In JPL's Mission Data System", AIAA Space Technology Conference and Exposition, September 28-30, 1999, Albuquerque, NM.
- [Fen97] Norman E. Fenton, Shari Lawrence Pfleeger; Software Metrics: A Rigorous and Practical Approach (2nd ed.), 1997, PWS Publishing Company, Boston, MA, ISBN 0534954251
- [Ghok97] S. S. Gokhale, M. R. Lyu, "Regression Tree Modeling for the Prediction of Software Quality", proceedings of the Third ISSAT International Conference on Reliability and Quality in Design, pp 31-36, Anaheim, CA, March 12-14, 1997
- [IEEE83] "IEEE Standard Glossary of Software Engineering Terminology", IEEE Std 729-1983, Institute of Electrical and Electronics Engineers, 1983.



References and Further Reading (cont'd)



- [IEEE88] "IEEE Standard Dictionary of Measures to Produce Reliable Software", IEEE Std 982.1-1988, Institute of Electrical and Electronics Engineers, 1989.
- [IEEE93] "IEEE Standard Classification for Software Anomalies", IEEE Std 1044-1993, Institute of Electrical and Electronics Engineers, 1994.
- [Khos01] T. Khoshgoftaar, "An Application of Zero-Inflated Poisson Regression for Software Fault Prediction", proceedings of the 12th International Symposium on Software Reliability Engineering, pp 66-73, Hong Kong, Nov, 2001.
- [Khos01a] T. M. Khoshgoftaar, E. B. Allen, "Modeling Software Quality with Classification Trees", in H. Pham (ed), Recent Advances in Reliability and Quality Engineering, Chapter 15, pp 247-270, World Scientific Publishing, Singapore, 2001.
- [Muns90] J. C. Munson and T. M. Khoshgoftaar, "Regression Modeling of Software Quality," Information and Software Technology, Vol. 32 No. 2 March 1990, pp. 105-114.
- [Muns98] J. Munson and A. Nikora, "Estimating Rates Of Fault Insertion And Test Effectiveness In Software Systems" Proceedings of the Fourth ISSAT International Conference on Reliability and Quality in Design, August 12-14, 1998 pp. 263-269.
- [Muns02] J. Munson, A. Nikora, "Toward a Quantifiable Definition of Software Faults", Proceedings of the 13th IEEE International Symposium on Software Reliability Engineering, IEEE Press.
- [Muns03] J. Munson, Software Engineering Measurement, CRC Press, 2003, ISBN 0849315034 .
- [Niko97] A. Nikora, J. Munson, "Finding Fault with Faults: A Case Study", with J. Munson, proceedings of the Annual Oregon Workshop on Software Metrics, Coeur d'Alene, ID, May 11-13, 1997.



References and Further Reading (cont'd)



- [Niko98] A. P. Nikora, J. C. Munson, "Determining Fault Insertion Rates For Evolving Software Systems", proceedings of the 1998 IEEE International Symposium of Software Reliability Engineering, Paderborn, Germany, November 1998, IEEE Computer Society Press.
- [Niko01] A. Nikora, J. Munson, "A Practical Software Fault Measurement and Estimation Framework", Industrial Presentations proceedings of the 12th International Symposium on Software Reliability Engineering, Hong Kong, Nov 27-30, 2001.
- [Niko03] A. Nikora, J. Munson, "Developing Fault Predictors for Evolving Software Systems", to appear in the proceedings of the 9th International Symposium on Software Metrics (Metircs2003), Sydney, Australia, Sep 3-5, 2003
- [Niko03a] A. Nikora, J. Munson, "Understanding the Nature of Software Evolution", to appear in the proceedings of the International Conference on Software Maintenance, September 22-26, 2003, Amsterdam, The Netherlands
- [Schn97] N. F. Schneidewind, "Software Metrics Model for Integrating Quality Control and Prediction", proceedings of the 8th International Symposium on Software Reliability Engineering, pp 402-415, Albuquerque, NM, Nov, 1997.
- [Schn01] N. F. Schneidewind, "Investigation of Logistic Regression as a Discriminant of Software Quality", proceedings of the 7th International Software Metrics Symposium, pp 328-337, London, April, 2001.
- [Schn01a] N. F. Schneidewind, A. P. Nikora, "Predicting Deviations in Software Quality by Using Relative Critical Value Deviation Metrics". proceedings of the 10th International Symposium on Software Reliability Engineering, pp 136-146, Boca Raton, FL, Nov 1-4, 1999