Information Hiding

15-214:
Principles of Software Construction

Jonathan Aldrich

Related Reading: D. L. Parnas. *On the Criteria To Be Used in Decomposing Systems into Modules.* CACM 15(12):1053-1058, Dec 1972.

Some ideas from David Notkin's CSE 503 class

What makes one design better than another?

- Not **what** result is produced, or whether it is right
- Instead, ***quality attributes***
  - **How** the result is produced
  - **Characteristics** of the code
- Examples:
  - **Evolvability**– ability to easily add and change capabilities
  - **Local reasoning**– ability to reason about parts separately
  - **Reuse** – avoid duplicating functionality
  - **Robustness** – operates under stress or invalid input
  - **Performance** – yields results at a high rate or with low latency
  - Testability, security, fault-tolerance,

Design Case Study: Key Word In Context (KWIC)

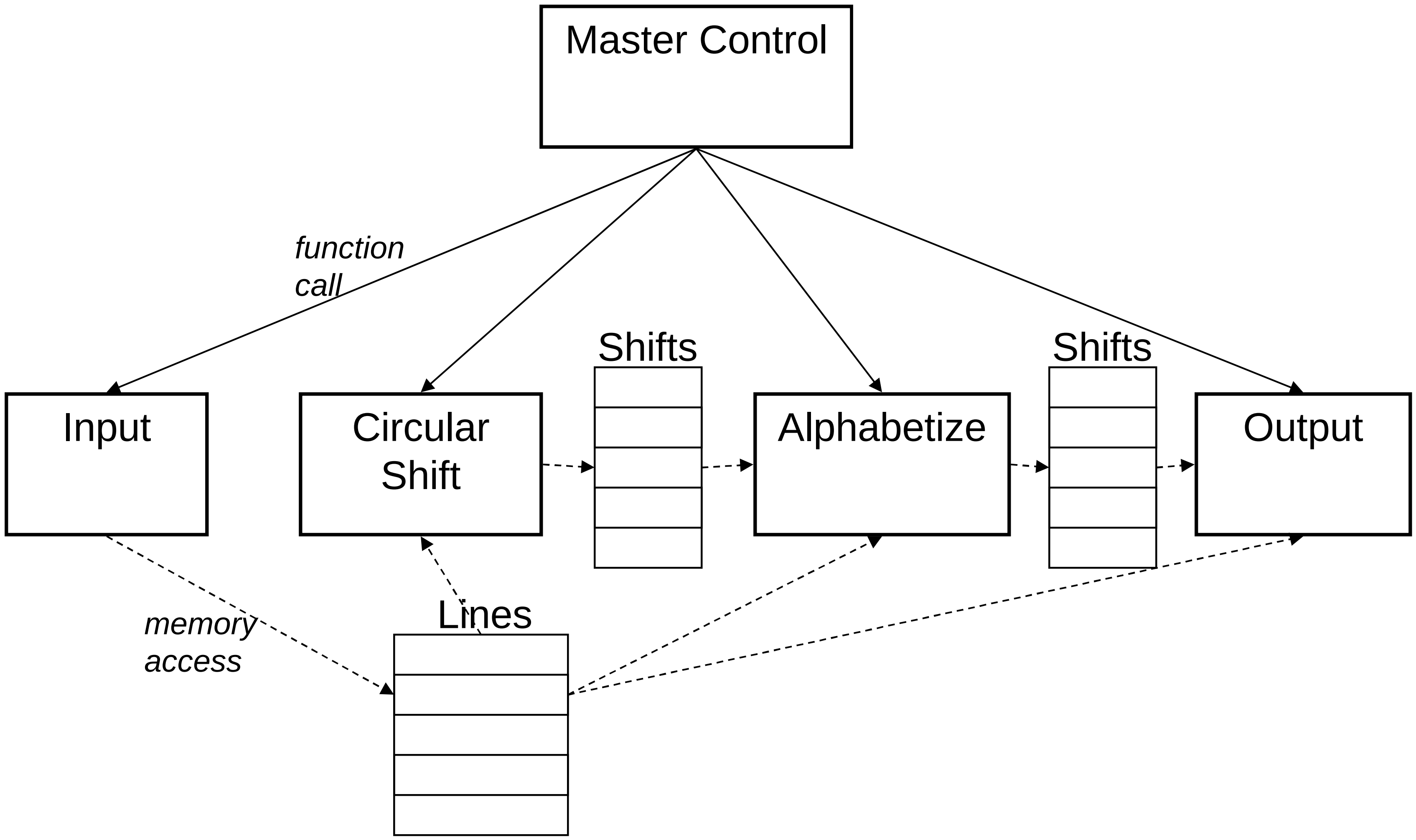
- “The KWIC [Key Word In Context] index system accepts an ordered set of lines, each line is an ordered set of words, and each word is an ordered set of characters. Any line may be "circularly shifted" by repeatedly removing the first word and appending it at the end of the line. The KWIC index system outputs a listing of all circular shifts of all lines in alphabetical order.”
  - Parnas, 1972

- Consider KWIC applied to the title of this slide

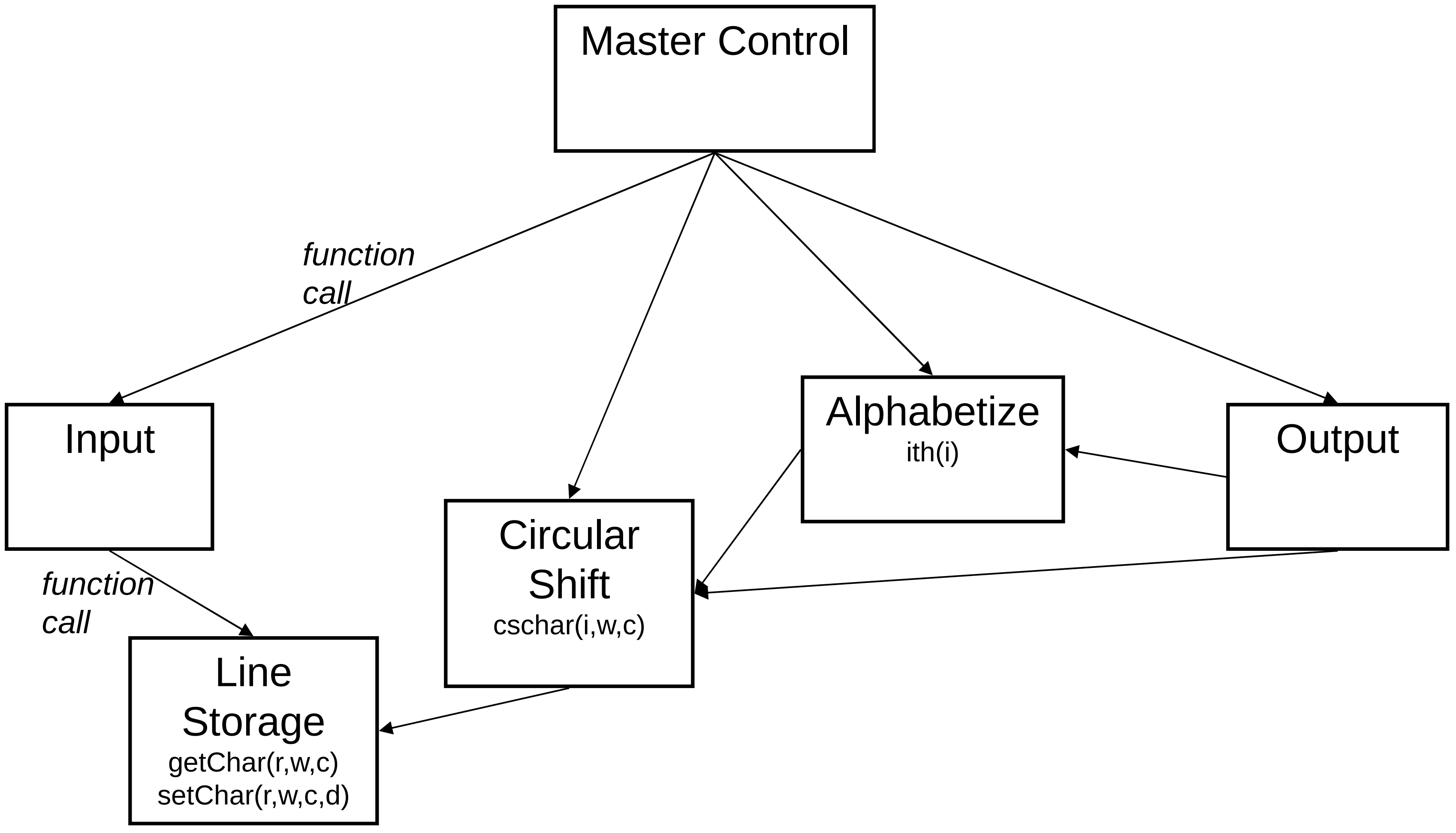
Design Case Study:
Case Study: Design
Study: Design Case
Key Word In Context (KWIC)
Word In Context (KWIC) Key
In Context (KWIC) Key Word
Context (KWIC) Key Word In
(KWIC) Key Word In Context

(KWIC) Key Word In Context
Case Study: Design
Context (KWIC) Key Word In
Design Case Study:
In Context (KWIC) Key Word
Key Word In Context (KWIC)
Study: Design Case
Word In Context (KWIC) Key

KWIC Modularization #1



KWIC Modularization #2



KWIC Observations

- Similar at run time
  - May have identical data representations, algorithms, even compiled code
- Different in code
  - Understanding
  - Documenting
  - Evolving

Software Change

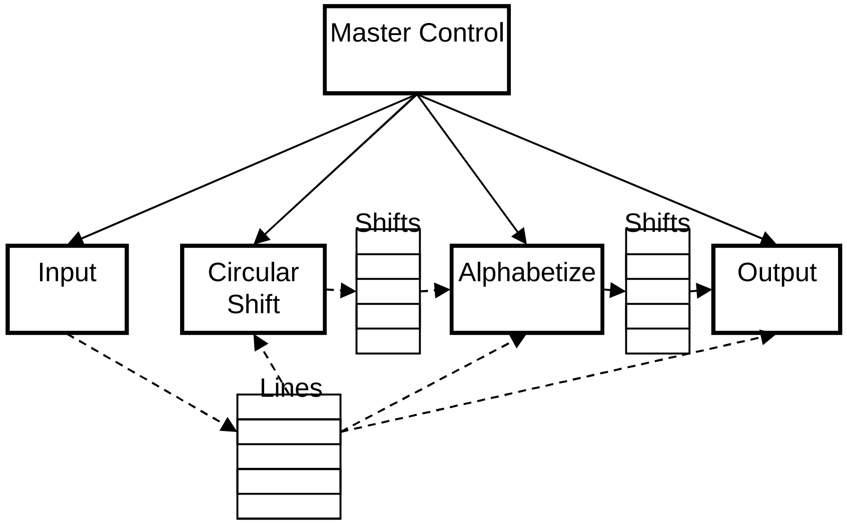
- …accept the fact of change as a way of life, rather than an untoward and annoying exception.
  —Brooks, 1974

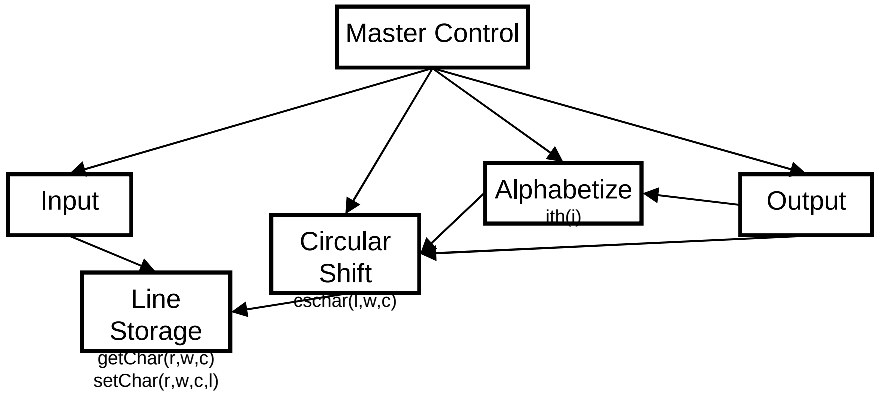
- Software that does not change becomes useless over time.
  —Belady and Lehman

- For successful software projects, most of the cost is spent evolving the system, not in initial development
  - Therefore, reducing the cost of change is one of the most important principles of software design

Exercise (paper): Effect of Change?

- Change input format
- Don’t store all lines in memory at once
- Use an encoding to save line storage space
- Store the shifts directly instead of indexing
- Amortize alphabetization over searches





Effect of Change?

- Change input format
    - Input module only
- Don’t store all lines in memory at once
    - Design #1: all modules
    - Design #2: Line Storage only
- Use an encoding to save line storage space
    - Design #1: all modules
    - Design #2: Line Storage only
- Store the shifts directly instead of indexing
    - Design #1: Circular Shift, Alphabetizer, Output
    - Design #2: Circular Shift only
- Amortize alphabetization over searches
    - Design #1: Alphabetizer, Output, and maybe Master Control
    - Design #2: Alphabetizer only

Other Factors

- Independent Development
  - Data formats (#1) more complex than data access interfaces (#2)
  - Easier to agree on interfaces in #2 because they are more abstract
  - More work is independent, less is shared
- Comprehensibility
  - Design of data formats in #1 depends on details of each module
  - More difficult to understand each module in isolation for #1

A Note on Performance

- Parnas says that if we are not careful, decomposition #2 will run slower
- He points out that a compiler can replace the function calls with inlined, efficient operations
- Lesson: don't prematurely optimize
  - Smart compilers enable smart designs
  - Evolvability usually trumps the overhead of a function call anyway

Decomposition Criteria

- Functional decomposition
  - Break down by major processing steps
- ***Information hiding*** decomposition
  - Each module is characterized by a design decision it hides from others
  - Interfaces chosen to reveal as little as possible about this

Information Hiding

Derived from definition by Edward Berard – concept due to Parnas

- Decide what design decisions are likely to change and which are likely to be stable
- Put each design decision likely to change into a module
- Assign each module an interface that hides the decision likely to change, and exposes only stable design decisions
- Ensure that the clients of a module depend only on the stable interface, not the implementation

- Benefit: if you correctly predict what may change, and hide information properly, then each change will only affect one module
  - That’s a big if…do you believe it?

Hiding design decisions

*Information hiding is **NOT** just about data representation*

Decision	Mechanism
• Data representation	
• Platform	
• I/O format	
• User Interface	
• Algorithm	

Hiding design decisions

- Algorithms – procedure
- Data representation – abstract data type
- Platform – virtual machine, hardware abstraction layer
- Input/output data format – I/O library
- User interface – model-view pattern

What is an Interface?

- Function signatures?
- Performance?
- Ordering of function calls?
- Resource use?
- Locking policies?

- Conceptually, an interface is everything clients are allowed to depend on
  - May not be expressible in your favorite programming language

Coupling and Information Hiding

- Coupling
  - How many dependencies?
  - Proxy for cost of interface change
- Information hiding
  - Depend only on stable design decisions
  - Incorporates likelihood of interface change
    - Thus a more direct measurement of a design's value
- Sometimes coupling is OK!
  - High coupling between framework and client
  - Framework interface captures assumptions that don't change between applications
    - Also hides framework implementation decisions that are likely to change
  - Client encapsulates code specific to an application

Design Analysis: Design Structure Matrices

K.J. Sullivan, W.G. Griswold, Y. Cai, and B. Hallen. The Structure and Value of Modularity in Software Design. Foundations of Software Engineering, 2001.

Carliss Baldwin and Kim Clark. Design Rules: The Power of Modularity. MIT Press.

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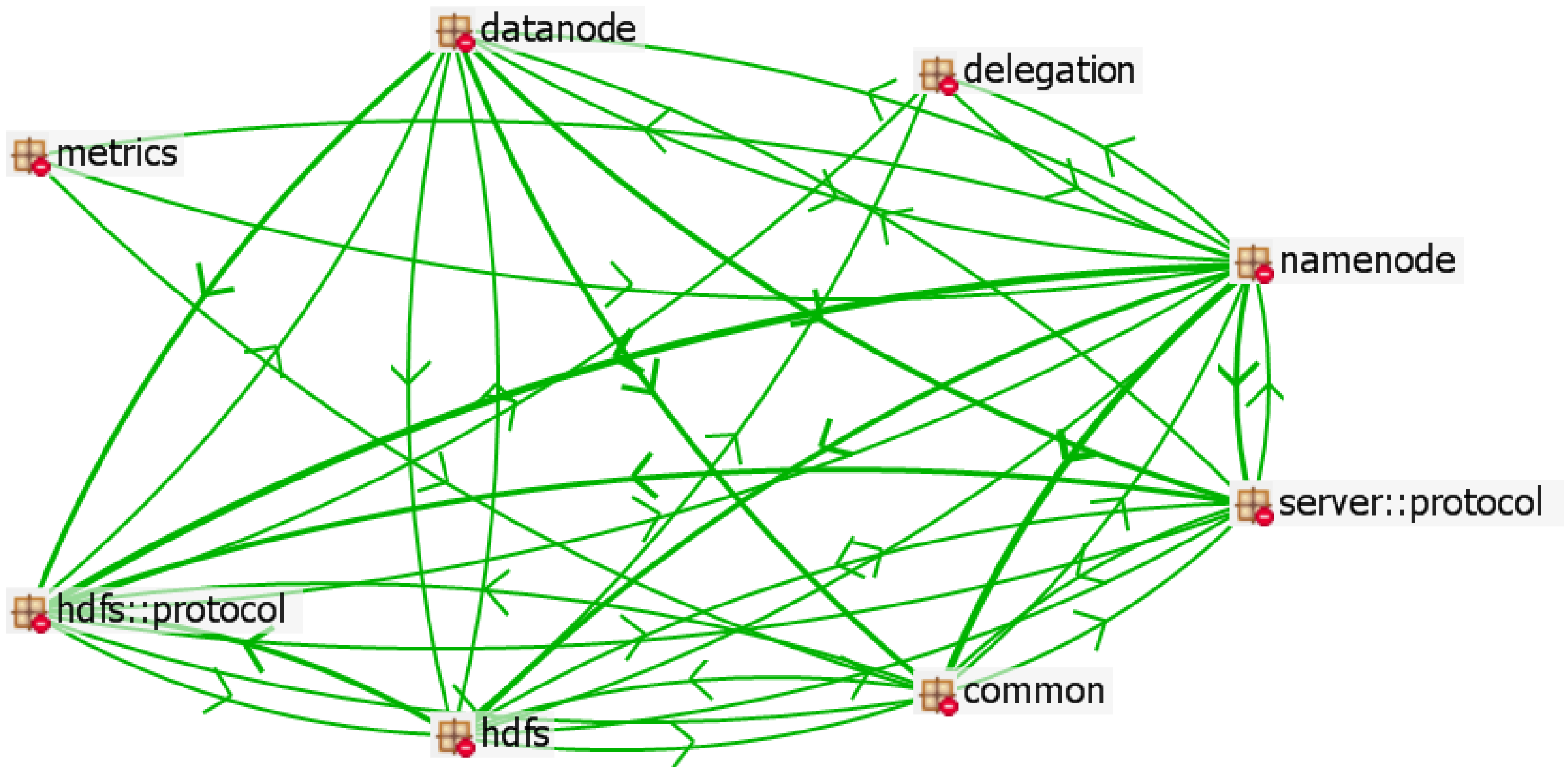
Module Dependencies

- Ideal: changes restricted to within a module
  - Goal of information hiding
  - Need to know which decisions may change
- Reality: some changes are surprises
  - These may affect module *interfaces*
  - Changes *propagate* to dependent modules
- How bad is this propagation?
  - It depends on coupling

Design Dependencies in Hadoop



Credit: Rick Kazman

The Design Structure Matrix (DSM)

- A DSM is an alternative to a directed graph
- An N by N matrix
  - Each row is a module in the system
  - Columns also labeled with modules, in same order
- Dependencies are marked with X’s
  - Marking row A, column B means A depends on B
  - The diagonal is ignored (self-dependence)
- Makes it easy to see common patterns

Credit: Rick Kazman

Design Structure Matrix (DSM) Example

	Model	GUI
Model	0	
GUI	X	0

Credit: Rick Kazman

Varying Degrees of Complexity: Fully Connected DSM

	A	B	C	D	E
A	O	X	X	X	X
B	X	O	X	X	X
C	X	X	O	X	X
D	X	X	X	O	X
E	X	X	X	X	O

Credit: Rick Kazman

Varying Degrees of Complexity: Fully Disconnected DSM

	A	B	C	D	E
A	O				
B		O			
C			O		
D				O	
E					O

Credit: Rick Kazman

Varying Degrees of Complexity: A Layered Architecture

	Kernel	Ring 1	Ring 2	Ring 3	Ring 4
Kernel	O				
Ring 1	X	O			
Ring 2	X	X	O		
Ring 3	X	X	X	O	
Ring 4	X	X	X	X	O

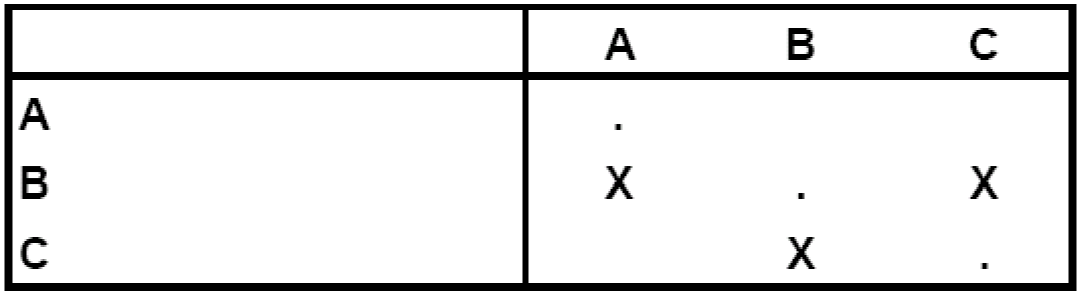
Credit: Rick Kazman

Varying Degrees of Complexity: A Strictly Layered Architecture

	OS	VM	I/O lib	Middle ware	App
OS	O				
VM	X	O			
I/O lib		X	O		
Middle ware			X	O	
App				X	O

Credit: Rick Kazman

Design Structure Matrices



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

Figure 1: DSM for a design of three parameters.

Meaning of the Matrix

A depends on nothing

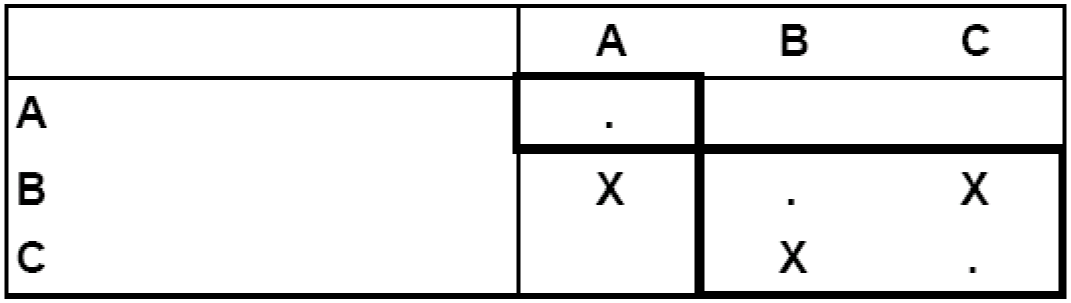
B depends on A and C

C depends on B

More terminology

- B is *hierarchically dependent* on A
  - If you change A, you might have to change B as well
  - Suggests you should implement A first
- B and C are *interdependent*
- C and A are *independent*

Design Structure Matrices



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

Figure 2: DSM for a proto-modular design.

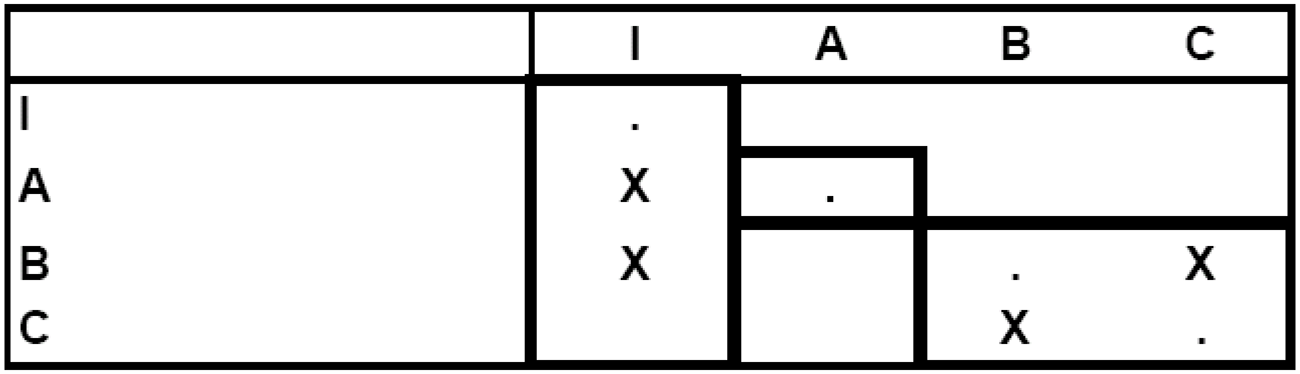
- Lines show clustering into proto-modules
  - Indicates several design decisions will be managed together
- True modules should be independent
  - i.e., no marks outside of its cluster
  - Not true here because B (in the B-C cluster) depends on A

Varying Degrees of Complexity: Layered Modules

	A	B	C	D	E
A	O				
B		O	X		
C	X	X	O		
D	X			O	
E	X	X		X	O

Credit: Rick Kazman

Design Structure Matrices

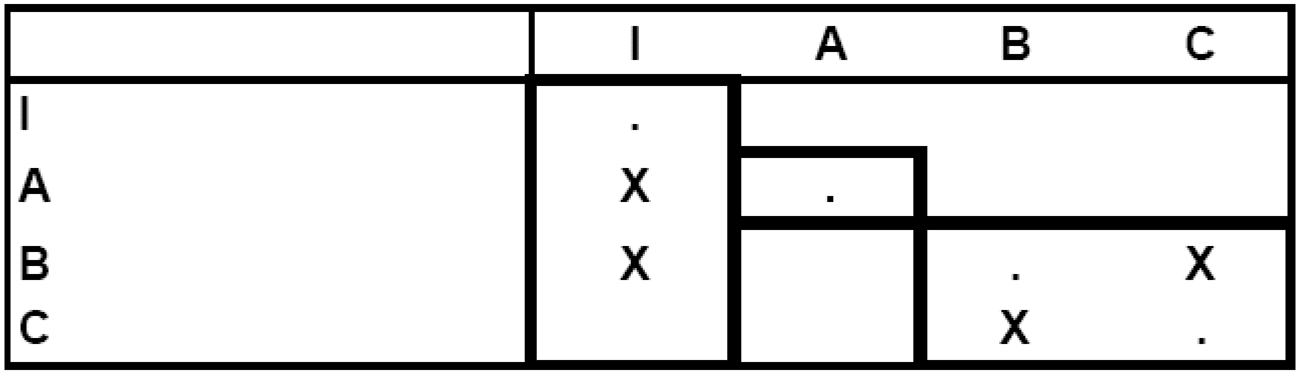


	I	A	B	C
I	.			
A	X	.		
B	X		.	X
C			X	.

Figure 3: DSM for a modular design obtained by splitting.

- Interface reifies the dependence as a separate entity
  - Instead of B depending on A, now A and B both depend on I
  - Serves to decouple A and B
  - Think of I as the interface of A

Value of Modularity

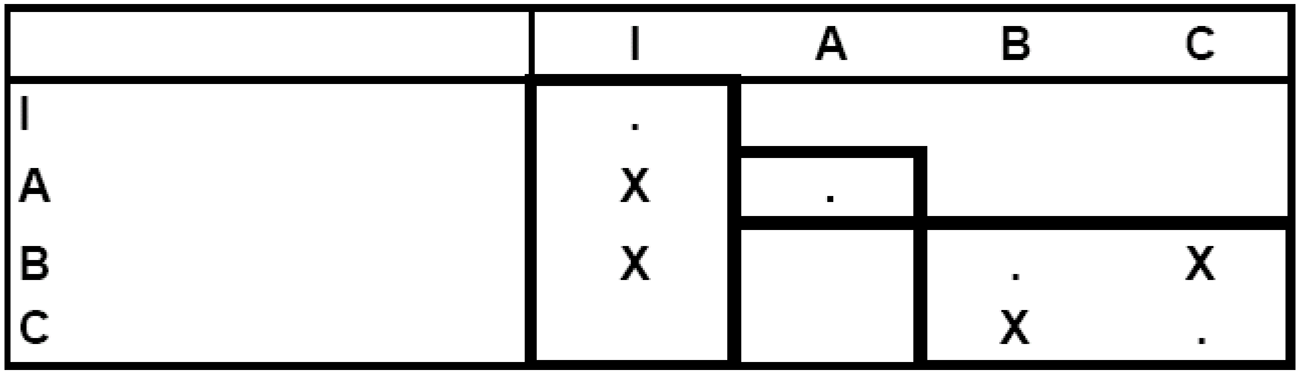


	I	A	B	C
I	.			
A	X	.		
B	X		.	X
C			X	.

Figure 3: DSM for a modular design obtained by splitting.

- Information Hiding
  - If you can anticipate which design decisions are likely to change and hide them in a module, then evolving the system when these changes occur will cost less
  - Reduces maintenance cost and time to market
  - Frees resources to invest in quality, features

Value of Modularity



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

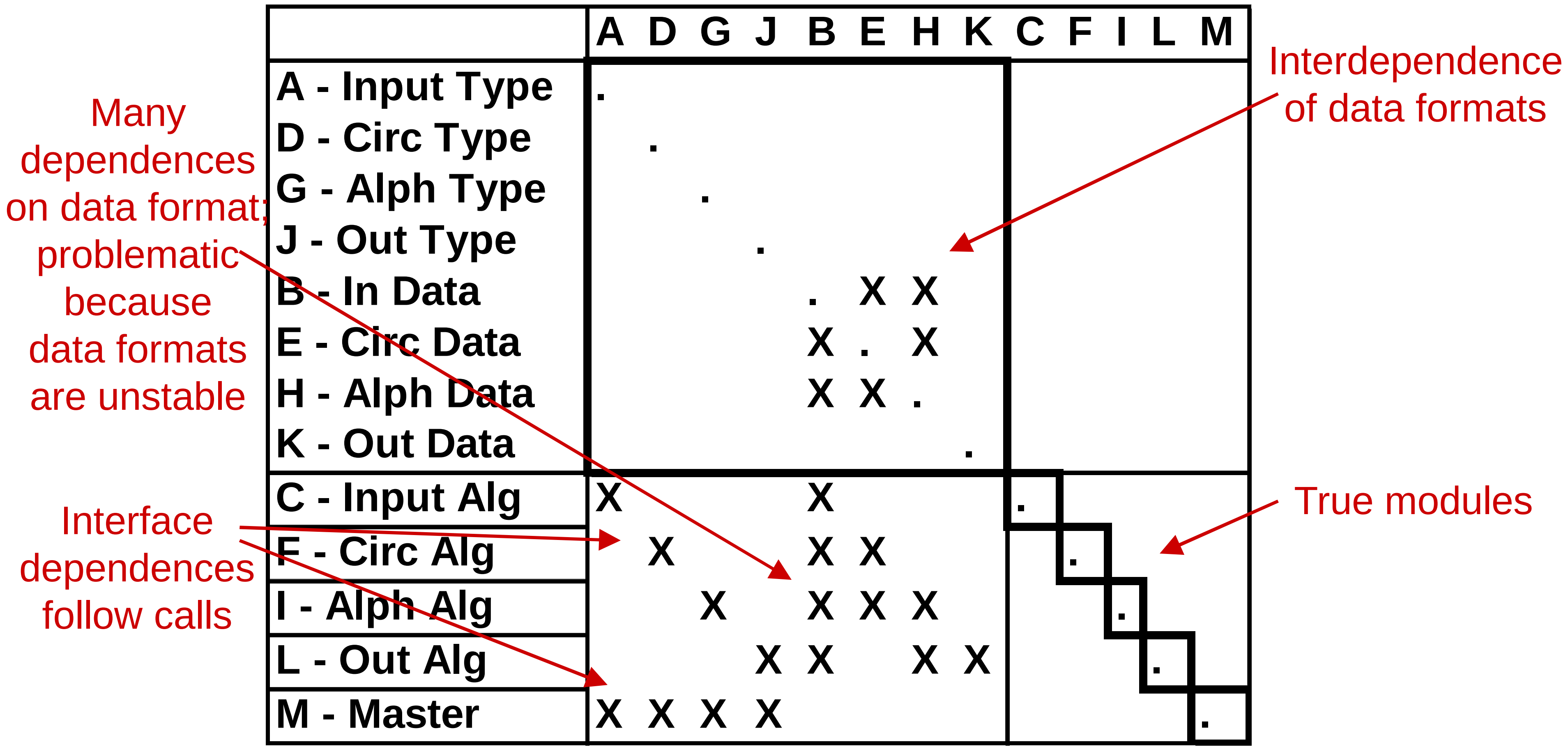
Figure 3: DSM for a modular design obtained by splitting.

- Option value of modules
  - The best design choice for A, B, and C may be uncertain and require experiments
  - Original design: B and C were dependent on A. Therefore if we build new A, B, C implementations, we must use all or reject all
  - New design: A and B,C decoupled through interface. We can build new A, B, and C implementations, and choose independently to use A and B,C
    - If one experiment fails we can still benefit from the others
  - Connection to economics: a portfolio of options is more valuable than an option on a portfolio

KWIC Design #1

	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					.								
E - Circ Data						.							
H - Alph Data							.						
K - Out Data								.					
C - Input Alg									.				
F - Circ Alg										.			
I - Alph Alg											.		
L - Out Alg												.	
M - Master													.

KWIC Design #1



	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									.

Many dependences on data format; problematic because data formats are unstable
Interdependence of data formats
Interface dependences follow calls
True modules

KWIC Design #2

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

KWIC Design #2

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

Dependence on interfaces

True modules

Which Design is Better?

	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									.

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

Comparing the Designs

	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									.

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

- Both designs allow changes within modules
- However, in the first design the modules do not hide much
  - Many dependencies (2-4 per module) on data structures
  - Data structure dependencies are strong: they restrict algorithms used
  - Furthermore, data structures are likely to change
- The second design is much less constrained
  - Fewer dependencies (1-2 per module)
  - Interfaces are more abstract, do not restrict code as much
  - Interfaces are more stable in the face of likely changes
- Result: design 2 minimizes re-engineering in response to change

EDSMs: Considering Possible Changes

- Environment and Design Structure Matrices
  - Sullivan et al., ESEC/FSE 2001
- Add changes as *environmental parameters*
  - *Note: slightly more concrete than what Sullivan et al. propose*
  - Only partially controlled by designer
  - May affect each other
  - May affect design decisions in code
- What interfaces are affected?
  - Information hiding: interfaces should be stable
- What implementations are affected?
  - Information hiding hypothesis: should be local to a module

Effect of Change – Design #1

	V	W	X	Y	Z	A	D	G	J	B	E	H	K	C	F	I	L	M
V - Input Fmt	.																	
W - Store Mem		.																
X - Compress			.															
Y - Shift Store				.														
Z - Amortize					.													
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									.

Effect of Change – Design #1

Unstable data interfaces depend on changes

Algorithms depend on data

	V	W	X	Y	Z	A	D	G	J	B	E	H	K	C	F	I	L	M
V - Input Fmt	.																	
W - Store Mem		.																
X - Compress			.															
Y - Shift Store				.														
Z - Amortize					.													
A - Input Type						.												
D - Circ Type							.											
G - Alph Type								.										
J - Out Type									.									
B - In Data		X	X							.	X	X						
E - Circ Data				X						X	.	X						
H - Alph Data				X	X					X	X	.						
K - Out Data													.					
C - Input Alg	X	X	X			X				X				.				
F - Circ Alg		X	X	X			X			X	X				.			
I - Alph Alg		X	X	X	X			X		X	X	X				.		
L - Out Alg		X	X	X	X				X	X		X	X				.	
M - Master					X	X	X	X	X									.

Effect of Change – Design #2

	V	W	X	Y	Z	N	A	D	G	J	O	P	B	C	E	F	H	I	K	L	M
V - Input Fmt	.																				
W - Store Mem		.																			
X - Compress			.																		
Y - Shift Store				.																	
Z - Amortize					.																
N - Line Type						.															
A - Input 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 - Input Alg						X	X						X	.							
E - Circ Data						X		X							.	X					
F - Circ Alg						X		X							X	.					
H - Alph Data									X								.	X			
I - Alph Alg								X	X								X	.			
K - Out Data										X									.	X	
L - Out Alg								X	X	X									X	.	
M - Master						X	X	X	X	X											.

Effect of Change – Design #2

Interfaces are stable

Effect of change is localized

	V	W	X	Y	Z	N	A	D	G	J	O	P	B	C	E	F	H	I	K	L	M
V - Input Fmt	.																				
W - Store Mem		.																			
X - Compress			.																		
Y - Shift Store				.																	
Z - Amortize					.																
N - Line Type						.															
A - Input 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 - In Data	X						X						.	X							
C - Input Alg	X					X	X						X	.							
E - Circ Data				X		X		X							.	X					
F - Circ Alg				X		X		X							X	.					
H - Alph Data					X				X								.	X			
I - Alph Alg					X			X	X								X	.			
K - Out Data										X									.	X	
L - Out Alg								X	X	X									X	.	
M - Master						X	X	X	X	X											.

Comparison

- Design 2 hides information better
  - Interfaces are unaffected by likely change scenarios
  - Changes required to implement likely change scenarios are local

Summary

- DSMs are a structured way of thinking about the value of design
  - Are design decisions isolated to a module, or do they affect several modules?
  - How do modules depend on interfaces?
  - On which parts of the system can I experiment independently?
  - How much value is there in the experiments?
    - Technical potential of the module
- EDSMs incorporate change scenarios
  - How are interfaces and code affected by change?
- More to explore
  - Baldwin and Clark – discuss value of modularity
  - Sullivan and Griswold – apply B&C to S/W, introduce EDSMs
  - Lattix LDM tool – derives DSMs from code