Course "Softwareprozesse"

Software Engineering Economics

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- Conventional view:
  High quality at low cost
  - Some known facts
- Economical view:
  High value at low cost
- Tracking earned value
  - conventional
  - value-centric
- Design as real options
  - valuating modularity

Learning objectives

- Understand the conventional, cost-centric view of SE
- Know some key facts of conventional SE economics

- Understand the economical, value-centric view of SE
- Learn about the broad-band nature of value-centric SE projects
- Learn about the view of modularity as real options

Conventional and economical view of software engineering

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Conventional view of software engineering:

- The goal of software engineering is producing high-quality software at low cost
  - cost-efficient quality

Economical view of software engineering:

- The goal of software engineering is *enabling* the creation of high value (via valuable software) at low cost
  - high value-added
  - Note: As a simplification, we will often talk about the value of the software, rather than the value created via using the software

Conventional view: Cost and quality

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Cost of software:

- Development cost and risk
  - for requirements analysis, design, implementation, test, documentation, delivery, […]
  - Risk: Chance of project failure
- Maintenance cost and risk
  - for analysis, design, […] of future changes
  - Risk: Chance of failing to change or of degrading the SW
- Operation cost and risk
  - Cost: e.g. →Efficiency, etc.
  - Risk: e.g. →Dependability, etc.
- Cost of time-to-market
  - Chances lost due to later availability of the SW

Quality of software:

- Fitness for purpose
  - Functionality
  - Compatibility
  - Dependability
    - reliability, availability, safety, security
  - Usability
    - Learnability, ease of use, tolerance for human error etc.
- Efficiency
  - Load on memory, disk, CPU, network bandwith, user work time etc.
- Maintainability
  - Portability
  - Modifiability
  - Robustness

Observations about the conventional view

- The conventional view is highly cost-focused:
  - The cost factors anyway
  - Most quality factors as well:
    - Efficiency is focused on operation cost
    - Maintainability is focused on maintenance cost and risk
    - Much of usability is focused on operation cost
    - Dependability is focused on operation risk
    - Usability is (in parts) focused on operation risk
- Only 'Functionality' directly targets the value of the software
  - But only insofar as the requirements were 'right'
    - also, some requirements will in fact be more valuable than others
  - Correctly implementing superfluous or ill-directed requirements does not provide positive value
    - but is considered quality during most activities of conventional SW processes

Some known facts of SW engineering economics

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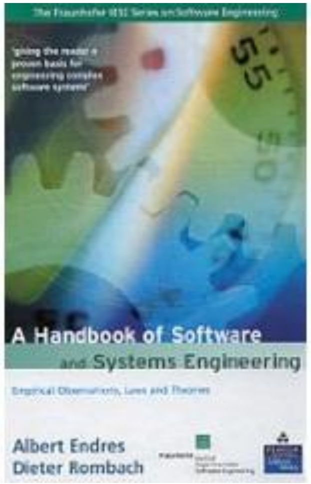


- Source: Albert Endres, Dieter Rombach: *"A Handbook of Software and Systems Engineering: Empirical Observations, Laws and Theories"*, Pearson 2003.
- L17: Inspections improve productivity (i.e. have high ROI), quality, and project stability
  - Hence every project should invest in inspections
- L2: The cost for removing a given defect is the larger, the later the defect is found
  - E.g. for requirements defects: often 100 times (or more) larger when found in the field as opposed to in requirements stage
  - Hence inspections of requirements and design are extremely valuable
- L15: Software reuse improves productivity (i.e. has high ROI) and software quality
  - Hence one should not develop something oneself needlessly

Some known facts of SW engineering economics (2)

- L24: 80% of the defects usually come from only about 20% of the modules
  - It pays off to identify these early and then inspect them or even implement them again from scratch
- L26: Usability is quantifiable
  - using measures such as time spent, success rate, error rate, frequency of help requests.
  - Such quantification is useful as it guides usability improvement
- L34: Cost estimates tend to be too low
  - "There are always surprises and all suprises involve more work"
  - Plan for contingencies and make sure your buffer is used only for them!
- L36: Adding people to a late project makes it later
  - Because more people means higher coordination effort and fresh people particularly so

Economical view: Cost and value

Cost of software:

- Cost for providing value
  - Finding and agreeing on value-enabling requirements
  - Writing code and documentation
  - Fitness-improving testing
  - Delivering software and bringing it into valuable use
  - Short time-to-market
- Cost for low-value insurance
  - All other quality assurance
- Cost for cost-reduction:
  - Product-related: anything that contributes to managability, testability, maintainability etc.
  - Process-related: Most process improvement

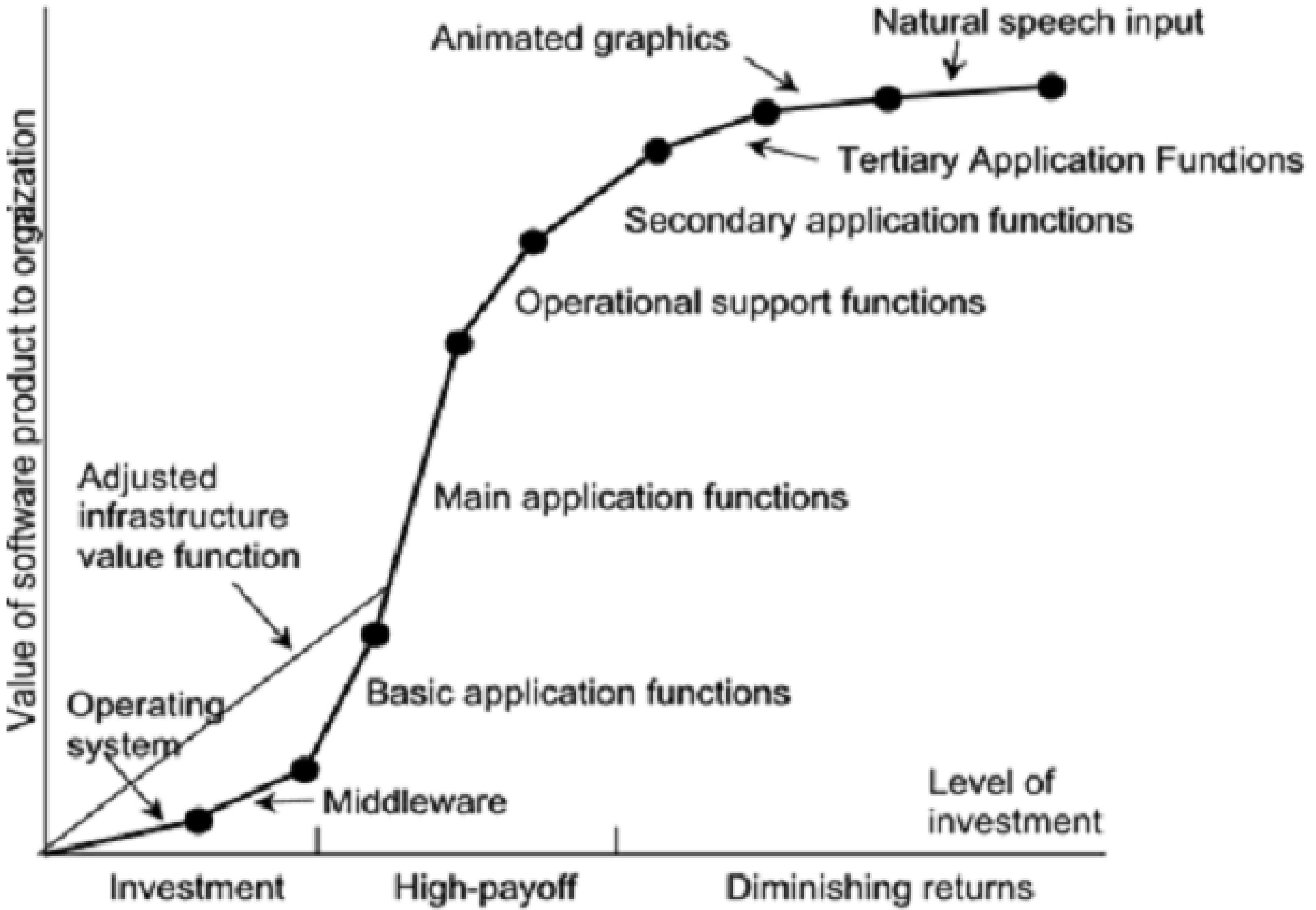
Value of software:

- For commercial SW products:
  - Revenue (or revenue increase) generated
- For custom software:
  - Added value and/or saved cost generated by using the software
    - This is also the basis for the revenue from commercial products if (and only if) there is no competition
- For Open Source software:
  - Its value is hard to measure

"Risk" is:

- Threats of increased cost or reduced value

Economical view: A typical cost-benefit curve



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Observations about the economical view

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The economical view redirects the focus of software engineering:

1. Away from the cost of individual process steps
   - to the cost for providing elements of the final value
   - or the cost for *preparing* to provide that value

2. Away from the invididual quality factors as such
   - to the value they provide (fitness for purpose, efficiency)
   - or the insurance they represent (testability, maintainability, etc.)

- Note: Of course, SW engineers have always used the economical view, too.
  - But it is useful to do it more explicitly

Observations about the economical view (2)

The economical view simplifies judging the importance of process steps and their products:

• requirements	prepare providing value, reduce risk
• design	reduces costs and risk
• program code	provides value
• user documentation	adds value (if done well)
• defect tests	add value (as long as they find value-reducing defects), reduce risk
• inspections	reduce costs and risk
• process improvement	reduces costs and risk
• etc.	

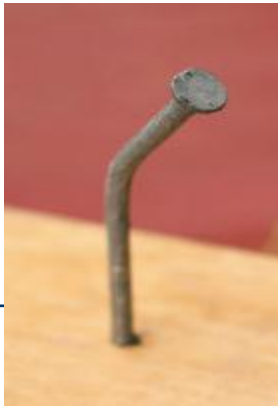
- Note: This is very simplified.
  For instance process improvement wrt. requirements engineering also improves the value-providing capabilities etc.

Quality assurance → Value assurance

- Conventional view:
  - The goal of quality assurance activities is to build software whose **quality is "as high as possible"**
    - with respect to the various aspects of quality
  - It is difficult to decide on the optimal extent of these activities
- Economical view:
  - The goal of quality assurance activities is to **reduce the risk** to the success of the value-generating activities,
    - i.e. to ensure that potential value is actually realized ("value assurance")
  - The extent of these QA activities depends on the size of the risk and the size of the value that is to be assured

The "good enough" principle

- In the conventional view, it is difficult to decide on the level of quality to be achieved
  - e.g. 100% reliability is usually impossible.
    If we currently have 19 known defects (failure modes) left in the system, do we need to eliminate them all?
- In the economical view, a (seemingly) simple rule guides these decisions:
  - Is the cost of making an improvement to the product smaller than the added value generated by the improvement?
  - If yes, make the improvement, otherwise don't.
  - (Note that cost is often and value is usually hard to estimate)
- This rule leads to the "good enough" approach to SW eng.:
  - Always try to understand when the SW is "good enough"
  - and then make it at least that good
  - but probably not much better



"Good enough" example: efficiency optimization

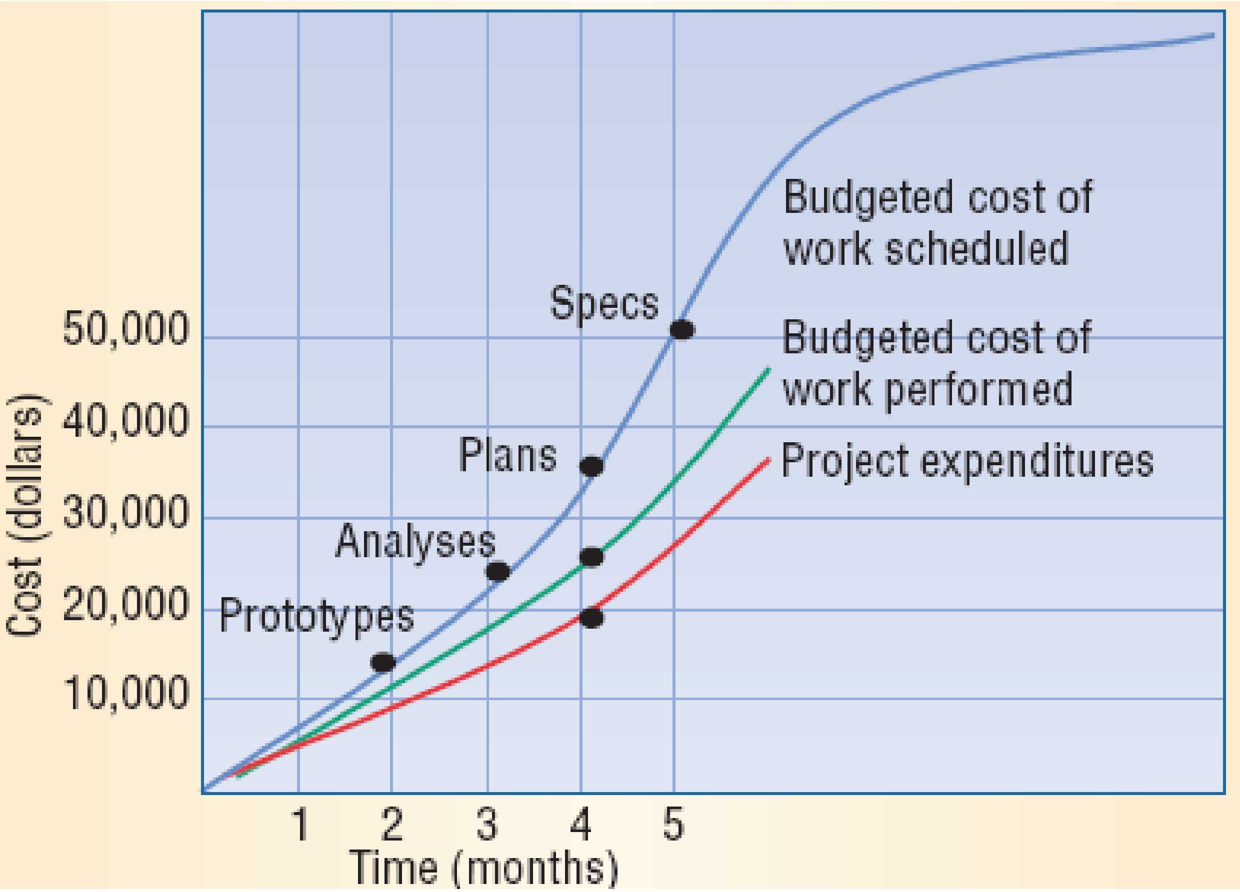
- Assume you could reduce the processing time of a program function by a factor of 10 by spending 9 days of effort

Should you do it?

- Depending on the importance of the function
  - if its overall value is small, probably not. Otherwise:
- Depending on current processing time (interactive SW), e.g.
  - 3 sec: yes
  - 0.1 sec: only if the work is on a high-load server/in a game, etc.
  - 100 sec: only if the function is used daily or by many people
- Depending on the current processing time (real-time system)
  - yes if this is necessary to meet hard deadlines
  - otherwise only if it frees enough resources to make implementing other tasks much simpler (→development cost reduction)

Project management: Tracking earned value

- Conventional PM uses *cost-based* earned-value tracking
  - Assumption 1: When, say, 10% of the project work are finished, also 10% of the project's value have been earned
  - Assumption 2: 10% have been finished if tasks have been finished that were planned to consume 10% of the total cost

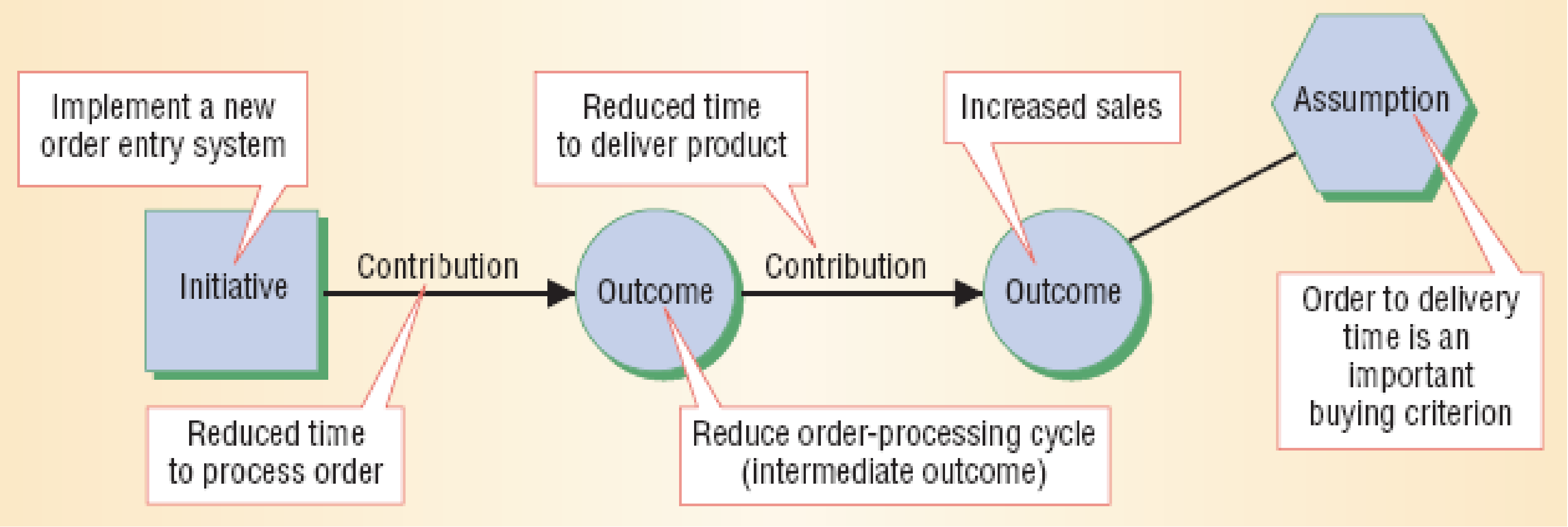


Project management: Tracking earned value (2)

- In contrast, PM based on the economics view would attempt to perform *value-based* earned-value tracking
  - For finished functionality as well as planned functionality
- To do this:
  1. Set up a business case to quantify the expected value (benefits)
  2. Involve more shareholders in order to perform all the additional activities that are need to realize the benefits
     - such as changes of people behavior, changes to related processes
  3. Track actual benefit objectively (quantitatively) where possible
     - Track estimated benefit subjectively elsewhere
  4. Adjust all of these as goals, markets, constraints, and environment change or as the expected value is not realized
- **Difficult!**
- For an example, see Barry Boehm, Li Guo Huang: *"Value based software engineering: A case study"*, IEEE Computer, March 2003 (see next few slides)

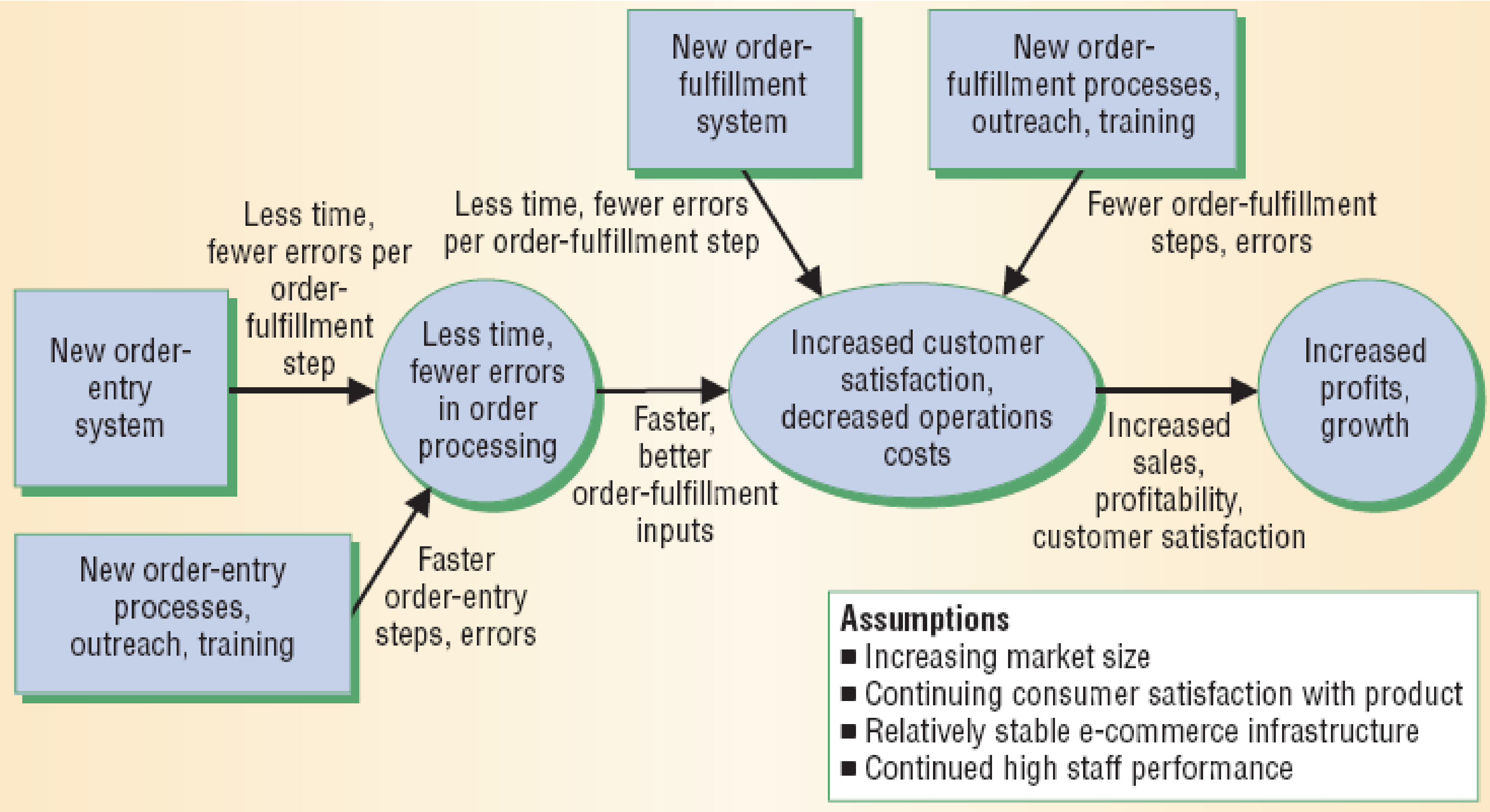
Value-tracking case study (1): Starting point

- Fictitious company: Sierra Mountainbikes
  - Renown for its outstanding quality bikes
  - Notorious for delivery delays, delivery mistakes, and disorganized handling of problems
- Enters a partnership with eServices Inc.
  - for joint development of better order-processing and fulfillment
- Value-realization chain (simplified):



Value-tracking case study (2): Proposed initiatives

- Full value-realization chain:



Value-tracking case study (3): Business case of initiatives

Projections		Current system			New system		
Date	Market size ($M)	Market share %	Sales	Profits	Market share %	Sales	Profits
31 Dec. 2003	360	20	72	7	20	72	7
31 Dec. 2004	400	20	80	8	20	80	8
31 Dec. 2005	440	20	88	9	22	97	10
31 Dec. 2006	480	20	96	10	25	120	13
31 Dec. 2007	520	20	104	11	28	146	16
31 Dec. 2008	560	20	112	12	30	168	19

	Expected improvements						Overall customer satisfaction		
date	Cost savings	Change in profits	Cumulative change in profits	Cumulative cost	Return on investment	Late delivery (percent)	Customer satisfaction	In-transit visibility	Ease of use
2003	0	0	0	0	0	12.4	1.7	1.0	1.8
2004	0	0	0	4.0	–1	11.4	3.0	2.5	3.0
2005	2.2	3.2	3.2	6.0	–.47	7.0	4.0	3.5	4.0
2006	3.2	6.2	9.4	6.5	.45	4.0	4.3	4.0	4.3
2007	4.0	9.0	18.4	7.0	1.63	3.0	4.5	4.3	4.5
2008	4.4	11.4	29.8	7.5	2.97	2.5	4.6	4.6	4.6

5=perfect

Value-tracking case study (4): Value tracking year 1

Milestone	Schedule	Cost ($K)	Op-Cost Savings %	Market Share ($M)	Annual Sales ($M)	Annual Profits	Cum∆	…
Life Cycle Architecture	*3/31/04* 3/31/04	*400* 427		*20* 20	*72* 72	*7.0* 7.0		Plan Act.
Core Capa-bility Demo (CCD)	*7/31/04* 7/20/04	*1050* 1096						
Software Init. Op. Capability (IOC)	*9/30/04* 9/30/04	*1400* 153						
Hardware IOC	*9/30/04* 10/11/04	*3500* 3432						
Deployed IOC	*12/31/04* 12/20/04	*4000* 4041		*20* 22	*80* 88	*8.0* 8.6	*0.0* 0.6	Plan Act.

more columns follow →

Value-tracking case study (5): Value tracking and countermeasures

Milestone	Schedule	…	Late Deliv.	Cust. Sat.	ITV	Ease of Use	Risks/Opportunities
Life Cycle Architecture	*3/31/04* 3/31/04		*12.4* 12.4	*1.7* 1.7	*1.0* 1.0	*1.8* 1.8	Increased COTS ITV risk. Fallback identified.
Core Capability Demo (CCD)	7/31/04 7/20/04			2.4*	1.0*	2.7*	Using COTS ITV fallback. New HW competitor; renegotiating HW
Software Init. Op. Capability (IOC)	9/30/04 9/30/04			2.7*	1.4*	2.8*	
Hardware IOC	9/30/04 10/11/04						$200K savings from renegotiated HW
Deployed IOC	12/31/04 12/20/04		*11.4* 10.8	*3.0* 2.8	*2.5* 1.6	*3.0* 3.2	New COTS ITV source identified, being prototyped

*alpha testing

Design process: Buying options

- Parnas' principle of information hiding suggests to form modules such that they encapsulate a design decision:
  - Should the decision ever need to change, the required modifications will be easier.

- The economical view suggests that information hiding can be viewed as buying a *real option*:
  - Encapsulating the decision requires effort (the cost of the option)
  - but it supplies you with the option (choice) to change the decision later on at lower cost
  - the difference in change-cost is the potential value of the option

(First use of real options regarded reserving olive oil presses long before the actual olive harvest.)

Thales von Milet
ca. 600 v.Chr

Olive oil press

Other kinds of design-related options

Other design issues can be viewed from an option perspective, too:

- Architecture:
  - A SW architecture does not provide value itself,
  - but it provides options to implement valuable functionality easily
- Program generators:
  - A code generator does not provide value itself,
  - but it provides options to implement valuable functionality easily
- Design-related risk management:
  - Risk assessment (e.g. by prototyping) is an investment that aims at estimating the value of certain options.

Not all decisions are encapsulated

- From these examples, it should be obvious that not all design decisions can be encapsulated – or should be
  - If you do not believe this, try encapsulating your decision for an architecture or for a programming language!
- Rather there are dependencies between design decisions
  - Decision A often depends on decision B or vice versa
    - but perhaps only for some choices of A or B
  - We call A and B **"design parameters" (DP)**
  - When thinking about a design, we may recognize some parameters (and many dependencies) only after a while
- We can reason economically about
  - how much certain dependencies hurt or
  - how valuable an encapsulation might be

Sullivan, Griswold, Cai, Hallen: *"The Structure and Value of Modularity in Software Design"*, ESEC/FSE 2001, ACM press

Design structure matrix (DSM)

- From an options perspective, a design is described by its parameters and their dependencies
  - Parameter: Choice of algorithm, data structure, interface, technology, etc.
  - Dependency: Choice of one parameter influences the decision space of the other
    - e.g. choice of component technology influences design of components
- Design structure matrix captures parameters and dependencies:

"(col) has influence on (row)"

"(row) depends on (col)"	A	B	C
A	.		
B	X	.	X
C		X	.

Dependencies are costly

- Whenever A changes, B may have to change, too
  - Thus, the person working on B has to be notified
- If now B changes, C may have to change, too
  - Thus, the person working on C has to be notified
- If now C changes, B may have to change <u>again</u> etc.

"has influence on" (used by)

"depends on" (uses)	A	B	C
A	.		
B	X	.	X
C		X	.

How to break dependencies

- Dependencies that result in such ripple effects can often be avoided by voluntarily introducing an additional design parameter and keeping it fixed:
  - I (an interface to A) is introduced and defined as unchanging
  - Now B no longer depends on A and A can change freely
  - We call this operation "splitting" and call I a **"design rule" (DR)**
- If I is fixed, the resulting example design is now modular:
  - A forms one module, B+C form another, I forms a design rule

	I	A	B	C
I	.			
A	X	.		
B	X		.	X
C			X	.

The value of modularity

- By exercising our option to define I as it is
  - and then keeping it fixed
- we gain the option to modify A and B+C independently
  - Beforehands, we could only modify both of them together
  - This difference is crucial: It allows for incremental improvement
    - Individual changes do no longer require changes elsewhere
    - Individual changes do no longer require coordination

- We call I a *visible module*
- We call A and B+C *hidden modules*
  - We can change the value (implementation) of the parameters, within a hidden module but this fact is not declared anywhere
- Other design parameters that depend on anything else than a design rule would be non-modular

Modularization case study: KWIC: Keyword-in-context

- Parnas' classical modularization example:
  Keyword-in-context (KWIC)
- Input: a list of book titles.
  For example
  - UML reference
  - UML user guide
  - Eclipse user manual
- Output:
  "Keyword-in-context" index
  - Eclipse user manual
  - guide UML user
  - manual Eclipse user
  - reference UML
  - UML reference
  - UML user guide
  - user guide UML
  - user manual Eclipse

David Parnas: **"On the criteria to be used in decomposing systems into modules",**
Communications of the ACM 15(12):1053-1058, December 1972

Modularization case study: "Strawman" design of KWIC

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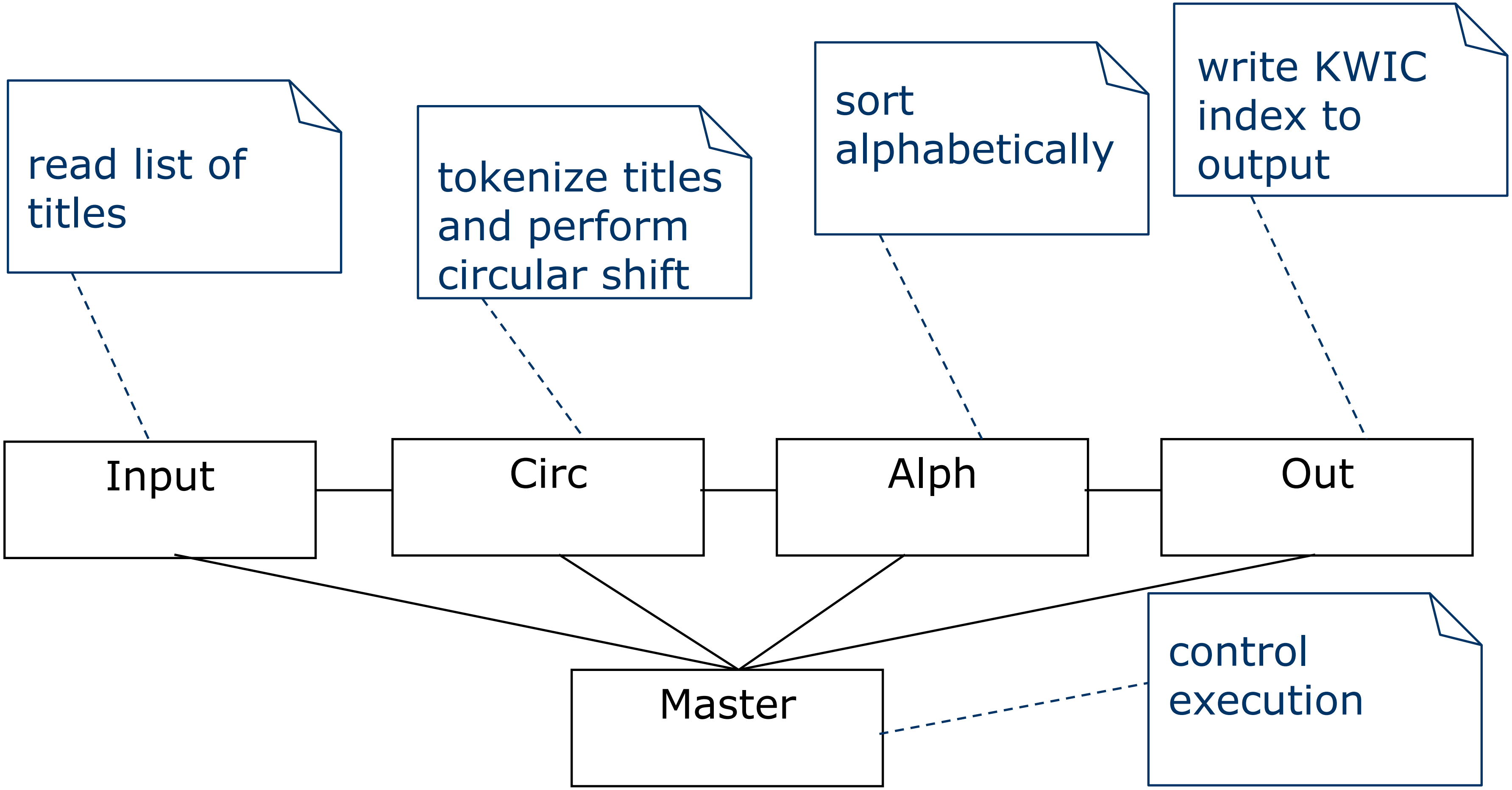
- Design parameters (DP) are: the data types ("Data"), procedure interfaces ("Type"), and implementations ("Alg")



Modularization case study: DSM for "strawman" design

	A	D	G	J	B	E	H	K	C	F	I	L	M
A - Input Type	.												
D - Circ Type		.											
G - Alph Type			.										
J - Out Type				.									
B - In Data					.	X	X						
E - Circ Data					X	.	X						
H - Alph Data					X	X	.						
K - Out Data								.					
C - Input Alg	X				X				.				
F - Circ Alg		X			X	X				.			
I - Alph Alg			X		X	X	X				.		
L - Out Alg				X	X		X	X				.	
M - Master	X	X	X	X									.

'type' = call interface

Design rules

Implementation constraints

Modules

Very little freedom!

Modularization case study: DSM for information hiding design

	N	A	D	G	J	O	P	B	C	E	F	H	I	K	L	M
N - Line Type	.															
A - In Type		.														
D - Circ Type			.													
G - Alph Type				.												
J - Out Type					.											
O - Line Data	X					.	X									
P - Line Alg	X					X	.									
B - In Data		X						.	X							
C - In Alg	X	X						X	.							
E - Circ Data	X		X							.	X					
F - Circ Alg	X		X							X	.					
H - Alph Data	X			X								.	X			
I - Alph Alg	X			X								X	.			
K - Out Data					X									.	X	
L - Out Alg	X				X									X	.	
M - Master	X	X	X	X	X											.

Introduces three new parameters N, O, P (Line Store module).

Design rules

Implementation constraints

Modules: more hidden information gives more room for improving the design

Everybody calls the line store, thus decoupling the other parts

Modularization case study: Modeling external forces: EP, EDSM

- A design is good if none of the likely changes needed for the system require modifying a design rule (DR)
- To model this, we extend the DSM into an ***EDSM*** by introducing ***environment parameters* (EP)**
  - Other than the DP, the EP are not controlled by the designer
  - So we now have EP and DP (the latter as normal DP and as DR)
  - KWIC EPs: **X**. Computer has more or less memory,
    Y. input corpus (title list) may be long or short,
    Z. user req's may change (input format, shifting, sorting).
  - Note that introducing EP is useful:
    discussing EPs is more focused than discussing design decisions
- In a good design, no DR depends on an EP
  - When an EP changes, all influence should be on normal DP only
  - i.e., we must adapt only internals of modules, but not interfaces

First the "strawman" design again:

Modularization case study: EDSM for "strawman" design

	X	Y	Z	A	D	G	J	B	E	H	K	C	F	I	L	M
X - Computer	.															
Y - Corpus	X	.	X													
Z - User	X		.													
A - In Type				.												
D - Circ Type					.											
G - Alph Type						.										
J - Out Type							.									
B -In Data	X	X						.	X	X						
E - Circ Data	X	X						X	.	X						
H - Alph Data	X	X						X	X	.						
K - Out Data	X	X									.					
C - In Alg	X	X		X				X				.				
F - Circ Alg		X	X		X			X	X				.			
I - Alph Alg	X	X	X			X		X	X	X				.		
L - Out Alg	X	X					X	X		X	X				.	
M - Master			X	X	X	X	X									.

Environment parameters (EP)

Design rules (DR)

Influence of EP on DR: **that's bad!**

Influence of EP on implementation DP: acceptable

Modularization case study: EDSM for information hiding design

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	X	Y	Z	N	A	D	G	J	O	P	B	C	E	F	H	I	K	L	M
X - Computer	.																		
Y - Corpus	X	.	X																
Z - User	X		.																
N - Line Type				.															
A - In Type					.														
D - Circ Type						.													
G - Alph Type							.												
J - Out Type								.											
O - Line Data	X	X		X					.	X									
P - Line Alg	X	X		X					X	.									
B - Input Data	X	X			X						.	X							
C - Input Alg		X	X	X	X						X	.							
E - Circ Data	X	X		X		X							.	X					
F - Circ Alg		X	X	X		X							X	.					
H - Alph Data	X	X		X			X								.	X			
I - Alph Alg	X	X	X	X			X								X	.			
K - Out Data	X	X						X									.	X	
L - Out Alg	X	X		X				X									X	.	
M - Master			X	X	X	X	X	X											.

Environment parameters (EP)

Design rules (DR)

No more influence of EP on DR!

Influence of EP on implementation DP: acceptable

Modularization case study: Model for valuating modularization

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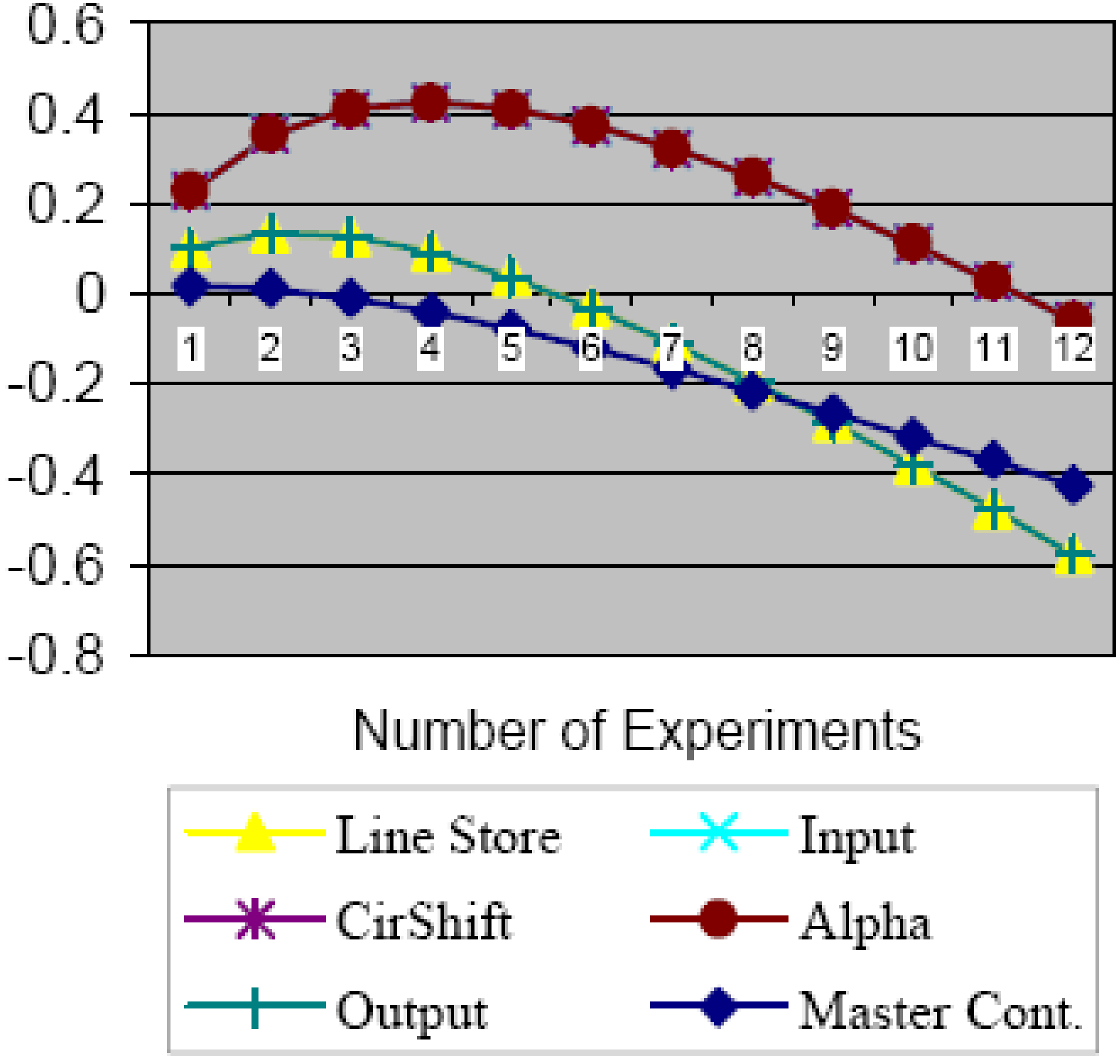
- Any module M provides the option to replace it
- An arbitrary replacement M_R may be better (i.e., add value)
  - We model the improvement $I = V(M_R)-V(M)$ as a random variable with normal distribution with mean zero
  - the variance is proportional to the module's *technical potential*
- Building M_R costs something (which reduces value)
  - proportional to the complexity of M
- To use M_R costs something more
  - proportional to the number of modules that depend on M

- Depending on these costs, it may or may not be helpful to make several *experiments* building a new M_R each to find the best replacement
  - The expected added value for the optimal number of experiments represents the *option value* of M

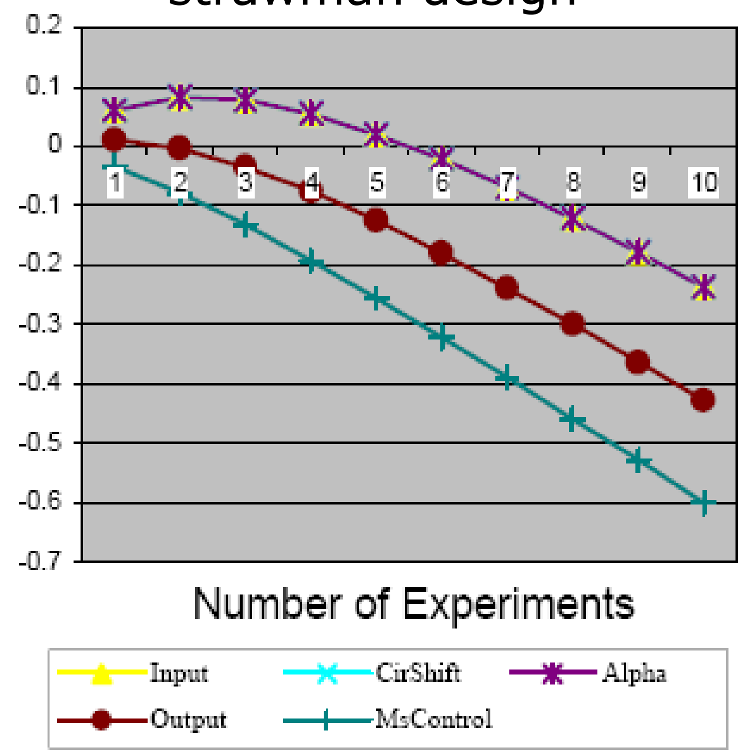
Modularization case study: Option values of the KWIC modules

information hiding design



(some parameter details are missing)

strawman design



complexity and coordination cost are assumed as 1 per parameter

Modularization case study: Conclusion

- Modularization can be understood in terms of
  - design parameters (DP, in particular fixed ones: design rules DR)
  - environment parameters (EP)
  - dependencies among these, which result in coordination costs for changes and possibly avalanching changes
- Modularization provides change options
  - Changes can add value to a system
- Good modularizations are good because:
  They allow changes that add more value than they cost

Further literature

- Workshop on economics-driven software engineering research
  - aka EDSER, a yearly workshop focussing on the economical view
  - proceedings appear at ACM press
  - www.acm.org (Volltexte verfügbar aus dem Uninetz heraus)

Summary

- The conventional view of SE focuses on cost and quality
- This view ignores the fact that different requirements provide different value

- An economical view of SE should take value into account
- For instance by using
  - value-based project planning
    - which automatically leads to additional business process changes and a holistic (rather than SW-focused) view of value optimization
  - value-based project progress tracking
  - a view of modularity as providing flexibility value by generating real options (namely for changes)

Thank you!