FEAST/1 Final Report - Grant Number GR/K86008

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**Background**: The project was conceived in 1994 following formulation of a FEAST hypothesis. This stated that the software evolution process is a feedback system and must be treated as such to achieve major process improvement. Three self-funding international workshops were held at IC [fea94,5] to explore the hypothesis, with some 40 participants from the UK, Europe and North America at each. Following successful interchanges and constructive criticism, the FEAST/1 proposal was prepared and submitted to EPSRC [leh96a] and was subsequently awarded under grant GR/K86008.

The project started in October 1996 with two research associates (Dr Paul Wernick and Mr Juan Fernandez-Ramil) and a part time secretary, under the general direction of the principal investigator Prof. M M Lehman. The project also benefited significantly from the active involvement of Professor W M Turski of Warsaw University and Dr Dewayne Perry of Bell Labs - Lucent Technologies, who had previously met several times with the PI to explore the hypothesis. Recognising its potential significance, this core group prepared the workshops mentioned above. Thereafter, and, following award of successive EPSRC SVF grants, GR/L07437 and GR/L96561, Turski and Perry participated in preparing the FEAST/1 plan and, subsequently, in that project.

Industrial collaborators were Matra - BAe Dynamics, ICL High Performance Systems and Logica plc (Banking division) with Mr Dave Nuttall, Mr Brian Chatters and Mr Joe Halberstadt respectively as the principal contacts. As a result of Dr Perry's involvement in the project, Lucent Technologies became *de facto* collaborators. Many other individuals from these organisations, Mr Les Barker of BAe, in particular, also made important contributions through their interaction with the project team. As a result of management changes the MoD, though a sponsoring collaborator, withdrew the project that was to have been studied from FEAST/1 and failed to come up with an alternative. DERA remained with the project but preoccupation with other assignments severely restricted their active participation.

**Summary of Results**: As illustrated by the examples that follow FEAST/1 has been an overall and significant success in terms of both the goals and the specific objectives stated in the proposal.

The overall goals were to:

- i provide objective evidence of the presence and impact of feedback and systems dynamics in the software process
- ii demonstrate that they can be exploited for managing and improving industrial processes
- iii produce justification for more substantial study of the feedback perspective and its implications

Of these three, i and iii have been met. The results raise new questions and open up paths for further investigation. Confidence in the conclusions must be further strengthened, detail examined, the predictive precision of models monitored and improved as data becomes available. More precise identification of feedback mechanisms responsible for observed behaviour must be obtained. FEAST/2 [leh98c] will broaden and extend the FEAST/1 results along these lines. A summary report "Rules and Tools for Software Evolution Planning and Management", now in preparation, will show that goal ii has also been met in principle but that further work is required to achieve practical application. The study of feedback in the software process is innovative, pioneering and intrinsically difficult. There is little, if any, parallel work elsewhere and the present work represents a first step. Its refinement must follow.

Specific objectives were also identified:

- i provide models of the long term (multi-release) behaviour of industrial software processes and their products that are more extensive and precise than any hitherto available
- ii provide calibrated and validated SD models of development processes for individual systems
- iii use these models to expose feedback phenomena within such processes
- iv demonstrate the predictive capability of the models
- v identify process improvements suggested by the models and assess their practical impact
- vi demonstrate the need for further studies and define their nature

These objectives have also been largely achieved. The results are compatible with and supportive of earlier work [leh85]. In some areas they have gone beyond what was envisaged in the FEAST/1 proposal. For example, with minor modifications, the interpretations and generalisations achieved provide confirmation of the behaviour described by the laws of software evolution as formulated in the 70s and 80s [leh78,80], recently revised [leh96b,97b,98e]. Appendix 2 shows their current formulation [leh98f].

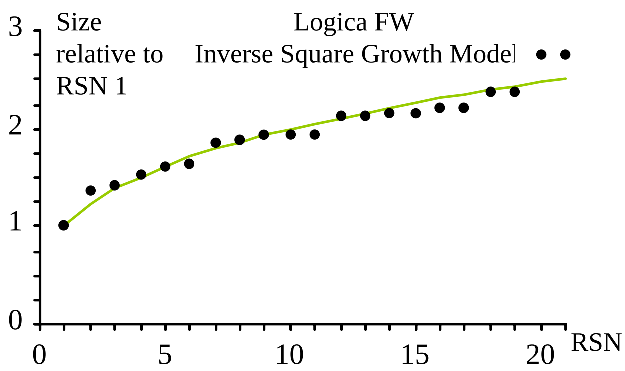
**Results - general remarks**: The output from the project falls into five categories. *Black box* models were derived from evolution data provided by the collaborators on four evolving systems. W*hite box, system dynamics* (SD), models were constructed on the basis of extensive discussions with the relevant collaborators. The third encompasses *interpretation* in behavioural terms of both black and white box models. The fourth comprises proposals for *techniques and tools* for practical application derived from the models and interpretations. Finally, the basis of a *theory* of software evolution and the software process is emerging from the team's developing insight into software evolution. The laws of software evolution [leh78,80] constitute an encapsulation of the current state of such a theory. Detailed discussion and the reasoning underlying them have been published over the years [eg. leh96b,97b,98b,e,f].

A short report such as this cannot possibly do justice to all that has been achieved in each of these categories. Instead, project output is exemplified by data plots and reference to some of the inferences that have been drawn from them. It provides a high level view of one aspect of the investigation. A fuller discussion and more complete descriptions of the data sets, models, interpretations and practical implications can be found in the listed publications. The list includes over forty reports and papers published since formulation of the hypothesis in 1994 and, more especially, project inception in 1996.

One further observation must be noted. Data on five software systems, a Matra-BAe weapons system, the ICL VME operating system kernel, the Logica FastWire (FW) system and two variants of a Lucent Technologies real time system were provided to the project. Moreover, a further five systems, starting with OS/360, were studied in the seventies, though not as extensively. The results from all these cannot be included and compared here. Brief scrutiny of the published material will confirm that, in general and at the level of detail provided, systems and behaviours shown here are a fair sample of the overall achievement. The totality of results support and reinforce one another. There are, of course, differences in detail. These are likely to relate, for example, to the different application areas addressed, different environments in which the systems are being evolved and different domains in which they operate. The FEAST/2 project, starting in March 1999 will, *inter alia*, refine the results and investigate this hypothesis.

**Results - examples**: Figure 1 shows the ***growth trend*** of two of the systems studied in FEAST/1. The abscissas constitute a pseudo time scale expressed in the *sequence number* (rsn) [cox66] of each release plotted. The ordinates provide a size scale expressed in modules. Considerations underlying the use of these metrics have been discussed elsewhere [cox66, leh85,97b,98e,f].

Despite occasional shrinkage, the continual growth trend is self evident from these plots and other available data. It therefore supports the first and sixth laws. From currently available metrics it has not been possible to separate out the specific support for each of these but the basic observation is indisputable. Also observable in each of the plots is the ripple that, when first observed in the OS/360 study, suggested that the growth process was self stabilising. This observation and its interpretation provided the first metric evidence for the feedback system nature of the software process [bel72].



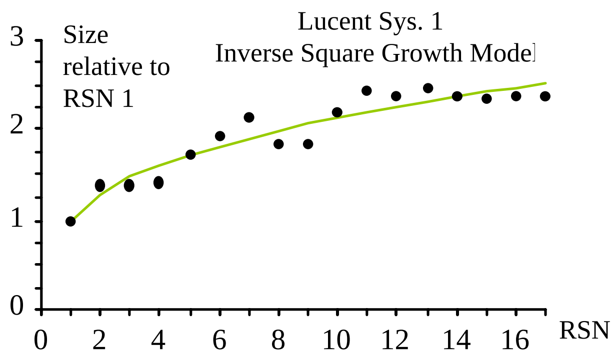




**Figure 1 Software System Growth Trends over Releases**

The plot of incremental growth per rsn (first difference of figure 1 data) as in figure 2, provides further support for the laws, clearly displaying the self stabilisation process. The growth in proceeding from release to release could be interpreted as reflecting management decision. Phenomenology and patterns suggest otherwise; that declines are, at least in part, a consequence of increments that exceed process capacity. Autocorrelation and runs tests appear to confirm that the observed patterns reflect a degree of serial correlation though the paucity of data makes significance difficult to establish. More refined tests are planned. It will be of particular interest to determine whether, as suggested in the fifth law, there exists some level of incremental growth, the threshold m + 2s (average growth plus twice standard deviation) used in statistical process control [wet91] for example, that indicates an upper bound on process capacity. When approached or exceeded this triggers a decline in growth rate. The small number of points in the available data sequences have not yet permitted accurate testing of this hypothesis.

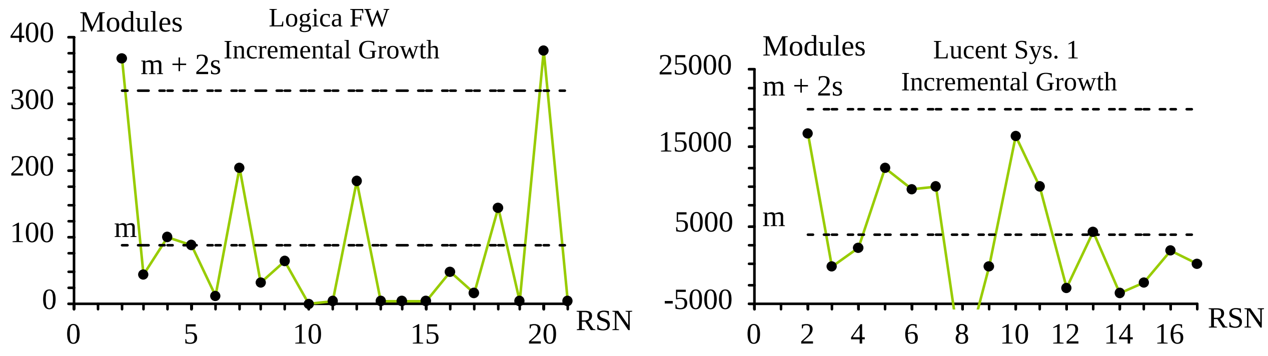



**Figure 2 Incremental Growth Over Releases**

The full lines in figure 1 illustrate an inverse square growth trend [tur96]. This has also been observed for the Lucent System 2. For the ICL system a two segment inverse square model yielded an improved fit. For OS/360 a linear fit proved more appropriate. A likely reason for this difference in behaviour and its consequences are discussed elsewhere [eg leh97b]. In summary, the common pattern observed in all the systems except OS/360, and the consequences of the deviation from that pattern in the latter case, suggest that the growth rate is constrained by increasing complexity. An inverse square trend has also been observed in the SD models of the Matra-BAe system though, as an *ab initio* development rather than evolution over successive releases, the domain is quite different.

Process behaviour implied by fig. 2 and corresponding plots of the other systems, strengthen confidence in the laws [leh98f]. The evidence is also fully compatible with the thesis that process dynamics plays a major role in determining the global evolution trend. For example *closeness of fit* tests of the models as predictors yield a mean absolute error expressed as a percentage of the size (%mae), that varies from 3.6% to 8% for the systems studied. The standard deviation of the %residuals varies from 4.8% to 11.4% [leh98b]. These results, consistent with feedback controlled growth, reflect an unexpectedly good fit for human managed processes. They indicate the presence of a strong deterministic component in the trends.

The presence and strength of the system dynamics can be deduced from the plots of figure 3. They show the %mae over successive releases expressed as the mean absolute difference between the recorded size measured in modules (or equivalent) and the size predicted by the inverse square (OS/360, linear) model as a percentage of the actual size, plotted as a function of the number of data points used to estimate the model parameter. Following an initial settling period of from 4 to 6 data points, the error is, to all intents and purposes, steady at around 5% and varies only slightly from system to system. The knee preceding the steady state is believed to reflect the settling time of the model estimation process. This essentially constant error suggests that the growth trend is primarily determined by the system dynamics [tur96].

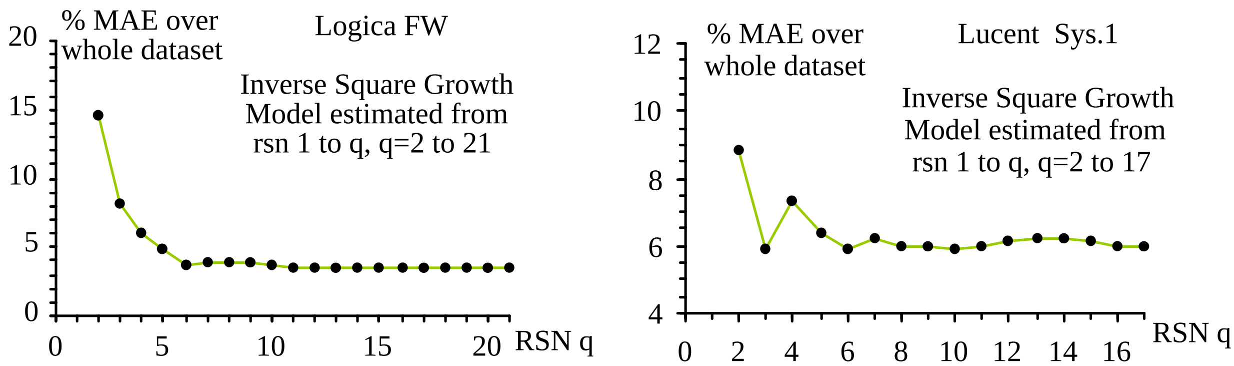



**Figure 3 The Strength of the Dynamics**

What determines the characteristics of that dynamic? Are they determined by the behaviour of the group responsible for each system's evolution? Do they reflect the organisational dynamics of the wider organisation within which the evolutionary process is conducted? Is it perhaps a still wider system that includes users of the system? Is it even wider? Does the observed dynamics reflect the evolution process of the system under investigation, the dynamics inherited from previous projects or from a corporate generic process? As an initial response to these questions %mae was computed for each system for data points beginning with rsn 1, 3, 5, 7 and 9 respectively. Figure 4 shows plots for the same systems.

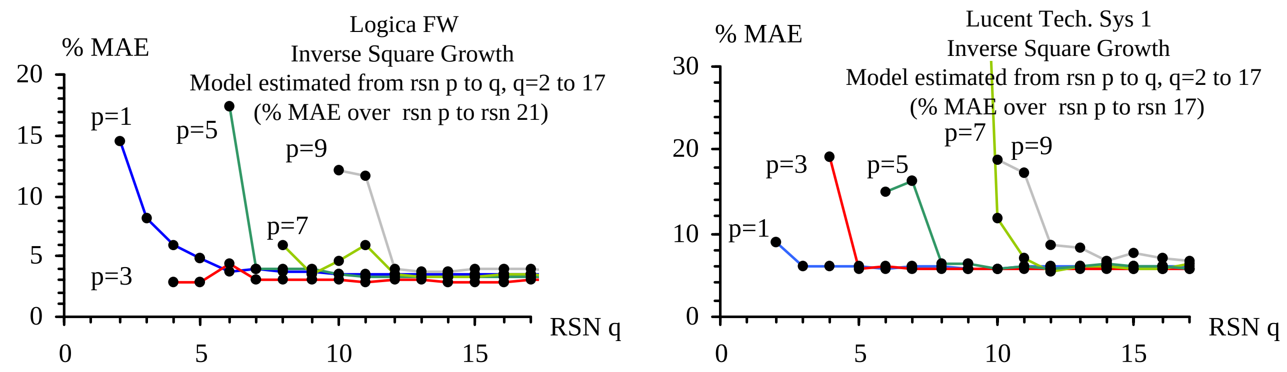



**Figure 4 Process-External Source of the Dynamics**

The choice of the initial element of the sequence used for model estimation clearly influences the settling behaviour of the %mae. But once settled, the %mae, and hence the predicted size, is independent of the subset and number of data points used to determine the model. This supports a conclusion reached by theoretical reasoning that the dynamics arises from sources largely outside the observed project. Its characteristics are dependent on factors outside the immediate technical evolution process. Confirmation by behavioural metrics is a most important result having major implications on approaches to software process improvement.

The black box analysis results obtained from the systems not illustrated here correspond to those shown. The conclusions reached are, therefore, likely to be widely applicable since it has also been possible to provide convincing phenomenological interpretations. With respect to the laws of software evolution as restated, six are directly supported by the black box analysis [leh97b,leh98b,e,f,g]. Law VII (appendix 2) is predicted by phenomenological analysis of the black box studies. Indications that support law IV have been obtained but are considered insufficient to provide either support or to disprove it. That law will be reconsidered if and when additional data is available. More detail on results obtained and conclusions reached are provided in the listed publications or will be included in future publications.

***System dynamics*** models of the evolution of VME and the Matra-BAe system have been developed in discussion with the respective organisations. One model of each system is shown in figure 5. Even these (by software process SD model standards) very simple models suggest new views of the respective processes. Their refinement and extension to identify global feedback mechanisms and controls, should provide potential for process improvement through new approaches to design, planning and control procedures. Detailed discussion of these and other models will be found in [leh98a,wer98,cha99]

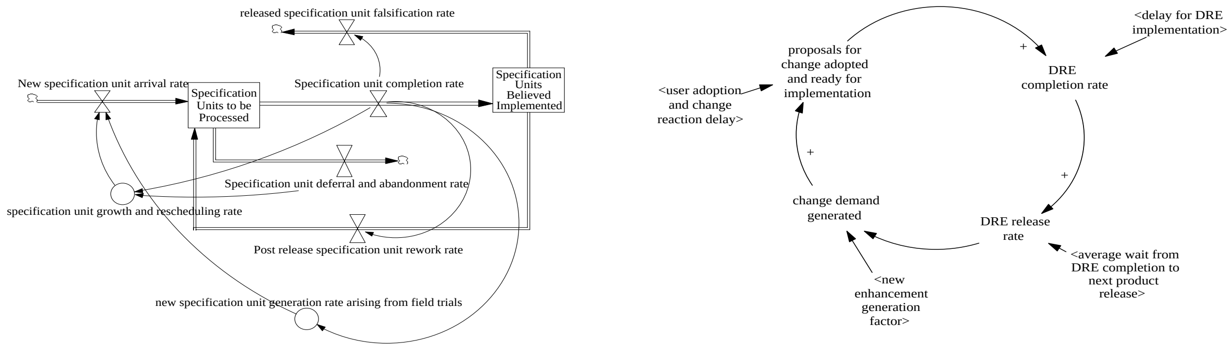



**Figure 5 System Dynamics Models of the Matra-BAe (left) and ICL (right) Systems**

The remarkable simplicity of the models is apparent. It is in stark contrast to the software process SD models reported in the literature [abd91] and reflects our conviction that broadly interpretable results can best be obtained from SD modelling of the software evolution process by a top down approach. One starts with the simplest of models that reflects some basic observation and proceeds with successive structural refinement and calibration to reproduce, when executed, the behaviour of the real world being studied [zur67,wer98]. Such elaboration procedures are to be applied in FEAST/2.

A key question to be asked about any SD model is the extent to which the result of model execution is a reflection of clever calibration and the extent to which it is an indication that model mechanisms reflect mechanisms of the real world process. This issue will be addressed in FEAST/2 for the current and future models. Meanwhile, figure 6 provides one illustration of an output for each of the figure 5 models.

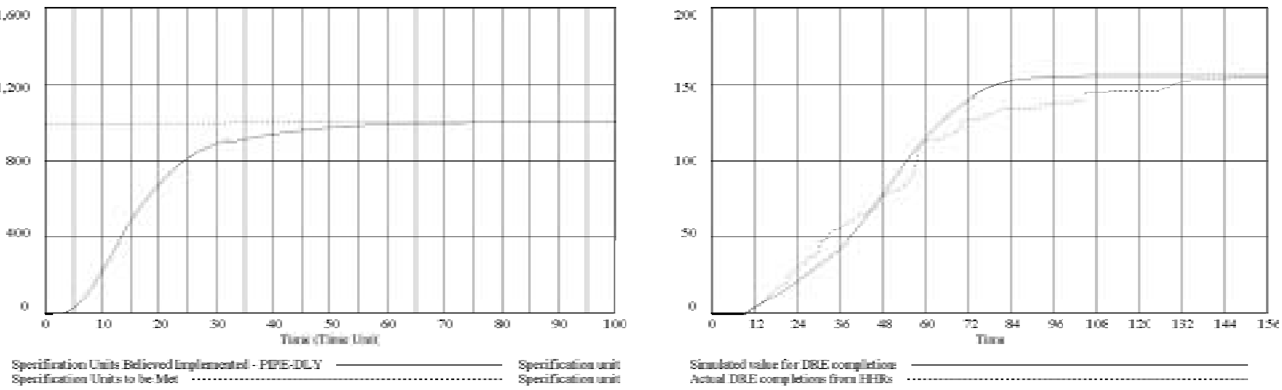



**Figure 6 Examples of Outputs from the Figure 5 Models**

These outputs indicate the growth trend of each system as measured in functionality or power. The most striking observation about them is their similarity. The Matra-BAe (left) output is considered a reasonable representation of past and anticipated future growth. Though no fit to actual data has yet been possible, the curve appears close to an inverse square plot reinforcing the conclusions about the likely relevance of this model. The SD models are more completely discussed in [leh98a,wer98,cha99] but the SD modelling results achieved to date, while encouraging, do not yet permit firm conclusions.

**Difficulties**: Not unnaturally, the FEAST/1 studies encountered difficulties, some anticipated some not. The small size (12 - 30) of data sets, for example, required a major search for useful statistical and other techniques and tools. This has slowed down and even blocked aspects of the data analysis and modelling, for example, when seeking to determine statistical significance. These problems were expected. Not anticipated was the fact that much of the data was raw and some only available in hard copy. All required considerable cleansing, interpretation and, in some cases, conversion to machine readable form. Perl scripts had to be developed to select, filter and prepare the data for analysis.

The system dynamics models were developed and executed using Vensim software, to explore various approaches to construction of the high level SD models of the respective processes. Calibration and refinement in consultation with process experts from Matra - Bae and ICL produced the models and outputs illustrated. Further refinement in FEAST/2 will seek to reproduce detailed process behaviour and to reveal feedback mechanisms, their controls and their impact.

**Project Workshops**: The collaborators and the two EPSRC SVFs all took an active role in the studies outlined above. The progress made would, indeed not have been possible without their strong and continuing interest and active support. In particular, all participated in seven one day workshops at quarterly intervals at which progress was reported, results critically discussed and extended, and further direction of the investigation agreed. Visitors, including Drs Adam Porter of the U. of Maryland, Larry Votta of Lucent Technologies - Bell Labs and Alan Whitfield were invited to participate in one or other of the workshops to contribute from their relevant experience and to comment on the FEAST/1 results.

**Dissemination**: This FEAST study is inherently difficult, essentially multi disciplinary and pioneering. Objective difficulties must be overcome in studying software evolution and seeking exploitation of feedback phenomena in the software process. The potential industrial significance of the findings and the fact that there is little, if any, parallel work going on elsewhere led to a major effort to keep the academic and industrial software engineering communities in general, and the software process community in particular, aware of the work and the progress being made. The interest and reactions of the empirical studies community have been particularly welcomed. The success of this dissemination effort is indicated by the approach from BT and their subsequent commitment as collaborators in FEAST/2.

The results have been presented as they emerged at conferences, workshops and symposia with publications in associated Proceedings or Journals such as JSS and the LNCS Springer series. Over forty reports and papers addressing FEAST related topics have been published or submitted for publication since the beginning of the study with the first FEAST workshop in October 1994. In addition, some 25 seminars have been given in the UK, Europe, the USA and Israel since the start of FEAST/1 at both academic and industrial locations. The lectures and published material include keynote and invited lectures. This provides evidence of the extent to which the work has become known nationally and internationally. The preparation of major journal publications has been deliberately delayed for the availability of more complete results and analysis expected to be (and now) available at the conclusion of the project. A full list of publications is included in the appendix to this report and texts of the more important are available via links from the FEAST web page at http://www-dse.doc.ic.ac.uk/~mml/FEAST/.

**Some significant results -** no significance to be attached to the ordering**:**

- Greatly increased understanding of software evolution, its regularities, patterns and constraints
- Consistent support for seven of the eight laws of software evolution
- Feedback and feedback control have significant impact on the software evolution (technical) process
- Dominant characteristics of resultant system dynamics inherited from outside the immediate process
- Inverse square model and its pointing to complexity growth of applications and of implementing software as the underlying constraint on continuing (and necessary) application and system evolution
- Incremental growth limits as a planning tool
- Advances in software process modelling, the application, analysis and interpretation of process metrics
- Simple SD models can produce meaningful results and insights
- Approaches to and procedures for the exploitation of software process metrics
- Design principals and seeds for specific software process analysis, planning, management and control procedures, tools with long term potential for generic stand alone or integrated tools
- Emerging understanding of and design principals for tools for software process improvement

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**Appendix 1**

## FEAST related publications

see http://www-dse.doc.ic.ac.uk/~mml/feast/ and links from there

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## Appendix 2

**Most Recent Statement of Laws of Software Evolution**

| No. | Brief Name | Law |
|---|---|---|
| I<br>1974 | Continuing Change | *E*-type systems must be continually adapted else they become progressively less satisfactory |
| II<br>1974 | Increasing Complexity | As an *E*-type system is evolved its complexity increases unless work is done to maintain or reduce it |
| III<br>1974 | Self Regulation | Global *E*-type system evolution processes are self regulating |
| IV<br>1980 | Conservation of Organisational Stability | Average effective global activity rate in an evolving *E*-type system tends to remain constant over long periods of system evolution though this may perhaps be overcome by adjusting feedback mechanisms |
| V<br>1980 | Conservation of Familiarity | The incremental growth of *E*-type systems tends to remain constant or to decline |
| VI<br>1980 | Continuing Growth | Functional content of *E*-type systems must be continually increased to maintain user satisfaction over lifetime |
| VII<br>1996 | Declining Quality | The quality of *E*-type systems will appear to be declining unless they are rigorously adapted to take into account changes in the operational environment |
| VIII<br>1996 | Feedback System<br>(Recognised 1971, formulated 1996) | *E*-type evolution processes are multi-level, multi-loop, multi-agent feedback systems and must, in general, be treated as such to achieve major process improvement for other than the most primitive processes. |