Supporting Forward and Reverse Engineering with Multiple Types of Models

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Thursday, September 21st
Models 2017 Keynote
Austin, Texas

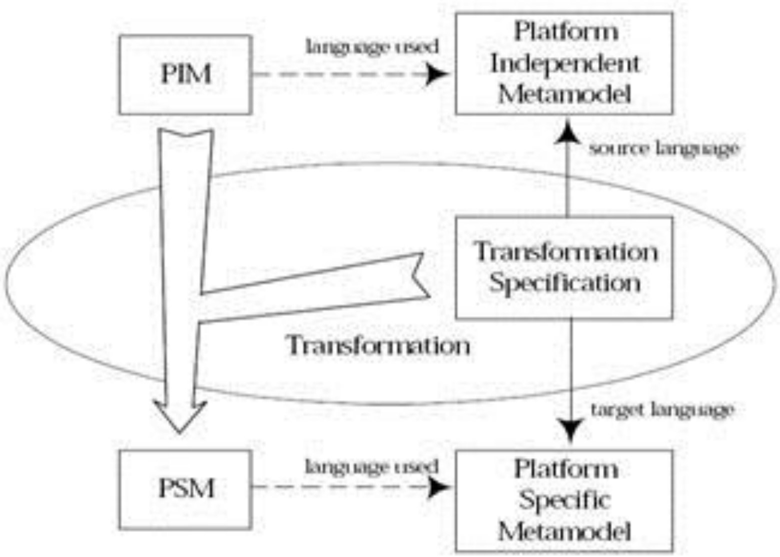
Software Engineering
State of the Art for Program Construction

- Deep Semantic Theory
- Requirements Capture and Traceability
- Formal Specifications in Domain Specific Languages or Models
- Mature Technologies: RDB, RPC, GUIs, …
- Modern languages with exceptions, generics, parallelism, …
- Automated Test Generation
- Configuration Management Tools
- Software Engineering Process and Methods
- **Model-driven engineering**

Model Driven Engineering
Software Development Problem Solved!

- Write a Model of a Desired Program
- Run the off-the-shelf Model-to-Code Generator
- Run Generated Code in Production
- Done!

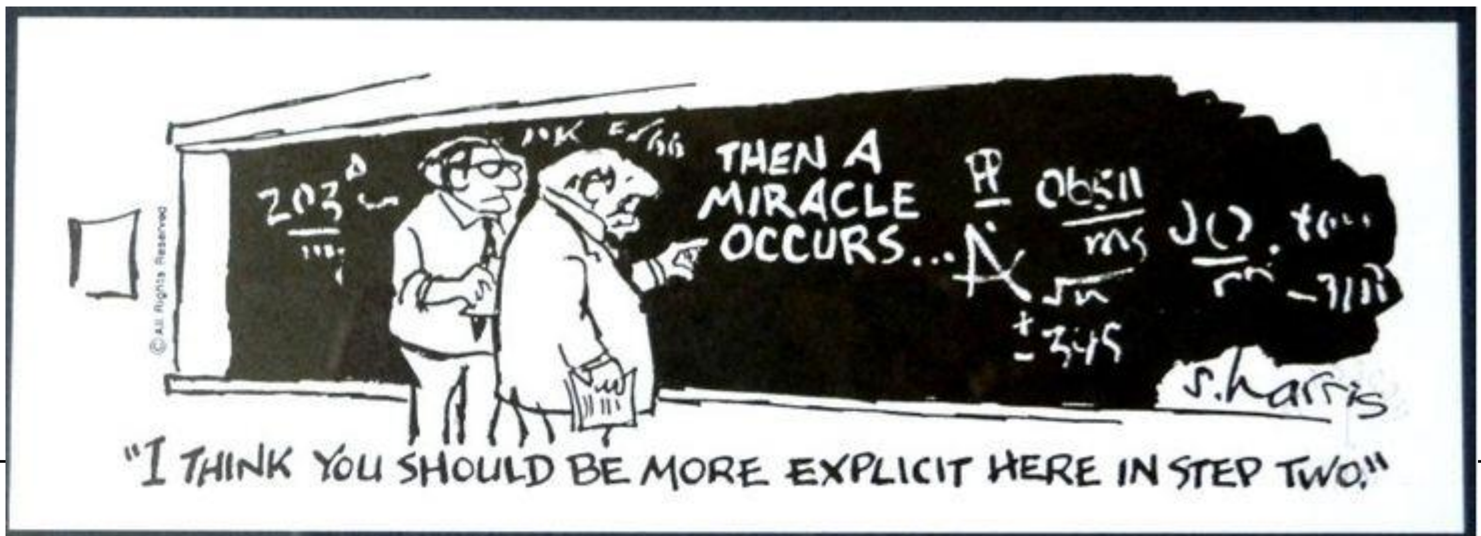
Problem 1: How Does This work?



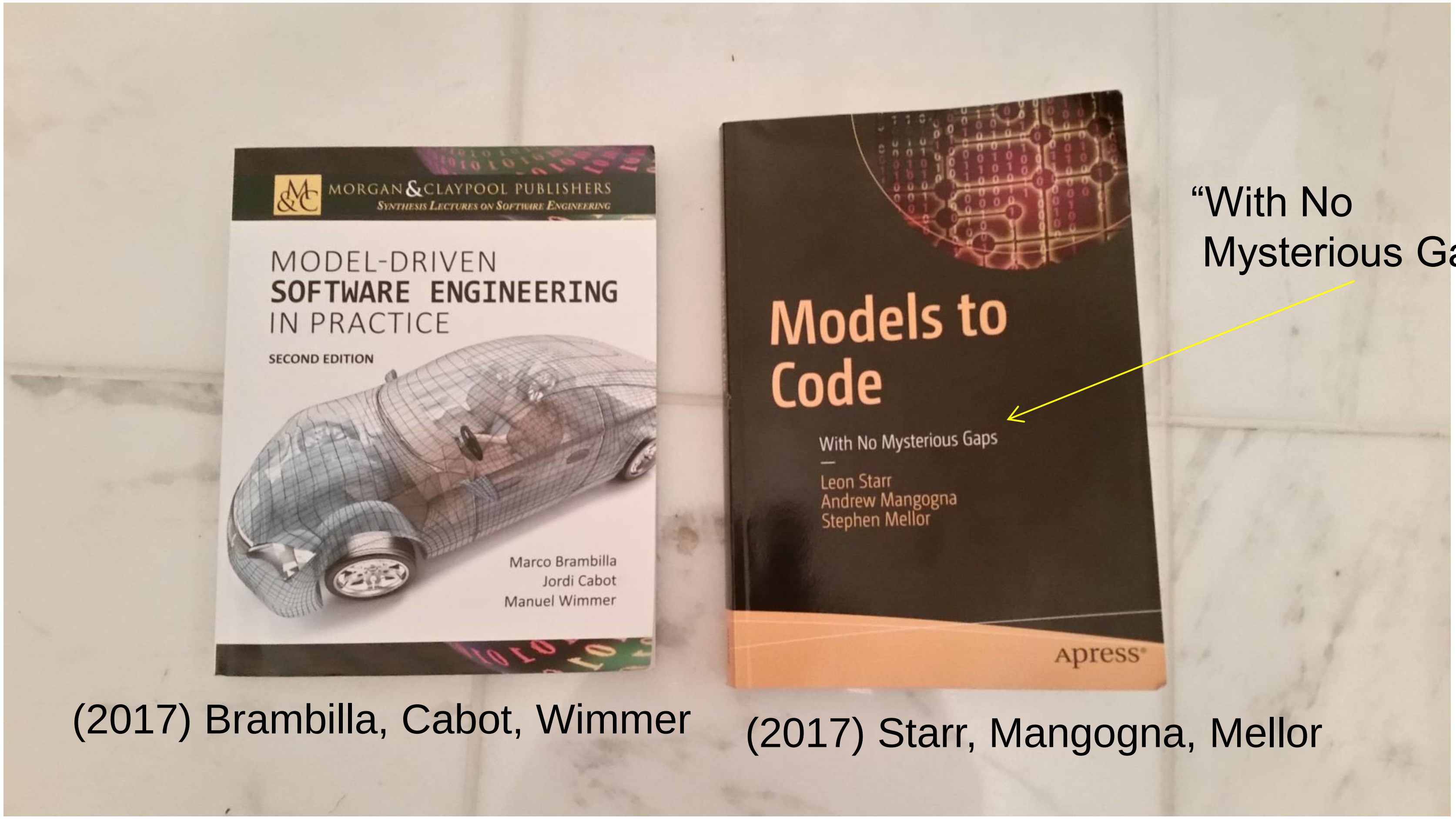
Step1

Step2

Step3



Modelling Background

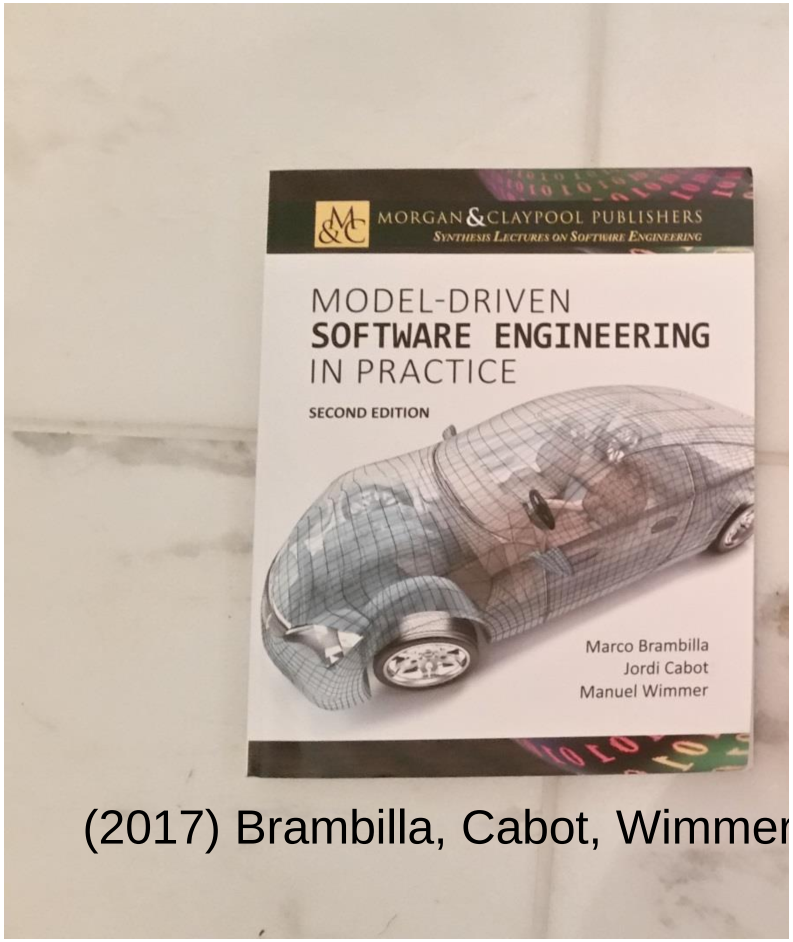


"With No Mysterious Gaps"

(2017) Brambilla, Cabot, Wimmer

(2017) Starr, Mangogna, Mellor

One MDE View

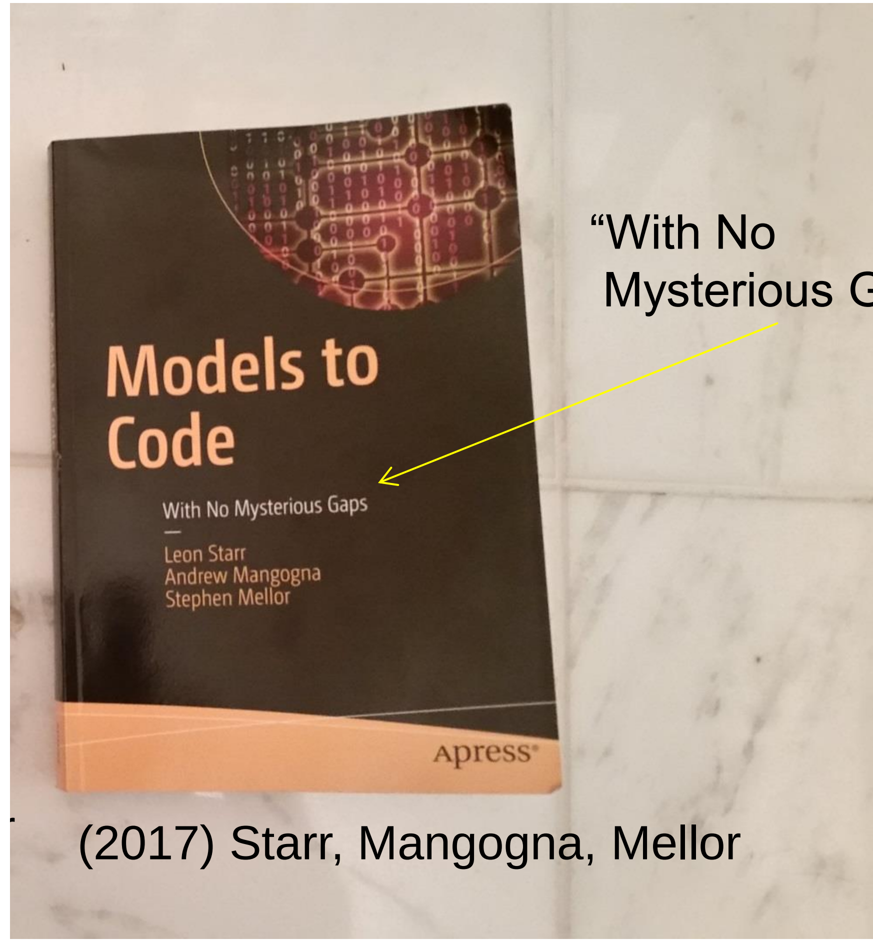


(2017) Brambilla, Cabot, Wimmer

- (to produce code) "**Model … must be executable** (page 26)" No!
- **ExecutableUML** as typical model
- Distinguishes concrete vs abstract syntax, semantics … but no discussion of latter
- Emphasizes (concrete) **graphical models** syntax = model conformance
- Emphasizes **simple model of generation**: M2M (optional) then M2T
- M2M as **graphical model to graphical model** transforms (Refinements)
- Code generation via Model2Text
  Size of semantic gap from Model to target
- Some references "graph transformation" literature

Alternate MDE View

- Shows one approach in detail
- **ExecutableUML** as “the model”
  - **Classes** with data elements
  - **Statecharts** as class-transition descriptions with signals to other class-statecharts
  - **Abstract actions** to navigate class relations, side-effect class data
- Text encoding of concept xUML into **Pycca syntax**
  - *Actions as explicit C code fragments*
  - *Data declarations as C code fragments*
- **Pycca M2T generator** produces
  - C structs for classes
  - FSA per class with continuations used to signal to other class-FSAs
- ***No mysterious gaps … 283 pages***
  but pretty weak generator
  where did Pycca come from?



(2017) Starr, Mangogna, Mellor

Model Driven Engineering
Software Development Problem Solved?

Problem 2

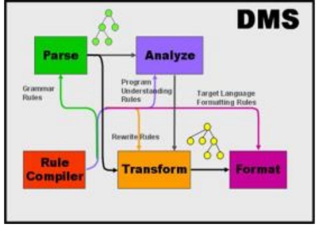
- Write a Model of a Desired Program
  - Where did my modelling notation come from?
  - What does it mean?
  - How did I get it into the computer?
  - Is it complete wrt Functionality? Performance?
  - Does my model mean what I think it means?
- Run the off-the-shelf Model-to-Code Generator
  - What machinery reads the model?
  - What is my choice of code targets? Is it only one language/technology?
  - How are model transformations specified?
  - How are they sequenced and executed?
  - How do I know they are right? Complete?
  - How long does code generation take to run?
- Run Generated Code in Production
  - Does the generated code need runtime support?
  - How do I debug problems using modelling terms?
- Done?
  - **Success breeds discontent: user needs change, external context changes**
  - How do I modify my model in an organized way to respond to these demands?
  - Do I regenerate all the code again, even for the parts of the model that don't change?

Problem 3: Maintenance

How do these tools really work??

- MDE suggests "models" and "transforms" but not a lot of detail
  - Generated systems seem rather "small"
  - Where is the theory?
  - How to improve it?

- We need a different *model* of model driven engineering!
- => Program Transformations
  - General "model" of specifications: any formal artifact
    …. don't have to executable or complete
  - Can define meaning of specifications using a variety of formalisms
  - Transforms as functions on specifications → **composable**
    realized in a wide variety of ways
  - Correctness as preservation of properties by transforms
  - Ability to operate at same level of abstraction or many levels of abstraction
  - Metaprogramming to realize design choices
  - Ability to produce large systems
  - Ability to choose a variety of different implementations
  - Ability to operate on "Text" part of M2T
  - *Perspective to define reverse engineering*

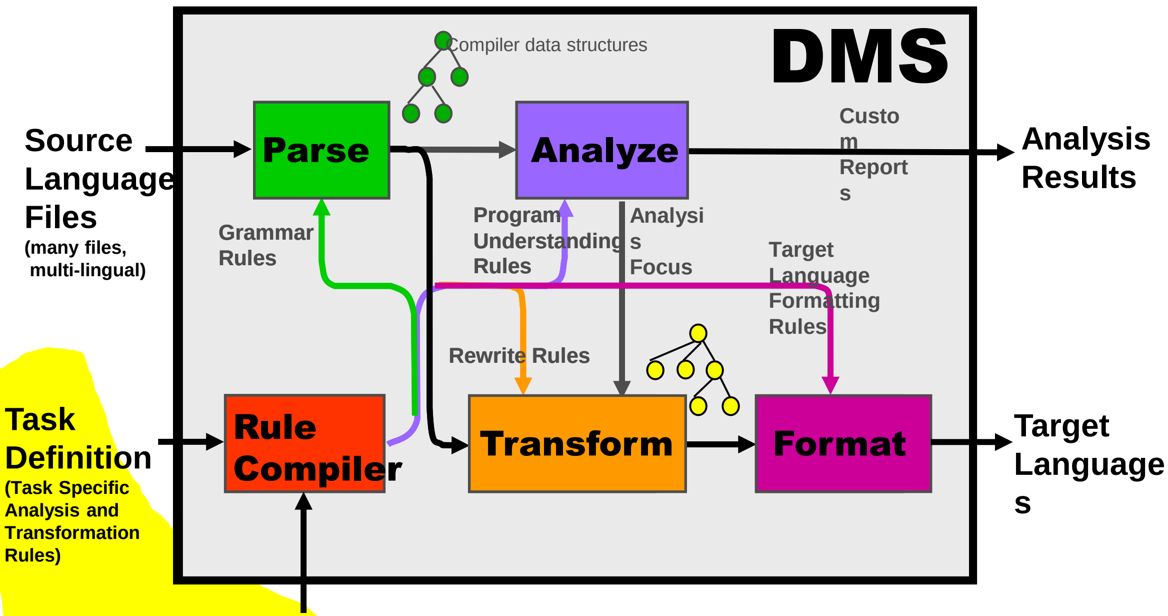


Background: Semantic Designs

- Automated Software Engineering Tools since 1996
- ***All*** tools derived from single **Program Transformation Engine**:
  DMS® Software Reengineering Toolkit
- **Focus on legacy code analysis/transformation**
- DMS based on 3 key foundations
  - Compiler Technology developed over last 50 years, *generalized*
  - Mathematical notion of A=B realized as mechanical *program transformations*
  - Scale support: large size, many languages, parallel computation for inference
- Some DMS tasks
  - Analysis of code structures at ANZ Bank (16MSLOC COBOL)
  - 100% fully automated migration of B-2 Stealth Bomber Mission Software
  - Rearchitect large C++ applictions in CORBA/RT compatible structure
  - Extraction of process-control models from legacy assembler code for Dow Chemical

DMS Software Reengineering Toolkit

Constant set of program manipulation services



Domains
== Language Definitions
•(Grammar Rules + General Analysis Rules + Formatting Rules
for many languages or custom, including

- **C++** *Factory*
- **C#** *Configuration*
- **HLASM**
- **HTML**
- **Java**
- **Natural**
- **SQL**

Understanding

- ✓ Language parsers
- ✓ Compiler data structures
- ✓ Deep data flow analysis
- ✓ Data flow *concept* matching

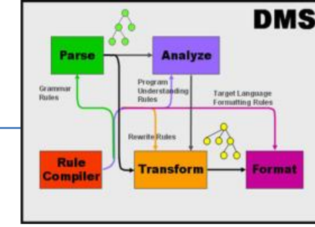
Transformation Engine

- ✓ Source Code Patterns
- ✓ Source Rewrite Rules
- ✓ Condition on analysis results

Designed for the real world

- ✓ Millions of lines
- ✓ Thousand of files
- ✓ Mixed languages
- ✓ Parallel processing
- ✓ Full Unicode/Native char sets
- ✓ Actively used and enhanced for over 20 years

Case Study: Large Banking System



Analyze: How are software elements connected?

Business Challenge: Programmers create new defects when making application changes

- Unhappy Customers (ATMs went offline for a day)
- Escalating maintenance costs

Technical Problem: Code and data dependencies obscured by application (Hogan) architecture

- 16+ Million lines of IBM Enterprise COBOL, JCL extended by Hogan
- 15,000 software components

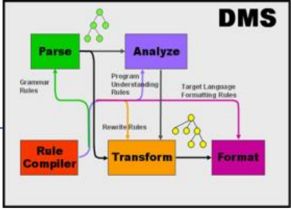
Solution: DMS custom analyzer visualizing Component Connectivity

- Define custom parser for Hogan to DMS
- Parse COBOL, JCL, Hogan DBs
- Compute interconnections
- Graphically display connections

Benefit: Impact/change analysis now possible

U.S. Social Security Administration:
Same Problem but 200M SLOC!
Now in use for 3+ years

Case Study: B2 Bomber Mission Software



Change: 100% Automated Migration Jovial to C

Business Challenge: Existing B-2 Mission software incapable of meeting new requirements

- Legacy JOVIAL software needed to be modernized
- Internal teams unable to re-write application

Technical Problem: Legacy Software Complexity

- Failed internal manual and semi-automated translations
- 1.2 million lines Black code; ***SD not allowed to see source***

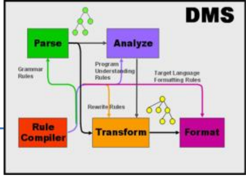
Solution: Migrated 100% by DMS

- Define JOVIAL language from scratch to DMS
- Reuse existing definition for C target language
- ~6000 translation rules
- Delivered in 9 months

•**Benefit: Trustworthy solution for critical software**

Operational in
B2 Bomber fleet

Case Study: Avionics Software



Change: OS replacement/Architectural shift

Business Challenge: Highly successful C++ product line for many Boeing military aircraft

- Hundreds of C++ components,
  communicating on limited-bandwidth internal aircraft data bus
- Military wants to add video cameras to all aircraft
- Internal bus overwhelmed; desperately need QoS data delivery guarantees

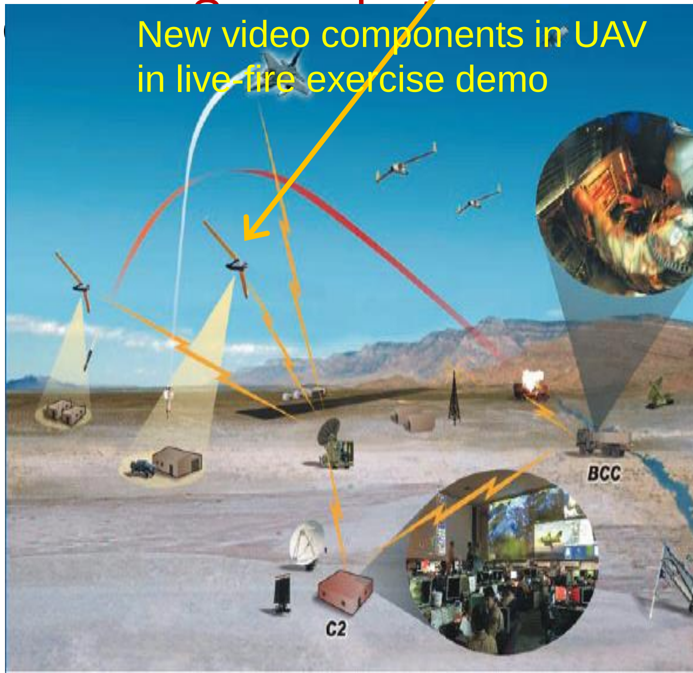
Technical Challenge: Replace legacy Boeing RTOS (no QoS) with CORBA/RT (QoS)

- Too big to do by hand: millions of SLOC
- Code architecture must change radically to match

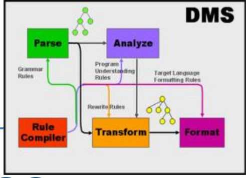
Solution: Mass change to replace legacy OS calls
then rearchitect

- Define C++ and Facet spec description to DMS
- **Add rules to map legacy OS calls to CORBA**
- **Add rules to reshape code into "facets"**

Benefit: 98% automated conversion of components
Savings of 1-2 man-months per component



Case Study: Chemical Plants



Change: Model/Migrate Software Running Manufacturing Process

Business Challenge: Trusted plant-controller computers starting to fail due to age

- Many different plants / **Thousands of control programs**
- Software had to be migrate to modern controller hardware
- Limited resources and time

Some plants now conve

Technical Challenge: Manual conversion impractical for scale

- Can't be wrong or factory may "blow up"
- Assembly like language difficult to analyze

Solution: Automated Tool to recover abstract process control model from "assembly code"

- Define Dowtran from scratch to DMS
- **Define abstractions in terms of data flows** with conditional implementations
- **DMS matches legacy code via data flows** ("Programmer's Apprentice") to produce model
- Generate new controller code from model

Benefit: Reliable migration of safety critical software + huge cost savings + *design capture*

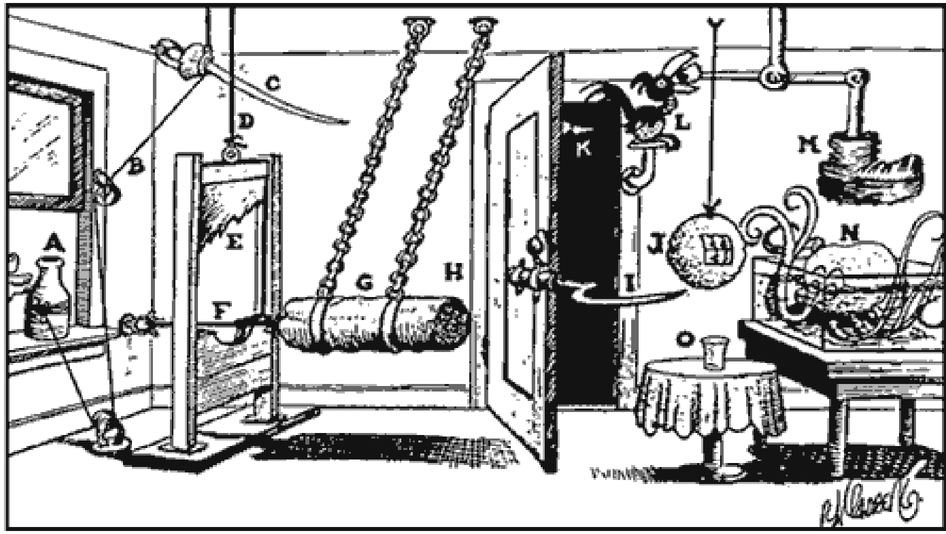
To a first order approximation,
there's no such thing as "new code".

There's only code
somebody else wrote yesterday,
that you want to change.

Software Engineering
State of Software Maintenance practice

- Theory: How to modify it?
  - How to describe a change?
  - Where to look for place to start?
  - How to make change?
  - How verify change?
  - How to verify rest of system?

?



- Practice: Key Problems
  - No specification
  - No design documents one can trust
  - Growing scale
  - No repeatable tests
  - Scar tissue from repeated hacking
- How are these systems going to have long lives?

How do we reconcile MBE and Software Maintenance?

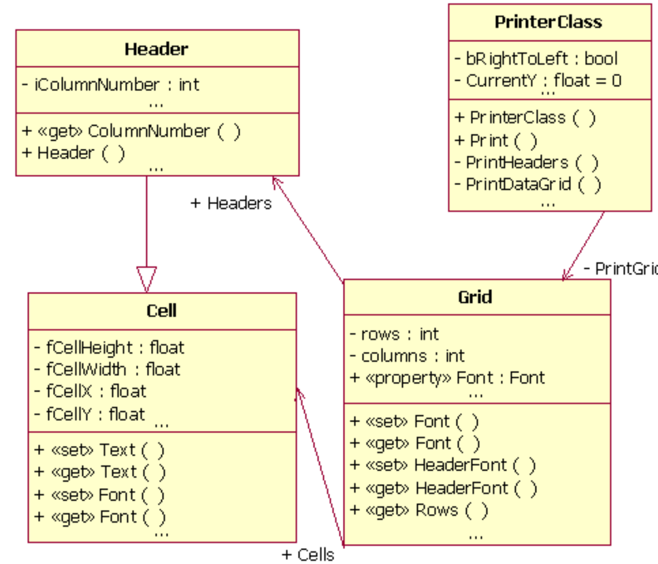
- We need a model of software construction

- Then we need a model of maintenance deltas wrt construction
  - How to specify?
  - Where to look for place to start?
  - How to make change?
  - How to determine parts of code that are inconsistent with desired change?
  - How verify change?
  - How to verify rest of system?

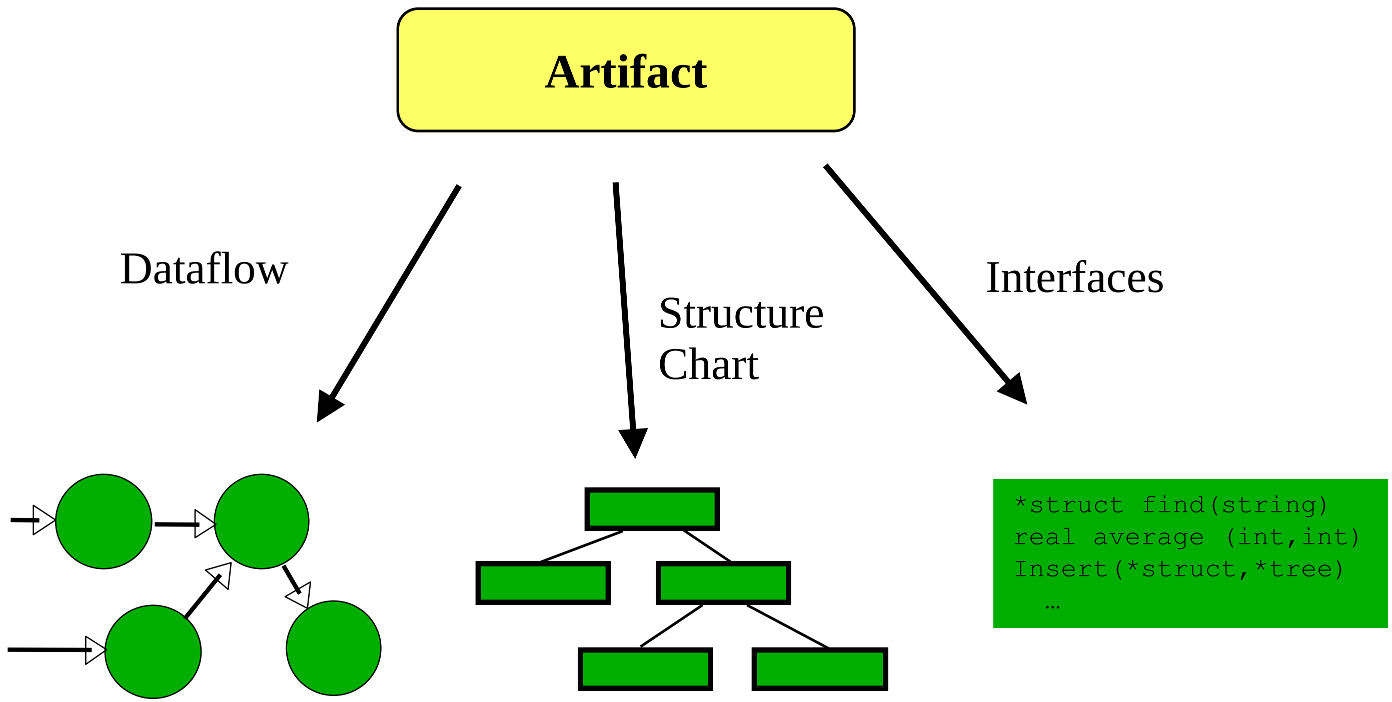
So Why the Maintenance Mess?

- System has a Design
  - Problem Domain
  - Implementation Steps
  - Components, connections
  - *…what else?*
- Consult Design for Guidance
  - Done!

- *Ooops. I forgot the Design!*
  - maybe didn’t know how to save it



Conventional Designs are just Artifact Projections



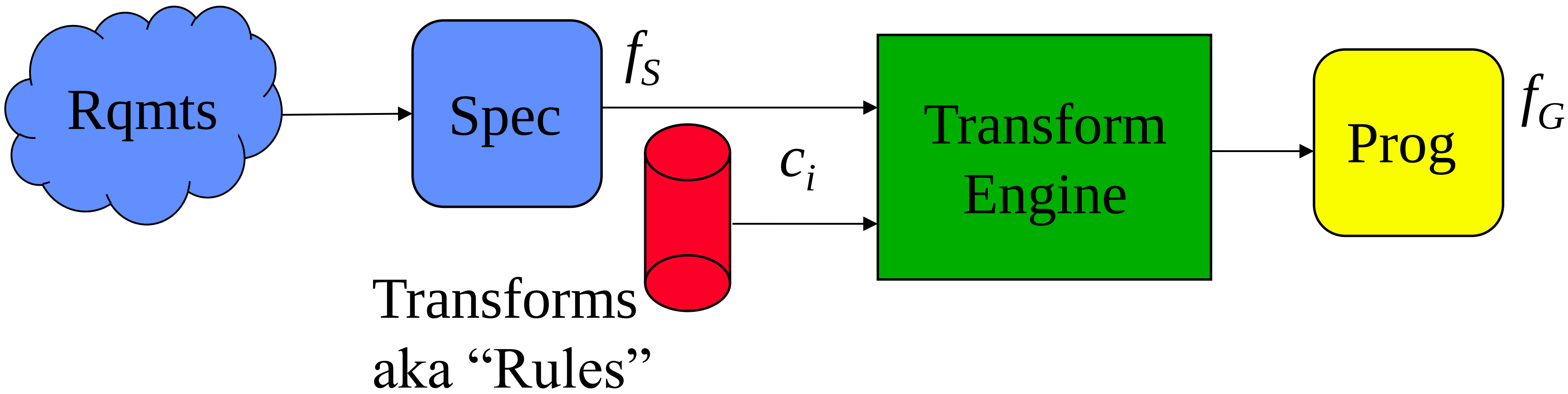
- Don’t explain all properties of artifact
- Don’t provide rationale for chosen structure
- *Wrong* to call these “designs”... perspectives?

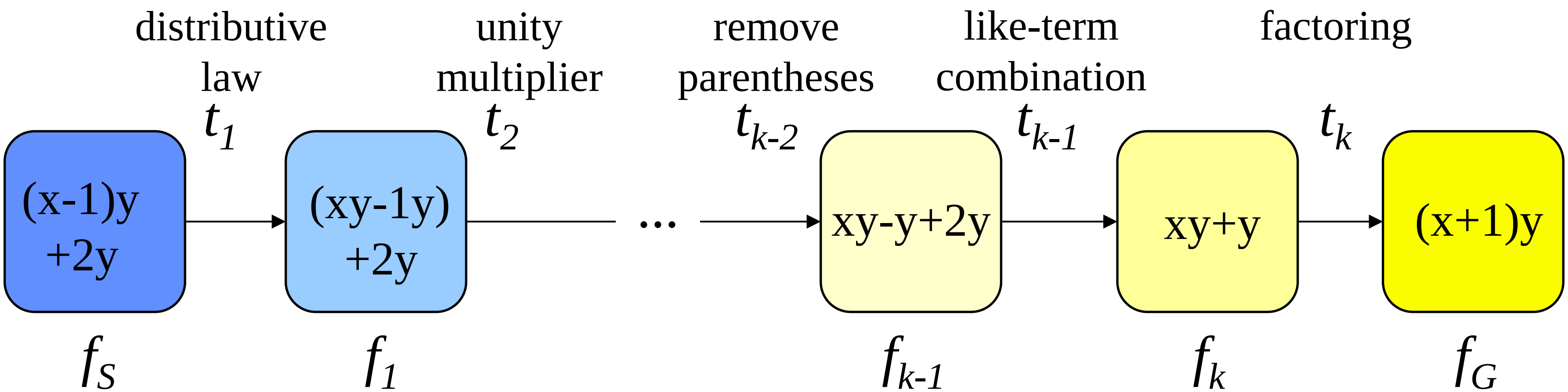
Better Model of Design? *Transformational* Explanation

- Based on *transformational program* generation
- Components:
  - *Formal* Specification
    - Functionality (what program does)
    - Performance (other program properties: size, speed, OS, languages)
      - Properties of the program, not the construction process
  - Transformation steps converting spec into code
    - Carry out implementation of Functionality fragments
  - Rationale for how steps contributes to desired performance
    - Direct contribution: optimizations, refinements
    - Indirect contributions: problem decomposition, solution preparation
    - Rejected Alternatives

Key Technology: Transformation Systems

Stepwise Semiautomatic Conversion of Specs to Code





What is a *transform*?

A partial function from specs/programs to specs/programs

t: Spec → Spec

Incredibly useful

Procedural: Compilers, YACC, VLSI synthesizers, refactorings

Often represented as a *rewrite rule with pattern variables*:

$x+0 \Rightarrow x$

optimization

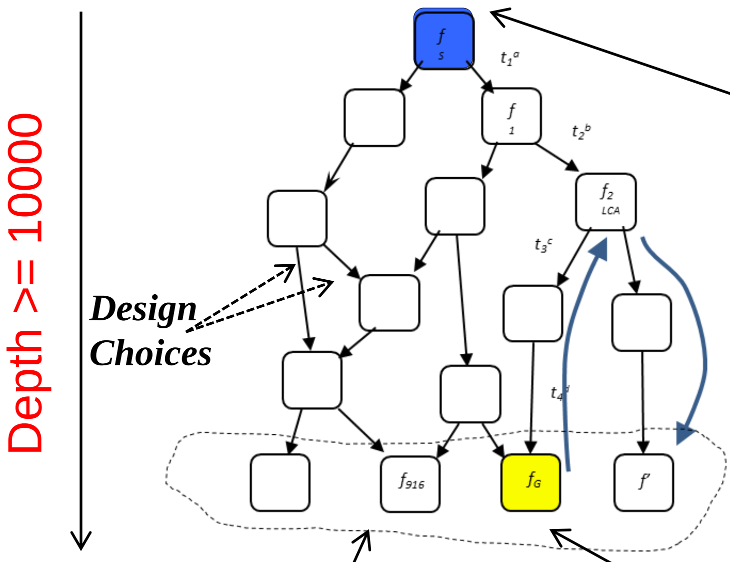
MDE world

t(Locator): Spec → Spec

```
sum(var,limit,vector) ⇒
   begin local s=0,var;
       do var=1 to limit;
         s=s+vector(var); enddo
      return s
   end
```

refinement

The design space caused by multiple transformation choices

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Dimensionality = 2;
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(* Program *)
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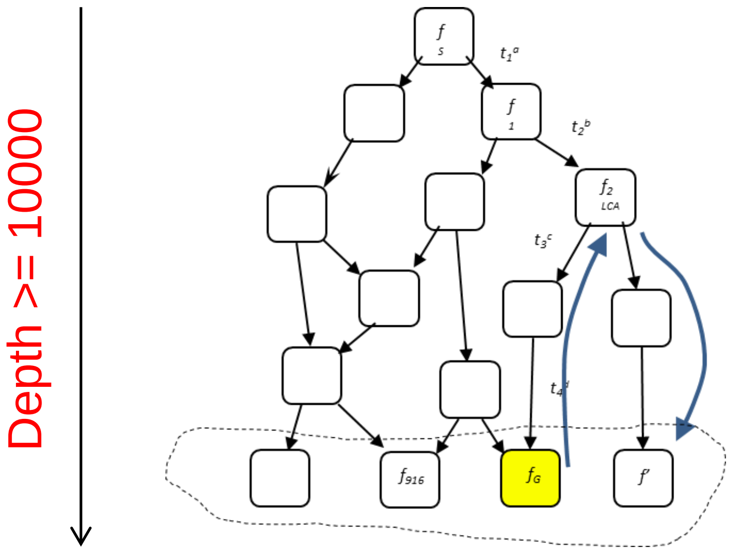
```

Sinapse Specification of 3D Sonic Wave Modelling Code
[Kant92: Synthesis of Mathematical Modeling Software]

Same function, different performance

10,000 lines of CM Fortran

Design Space Navigation
How to make implementation decisions?

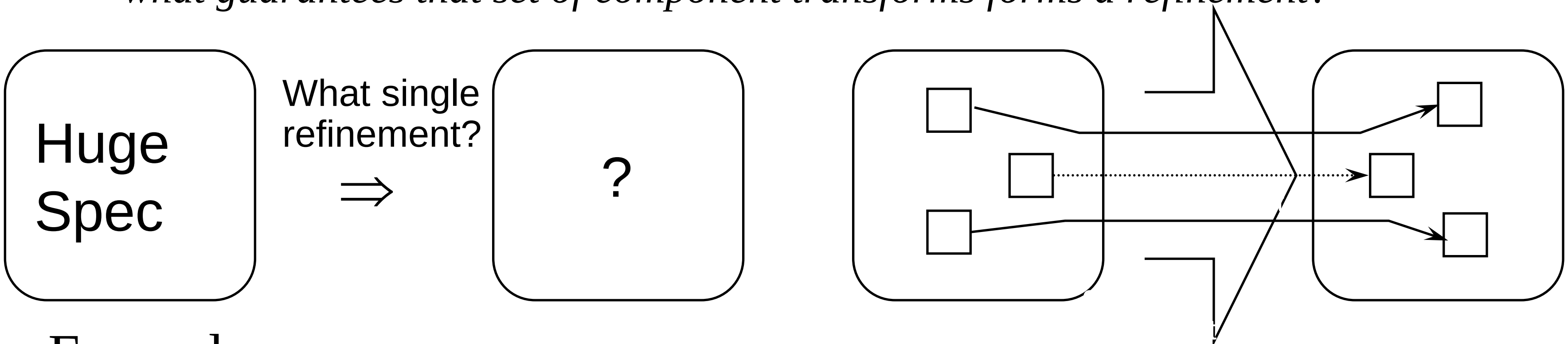


- Huge number of intermediate states
- At each intermediate state *many* transforms are applicable
- *How does machinery choose the "right" transformations to apply?*
- *How do we provide guidance? ("metaprogramming")*

MDE world often seems to offer only one choice

The Consistent Refinement Problem

- Not always practical to *refine* specification as monolith
  - so must “refine” parts of spec “independently”
  - must have separate “refinements” for parts (*component transforms*)
  - *what guarantees that set of component transforms forms a refinement?*



- Example:
  - Want to refine stack spec having **push** and **pop** actions
  - “Refine” **push** by adding new cell to linked list
  - “Refine” **pop** by decrementing pointer to array
  - Resulting program obviously doesn’t work!
  - The pair **push** ⇒ linked list & **pop** ⇒ array is *not* a refinement
- Must some how bundle sets of transforms as a consistent refinement

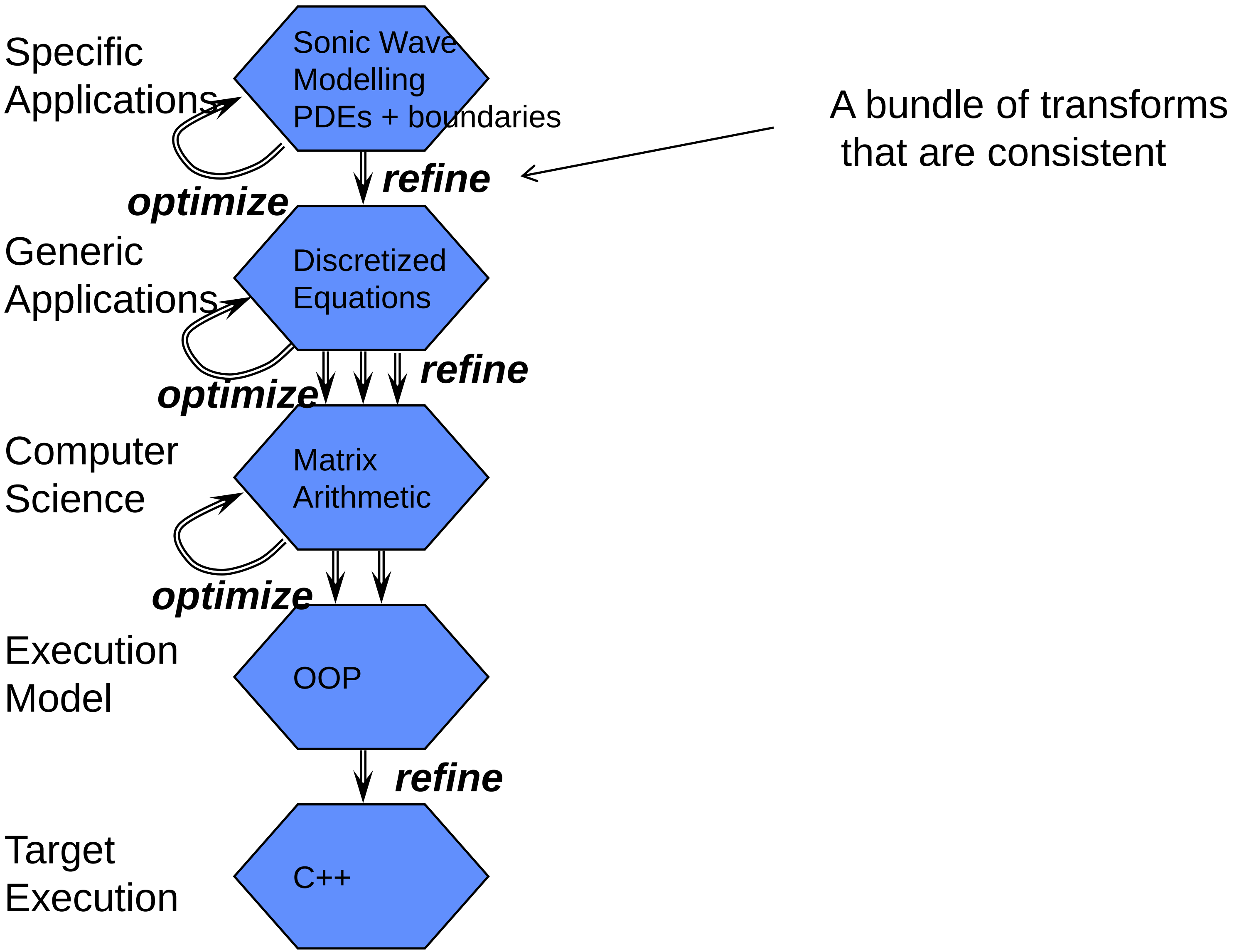
The Draco Paradigm[1]

DSLs and design space navigation

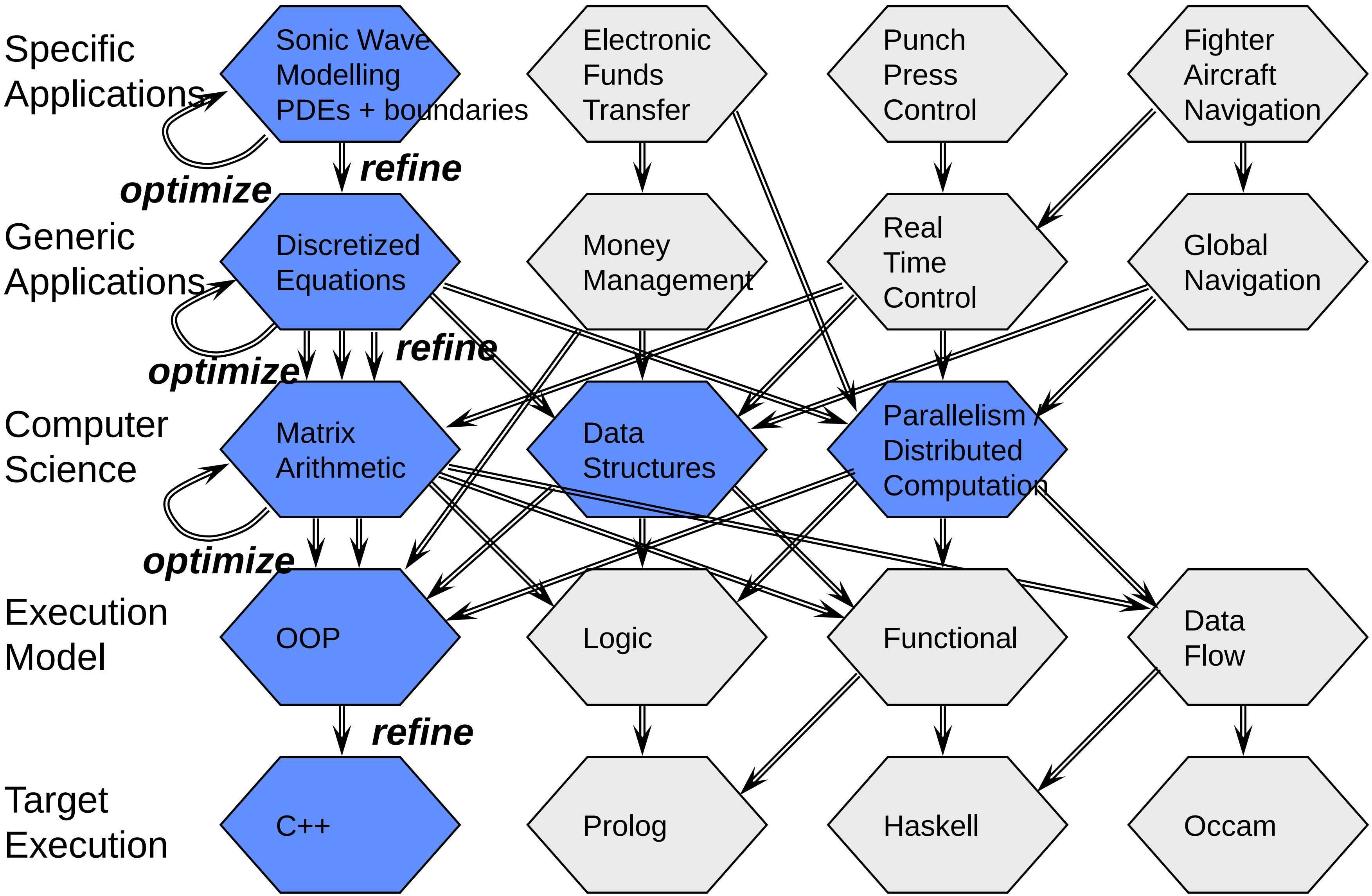
- Define a DSL
  - A Notational system for describing *problems* or *solutions* with shared agreement on meaning among domain experts
  - Tension between ease of problem specification and ability to achieve efficient implementation
    - ==> Sometimes contain implementation hints
- Specify application in DSL
- Repeat
  - Apply optimizations at DSL level
    - Uses domain-level knowledge *lost* in next step
    - Multiple optimizations added as knowledge as convenient
  - (Consistent) Refinement to lower DSL levels
    - Introduces implementation methods
    - Multiple refinements provide different results/performance
- Stop when final set of DSLs is executable

[1] [Neighbors78]

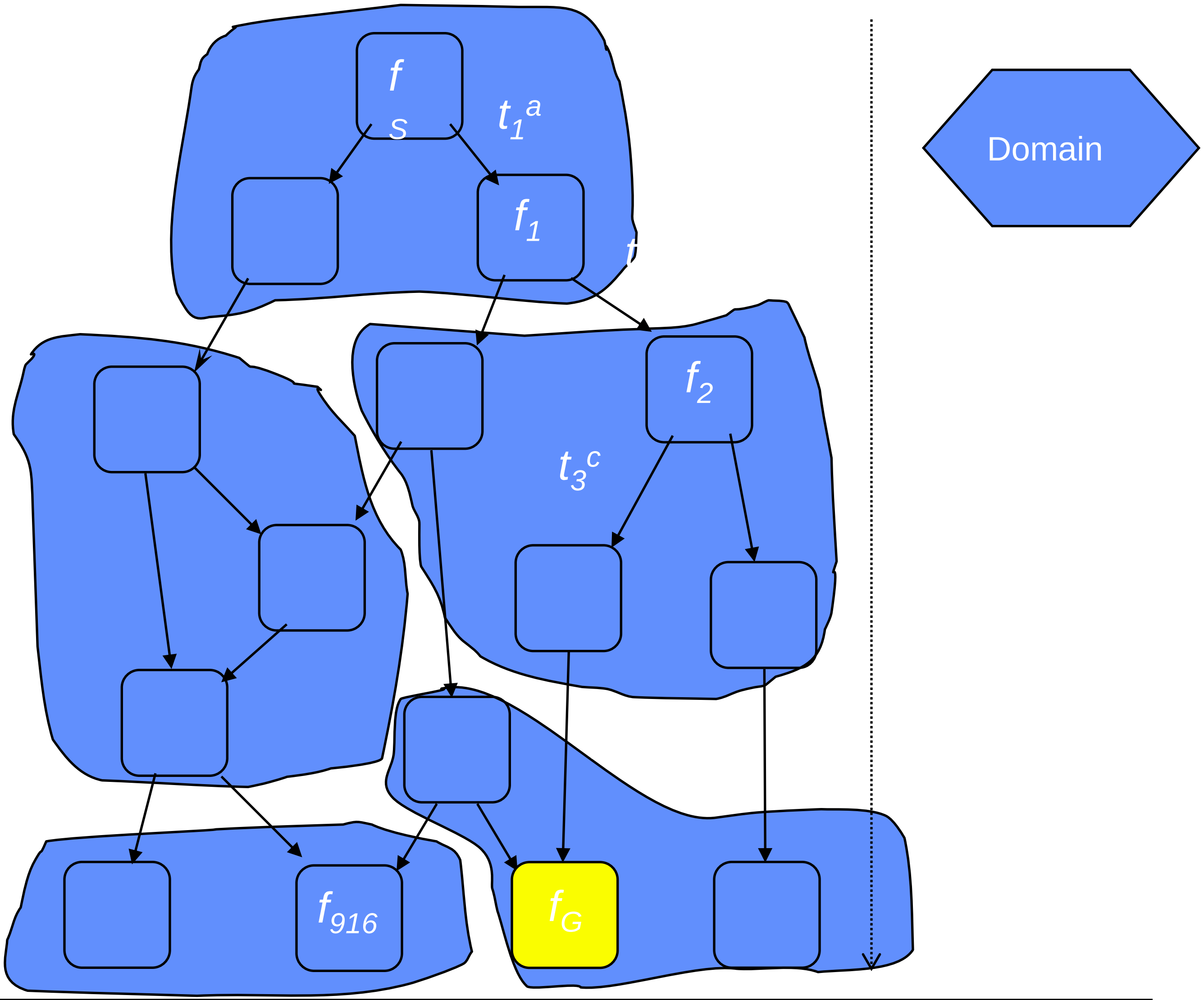
A Domain Network (for Sinapse)



A Reusable Domain Network



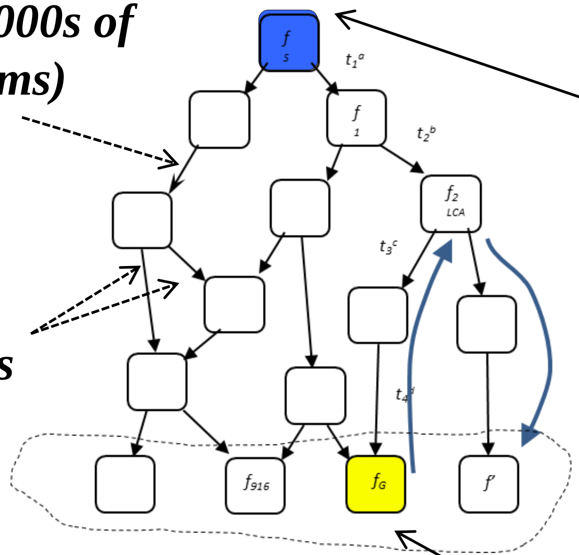
Navigating the implementation space using Domains



Design = details from Abstract Implementation Space => specification, transforms, choices

Implementation Steps (1000s of transforms)

Design Choices

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Sinapse Specification of 3D Sonic Wave Modelling Code
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10,000 lines of CM Fortran

Paradigm: *Design Capture*
= spec, transforms, …

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Sinapse Specification of 2D Sonic Wave Modelling Code
[Kant92: Synthesis of Mathematical Modeling Software]

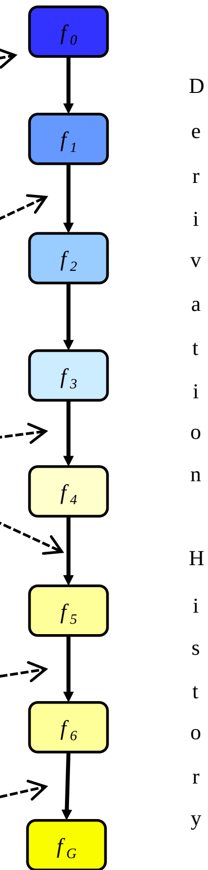
rho (*continuous*) →
rho (1000:1000:.001)

Implementation Steps (1000s of program transforms)

rho (1000:1000:.001)
→ ***…array of row ptrs…***

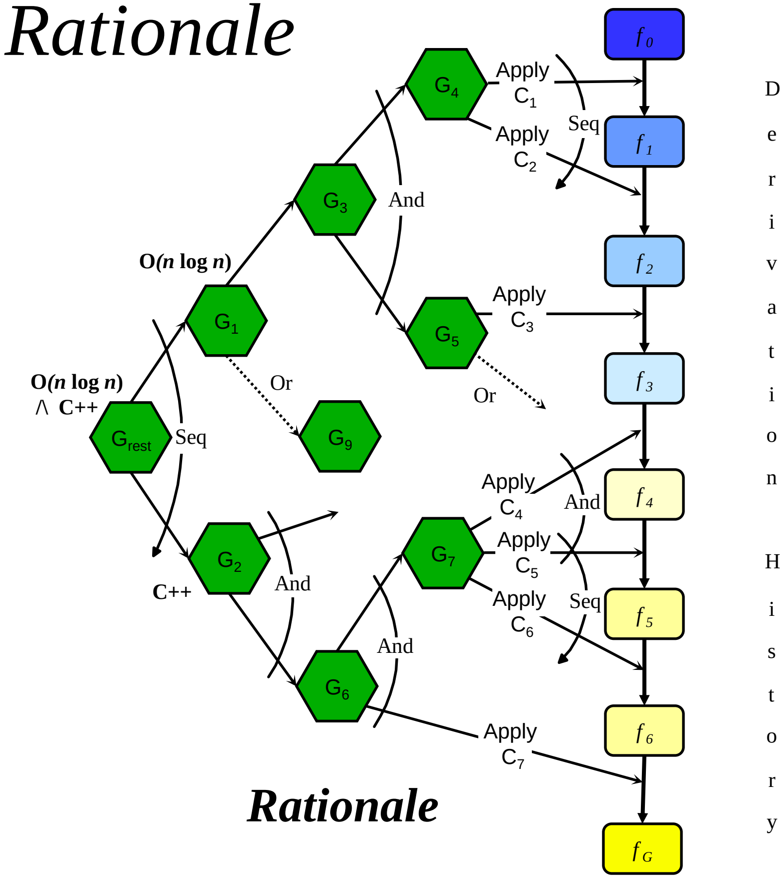
x+0 → x

10,000 lines of CM Fortran



Paradigm: *Design Capture with Rationale*

- Transformational Design
  - Functionality Spec (f_0) + Derivation
  - + Performance Spec (G_{rest})
    + Justification + Alternatives
- Metaprograms to construct design
  - Goal driven transform application

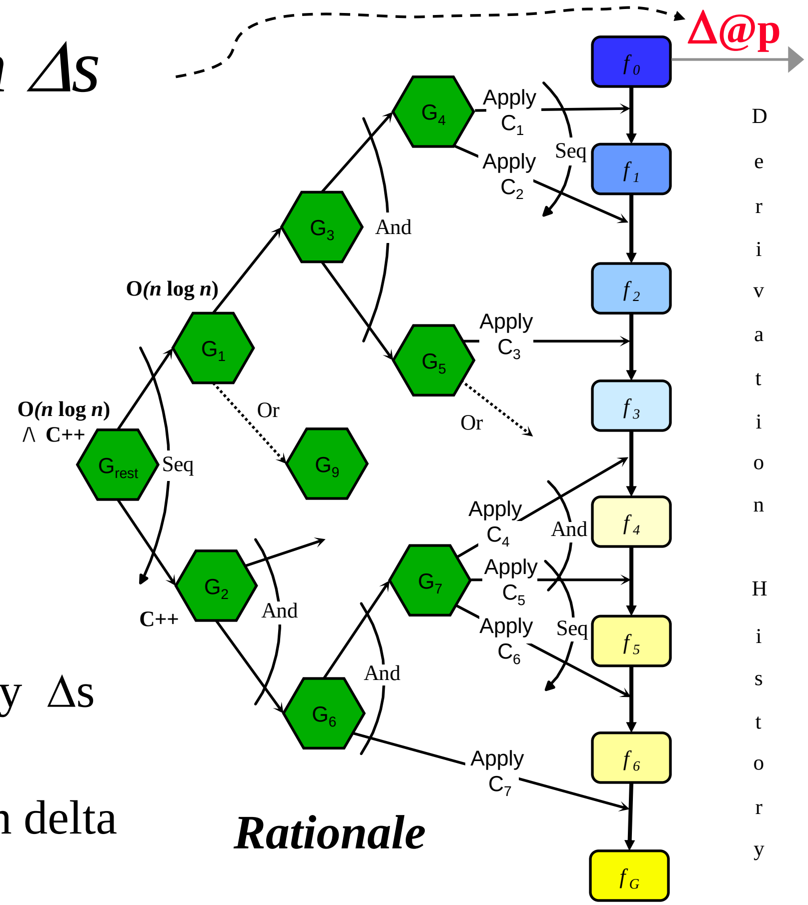


➔ *Transformational Design*

"[Baxter92 Design Maintenance Systems" CACM]

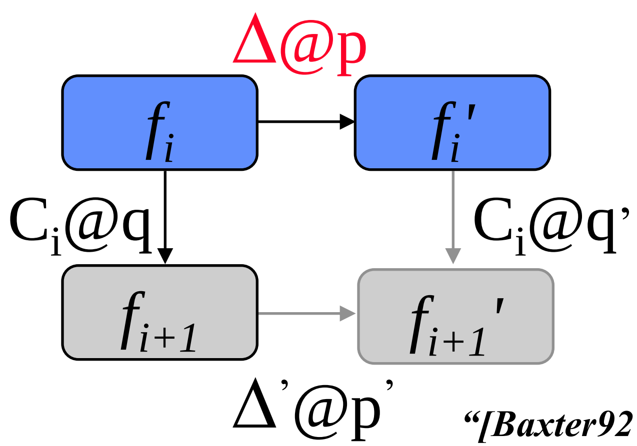
Paradigm: *Revising Design with Δs*

- Transformational Design
  - Functionality Spec (f_0) + Derivation
  - + Performance Spec (G_{rest})
    + Justification + Alternatives
- Metaprograms to construct design
  - Goal driven transform application
- *Incremental Updates as Δs*
  - Specification, Performance, Technology Δs
  - Δs drive design revision:
    retain transforms that *commute* with delta



$$\Delta@p(C_i@q(f_i)) = C_i@q'(\Delta'@p'(f_i))$$

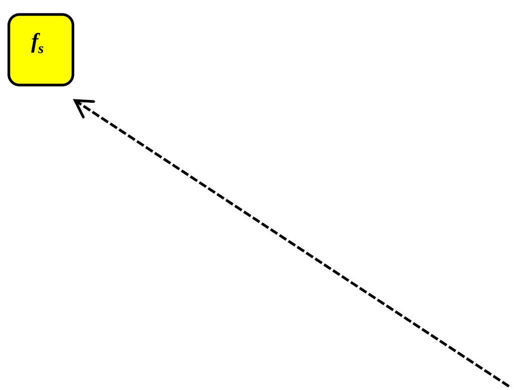
Commuting Transforms



➔ ***Transformational Design***

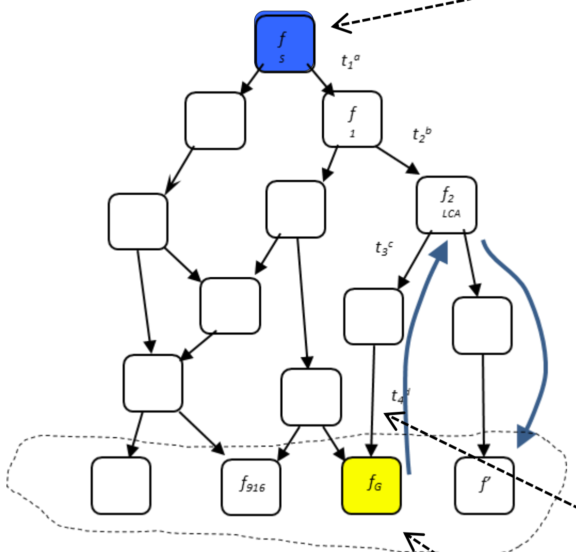
"[Baxter92 Design Maintenance Systems" CACM]

Reality: *What to do when all you have is code?*



1. You *are here with*
10,000 lines of CM Fortran

Practical: *(Incremental) Design Recovery*

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```

2. Recover design/spec by "running" transforms backwards!

1. You *are here with 10,000 lines of CM Fortran*

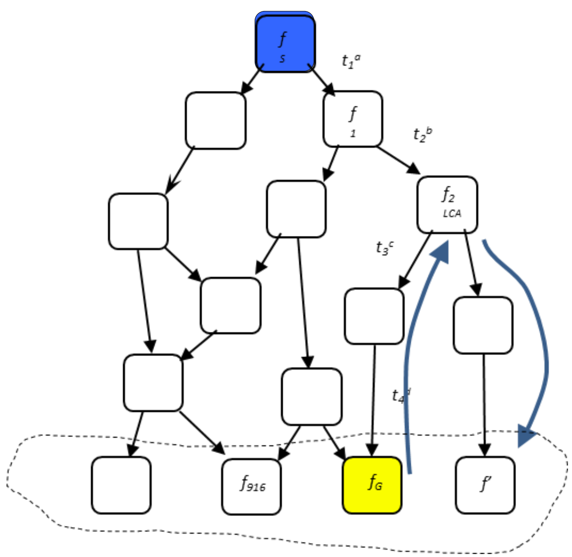
Syntax patterns:
Matching idioms to concepts to reverse engineer

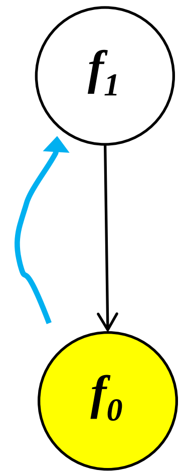
```
int getBankCode(int bn) {
        int bc;

        if (bn > 10 & bn <= 25)
                bc = 3;
        else
                bc = 0;

        return bc;
}
```

A code idiom






```
...
bc=get_bank_co
de(bn)
...
```

```
...
if (bn>10 & bn < 25)
   bc=3;
else
    bc = 0;
...
```

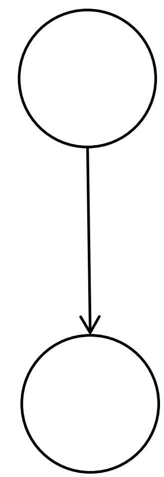
Syntax patterns:
Matching idioms to concepts to reverse engineer

```
int getBankCode(int bn) {
        int bc;

        if (bn > 10 & bn <= 25)
                bc = 3;
        else
                bc = 0;

        return bc;
}
```

A code idiom



```
...
bc=get_bank_co
de(bn)
...
```

```
...
if (bn>10 & bn < 25)
   bc=3;
else
    bc = 0;
...
```

```
default base domain C~ISO9899c1990.

public pattern
   get_bank_code(bank_number:IDENTIFIER,
        bank_code:IDENTIFIER):statement_seq
  = "if (\bank_number > 10 & \bank_number <= 25)
       \bank_code = 3; // bank of ethel
     else
       \bank_code = 0; // unknown bank number
    ".
```

Code pattern for idiom

Converting a real semaphore implementation back into abstraction

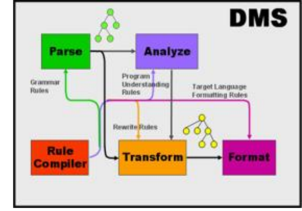
```
RT:UnLock ; unlock block of code whose semaphore is in (X)
  intds              ; lock out the world momentarily
  inc scb:count,x    ; anybody in queue ?
  bgt RT:ITSX        ; b/ no, done releasing resource
  stx itempx         ; save pointer to semaphore
  ldx scb:tcbq,x     ; pointer to TCB to activate
  ldd tcb:nexttcb,x  ; find pointer to TCB following that
  stx itempd         ; save pointer to TCB to activate
  ldx itempx         ; pointer to semaphore
  std scb:tcbq,x     ; remove task from SCB queue
  ldx itempd         ; pointer to TCB to make ready to run
RT:ITSC ; insert task at (X) into ready queue and switch contexts if needed
; Assert: interrupts are disabled here
  jsr RT:ITIQ        ; insert task into ready queue
  ldx RT:TCBQ        ; are we still highest priority task ?
  cmpx RT:CTCB       ; ... ?
  beq RT:ITSX        ; b/ yes, pass control to caller
  ldx #RT:ISCH       ; no, force task switch
  jmp RT:SInt        ; by interrupt to task scheduler
RT:ITSX inten        ; enable interrupts and return to caller
  rts
```

```
procedure RT_UnLock(x: ptr to semaphore)
begin
  // unlock specified semaphore
  V(x); // release a resource unit
  return ; // return to original caller
end;
```

30 transformation rules including de-optimizations

Baxter, I. and Mehlich, M.
Reverse Engineering is Reverse Forward Engineering.
Working Conference on Reverse Engineering, IEEE, 1997.
http://www.semanticdesigns.com/Company/Publications/WCRE97.pdf

Draco in reverse
Mainframe HLASM to C code




```
CVTUCB    BMOD  (0,5)
          USING UCBOB,R3
          CLC   UCBNAME,=C'UCB'
          BNE   UCB3
          LH    R0,UCBCHAN
          LA    R2,4(0,R2)
          LA    R4,4
HEXLOOP   SRDL  R0,4
          SRL   R1,28
          CH    R1,=H'10'
          BL    HEXLOW
          SH    R1,=H'9'
          STC   R1,0(0,R2)
          OI    0(R2),X'C0'
          B     HEXHI
HEXLOW    STC   R1,0(0,R2)
          OI    0(R2),X'F0'
HEXHI     BCTR  R2,0
          BCT   R4,HEXLOOP
          MVI   0(R2),C'/'
          B     UCB4
UCB3      MVC   2(3,R2),UCBNAME      UCBNAME
          MVC   0(2,R2),=C'/0'
UCB4      EMOD
```

```
void fnCvtucb(char *pc, struct Ucbob *pUcbob)
  { unsigned int i; unsigned int j; signed int k;
    if (memcmp(pUcbob->Ucbname, "UCB",
                 sizeof pUcbob->Ucbname) == 0) {
      i = (int) pUcbob->Ucbchan;
      pc += 4;
      k = 4;
      // label: hexloop
      do {
        j = i & 0x0f;
        i = i >> 4;
        if (j >= 10) {
          *pc = j - 9;
          *pc |= 0xc0;
        } else {
          // label: hexlow
          *pc = j;
          *pc |= 0xf0;
        }
        // label: hexhi
        --pc;
        --k;
      } while (k != 0);
      *pc = '/';
    } else {
      // label: ucb3
      memcpy(pc + 2, pUcbob->Ucbname, 3); // ucbname
      pc[0] = '/', pc[1] = '0';
    }
    return;
  }
```

Several hundred transformation rules including de-optimizations, goto removal

Data Flow patterns:
Matching code with dataflows, *not syntax*

```
int getBankCode(int bn) {
        int bc;

        if (bn > 10 & bn <= 25)
                bc = 3;
        else
                bc = 0;

        return bc;
}
```

A code idiom

```
int displayInfo(int rn) {
        boe_lower = 10;
        bank_number = lookup(rn);
        tmp = bank_number;
        boe_upper = 25;
        chkh = tmp <= boe_upper;
        if (!chkh)
                logOutOfRange(tmp);
        chkl = tmp > boe_lower;
        if (!chkl)
                logOutOfRange(tmp);
        chkr = chkh & chkl;
        if (chkr)
                logWithinRange(tmp);
        if (chkr) {
                boe_code = 3;
                printf("Bank of Ethel\n");
                tmp = boe_code;
        } else {
                u_code = 0;
                printf("Error: Unkown bank number.\n");
                tmp = u_code;
        }
        displayRecord(tmp,rn);
        return tmp;
}
```

Is the idiom somewhere in here? YES

```
default base domain C~ISO9899c1990.

public data flow pattern
   get_bank_code(bank_number:IDENTIFIER<~,
        bank_code:IDENTIFIER~>):statement_seq
  = "if (\bank_number > 10 & \bank_number <= 25)
       \bank_code = 3; // bank of ethel
     else
       \bank_code = 0; // unknown bank number
    ".
```

Data flow pattern for idiom

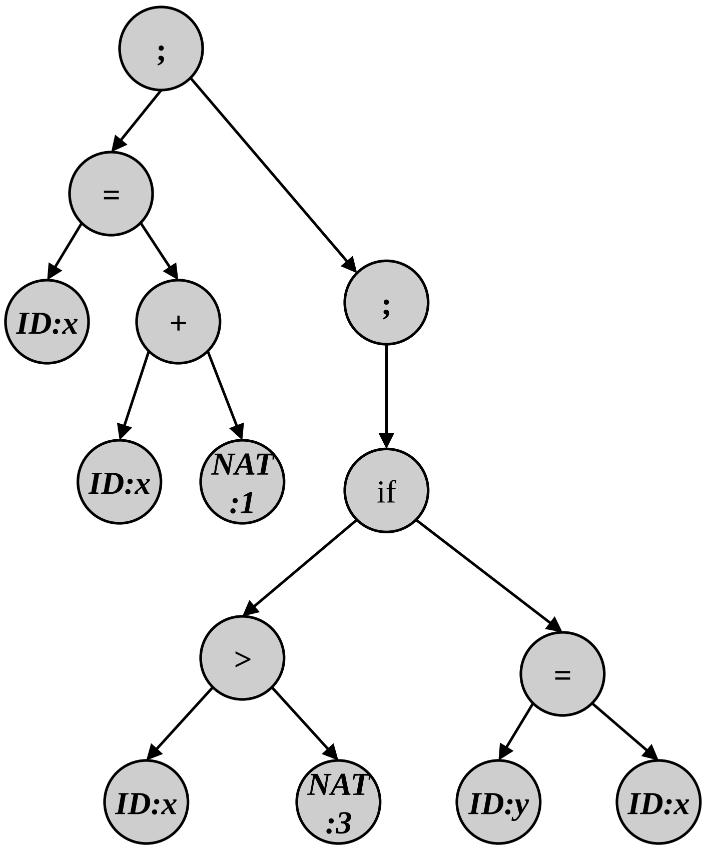
ASTs, Control Flow and Data Flow 0

Multiple Models of Code

```
x=x+1;
if x>3 then y=x;
```

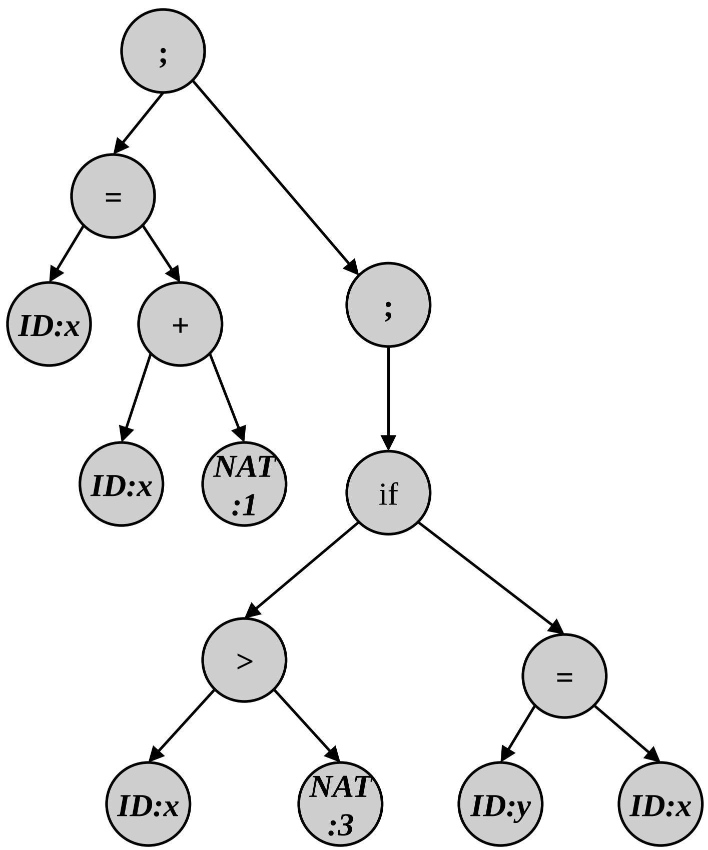
ASTs, Control Flow and Data Flow 1

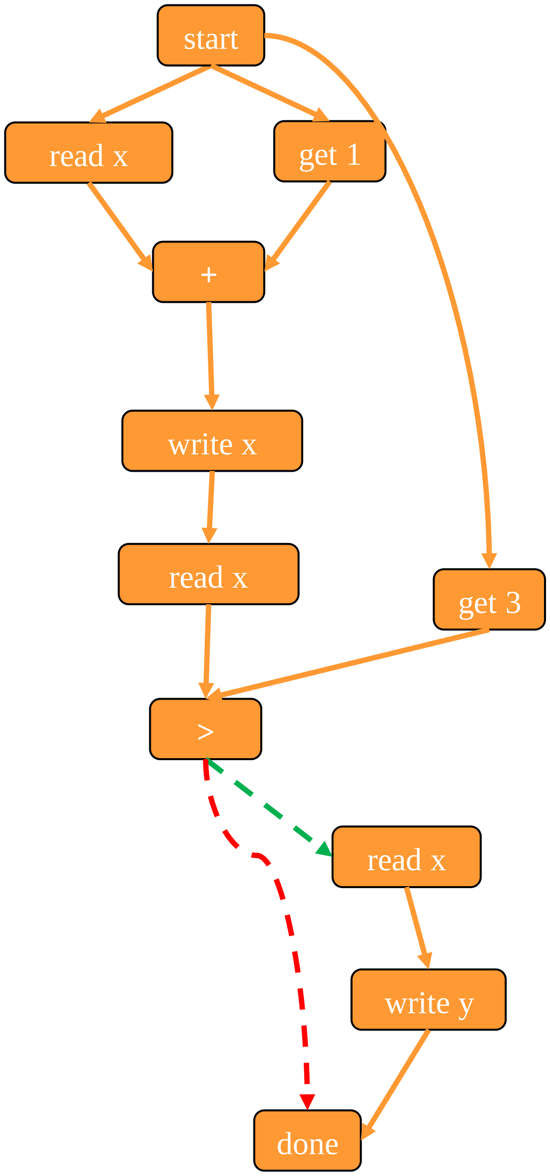
```
x=x+1;
if x>3 then y=x;
```



ASTs, Control Flow and Data Flow 2

```
x=x+1;
if x>3 then y=x;
```

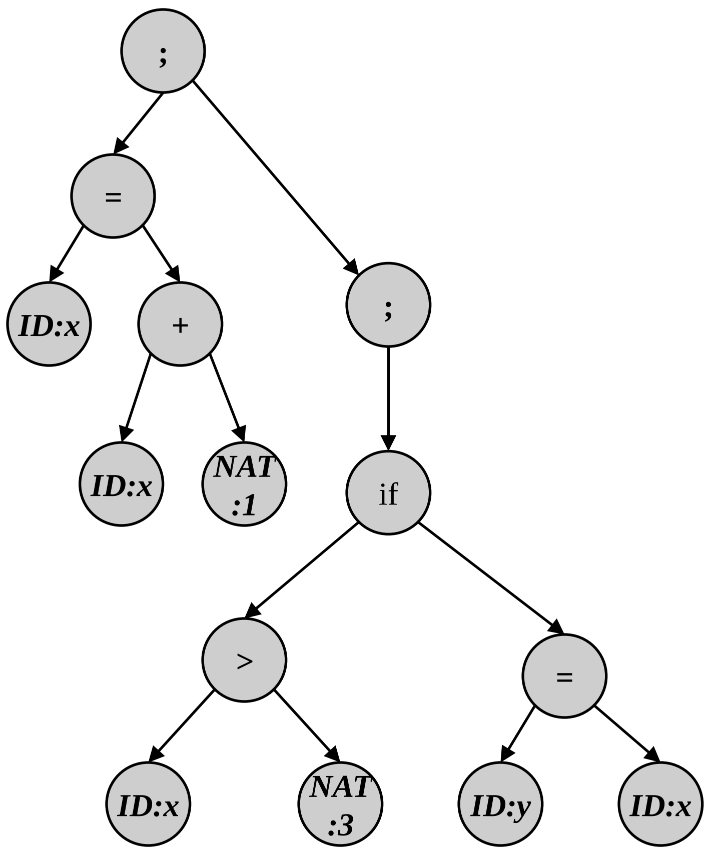


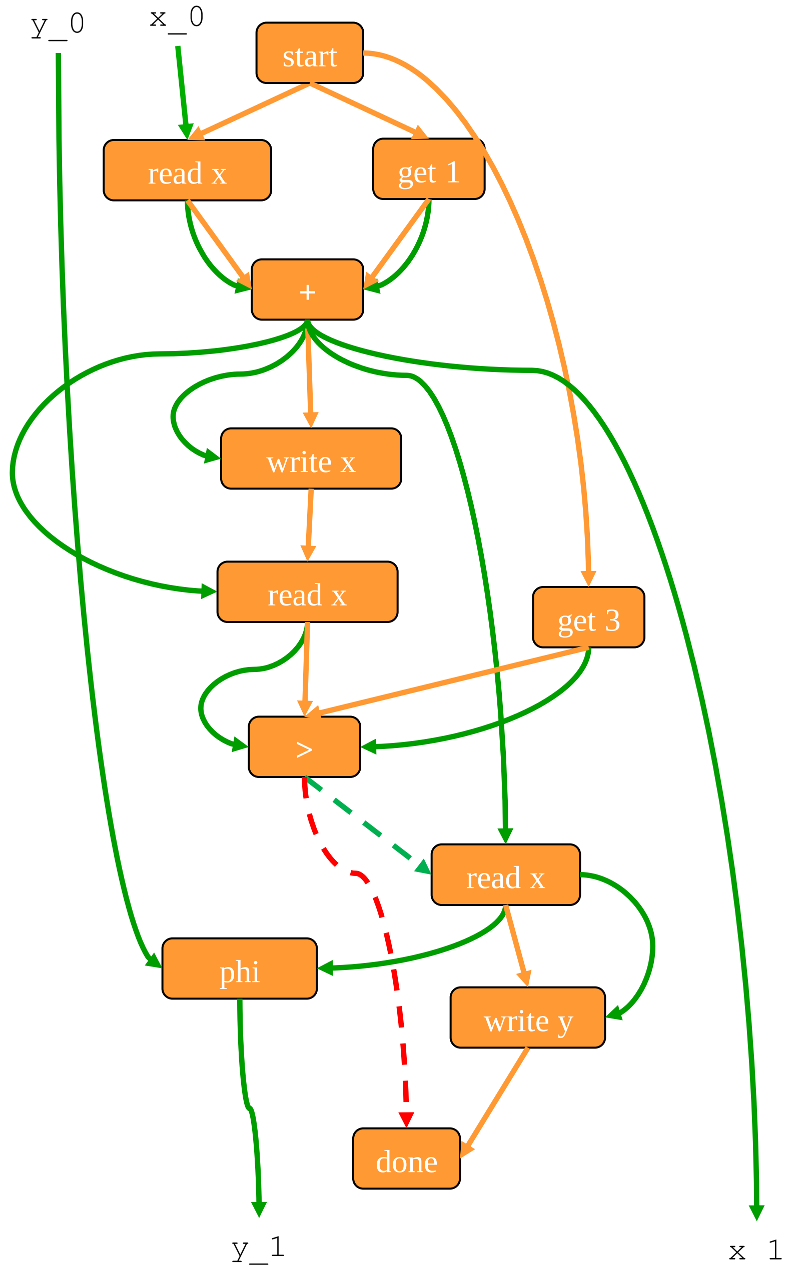


x_1

ASTs, Control Flow and Data Flow 3

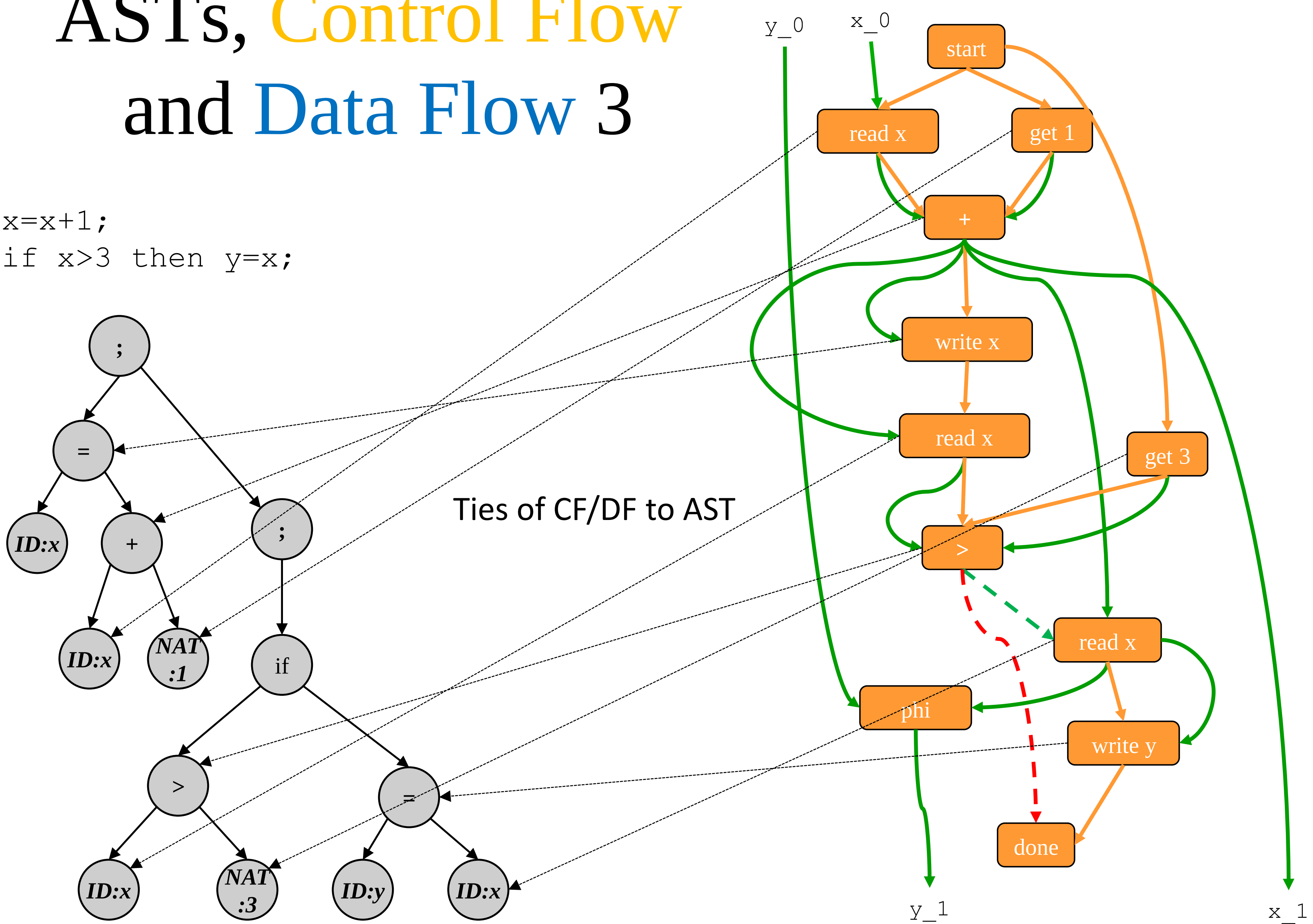
```
x=x+1;
if x>3 then y=x;
```





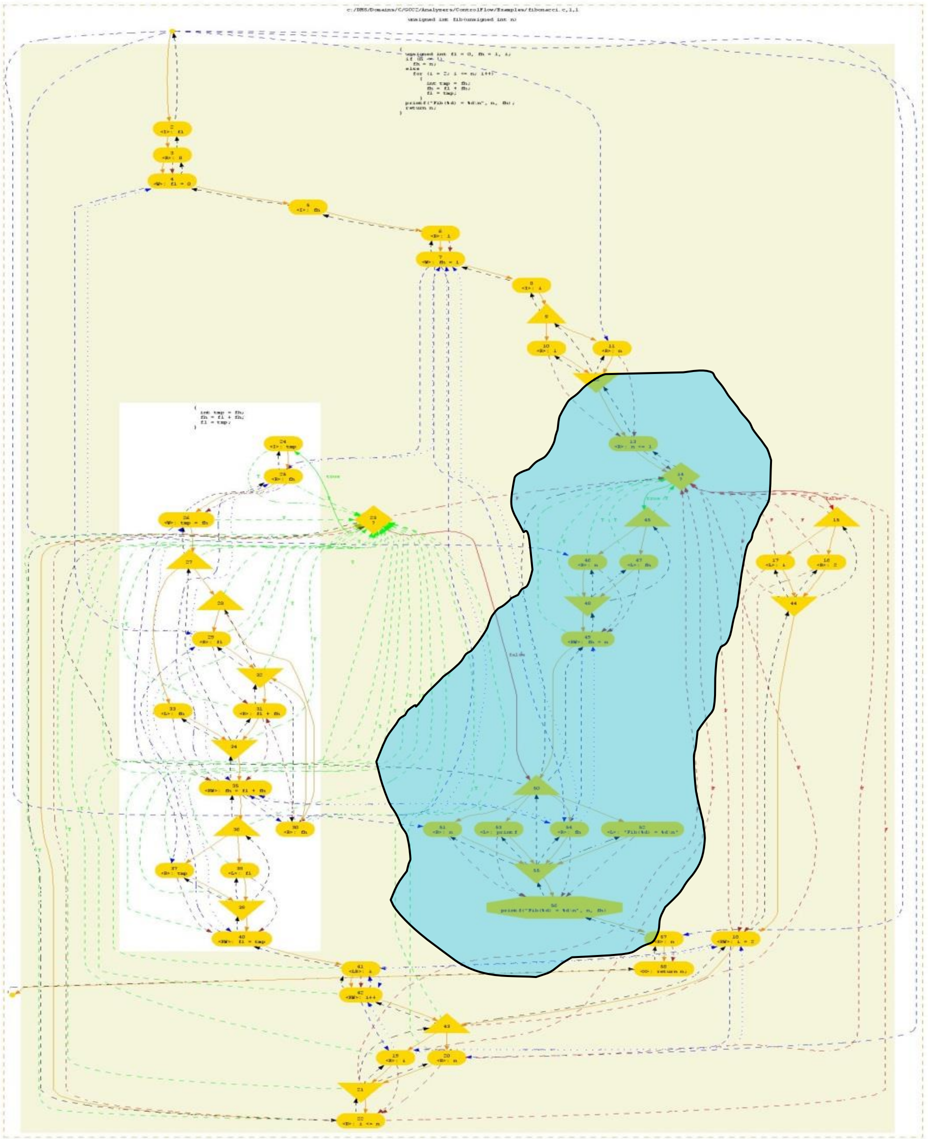
ASTs, Control Flow and Data Flow 3

```
x=x+1;
if x>3 then y=x;
```



What's inside a Computer Program?
A Data Flow Graph

```
int fibonacci(n)
{ unsigned int fl= 0, fh = 1, i;
  if (n <=1 )
    fh = n;
  else
     for (i= 2; i<=n; i++) {
        int tmp = fh;
        fh =fl + fh;
        fl = tmp;
     }
     print ("Fib(%d) = %d\n", n, fh);
     return n;
}
```



Big example wouldn't fit on football field…

Insight:
Maybe we can abstract away this detail

accumulate(fib#s)

COBOL tax computation Patterns

```
COMPUTE-TOTAL.
  MULTIPLY QUANTITY BY PRICE GIVING TOTAL-AMOUNT.
  IF TOTAL-AMOUNT > DISCOUNT-THRESHOLD
    MULTIPLY TOTAL-AMOUNT BY DISCOUNT-PERCENT
      GIVING DISCOUNT-AMOUNT
    DIVIDE 100 INTO  DISCOUNT-AMOUNT
    SUBTRACT DISCOUNT-AMOUNT FROM TOTAL-AMOUNT.
  ADD ONE TO VAT-RATE GIVING TAX-ADJUSTMENT.
  MULTIPLY TAX-ADJUSTMENT INTO TOTAL-AMOUNT.
  DISPLAY COMPANY-NAME.
  DISPLAY "Total: ", TOTAL-AMOUNT.
```

```
define TaxStyle = { `Added`, 'Multiplied' }
```

```
data flow pattern ComputeTax_by_multiplying(TaxRate:Constant,
                              Total:IDENTIFIER)
     :StatementSequence
   "Compute \Total = 1.0 + \TaxRate"
    if Value(TaxRate)>0.0 and Value(TaxRate)<1.0;
```

```
COMPUTE-INVOICE.
  MULTIPLY AMOUNT BY VAT-RATE GIVING TAX.
  Compute INSURANCE = INSURANCE_RATE * AMOUNT.
  ADD TAX TO AMOUNT.
  ADD INSURANCE TO AMOUNT GIVING INVOICE_TOTAL.
```

```
data flow pattern ComputeTax_by_adding(TaxRate:Constant,
                                  Total:IDENTIFIER)
          :StatementSequence
    Temp:IDENTIFIER
   "MULTIPLY \Total BY \TaxRate GIVING \Temp.
    ADD \Temp TO \Total"
    if Value(TaxRate)>0.0 and Value(TaxRate)<1.0
```

```
data flow pattern ComputeTax(TaxRate:Constant,
                             Total:IDENTIFIER):
               <HowTaxed:  TaxStyle>:
               StatementSequence
  case HowTaxed
     when `Added`
     ComputeTax_by_adding(TaxRate,Total)
     when 'Multiplied'
     ComputeTax_by_multiplying(TaxRate,Total)
  esac;
```

Choice/Decision data declarations 1

- Used to enumerate space of implementation choices
  - Each decision represents selection of specific alternative for a choice
  - Often there are complex relations across decisions
  - Stack-as-array cannot realize "pop" using link-list operations
  - Data flow pattern for alternative depends on stack-as-array feature
  - Called *generic* types
- Patterns encode valid decision combinations with arbitrary boolean constraints
  - Matcher generates decision sets producing coherent dataflows

```
generic type stack_implementation =
 enum { `stack_via_singly_linked_list`
        `stack_via_double_linked_list`
        `stack_via_array_with_index` };
```

Choice/Decision data declarations 2

- Syntax: `generic type` *identifier* `=` *typedeclaration* `;`
- *identifier* is an RSL standard identifier
- *typedeclaration*:
  - `boolean`, with decision being `True` or `False`
  - `character` (Unicode)
  - `string` (of Unicode characters)
  - `natural`
  - `natural` *unsigned_constant* `..` *unsigned_constant*
  - `integer`
  - `integer` *signed_constant* `..` *signed_constant*
  - `float`
  - `float` *float_constant* `..` *float_constant*
  - `rational`
  - `rational` *rational_constant* `..` *rational_constant*
  - `enum {` *decision_literal_string*, … `}`
    with decision_literal_strings being `` ` ``*text*`` ` `` (accent grave)
  - *identifier* (referring to an already named generic type)
  - `*` (RSL attempts to infer the type based its usage)

Matrix Multiply in real programs

- Abstract operation A*B
  - Fundamental to thinking about application
  - Rarely coded that way
- May be implemented in code in many ways
  - Algorithmic variations
    - Triply nested for loops
    - Strassen (recursive decomposition)
    - Library calls (BLAS == Basic Linear Algebra Subprograms)
  - Different data representations
    - Contiguous Memory Block: (row or column major order)
    - Sparse Matrix
    - Upper/Lower Triangular Matrix
- Matcher must find "matrix multiply" *in face of variations*

Matching abstract concepts using dataflow instead of syntax

```
private data flow pattern AddInto
    (t: IDENTIFIER, -- target being updated
     s: IDENTIFIER  -- value to add to target
    ):statement
    = "\t += \s;" ? "\t = \t + \s;".
public data flow pattern MatrixMultiply
    <i: Implementation,
     ra: Representation, oa: Order,
     rb: Representation, ob: Order,
     rc: Representation, oc: Order>
    (n: IDENTIFIER <~, -- in: matrix size parameter
     m: IDENTIFIER <~, -- in: matrix size parameter
     p: IDENTIFIER <~, -- in: matrix size parameter
     a: IDENTIFIER <~, -- in: source matrix
     b: IDENTIFIER <~, -- in: source matrix
     c: IDENTIFIER ~> -- out: target matrix
    ):statement
  = case
      when i == `Explicit Code` then
        [i: IDENTIFIER, j: IDENTIFIER, k: IDENTIFIFER,
         s: IDENTIFIER,
         ta: IDENTIFIER, tb: IDENTIFIER, tc: IDENTIFIER.
          "for (\i=0; \i<\n; \i++)
             for (\j=0; \j<\p; \j++) {
               \s=0;
               for (\k=0; \k<\m; \k++) {
\ReadElement\<ra,oa>\(\a\,\n\,\m\,\i\,\k\,\ta\)
\ReadElement\<rb,ob>\(\b\,\m\,\p\,\k\,\j\,\tb\)
\tc = \ta * \tb;
\AddInto\(\s\,tc\)
               }
\WriteElement\<rc,oc>\(\c\,\n\,\p\,\i\,\j\,\s\)
            }"
        ]
      when i == `BLAS` then
        …
    esac.
```

```
private data flow pattern AddInto
    (t: IDENTIFIER, -- target being updated
     s: IDENTIFIER  -- value to add to target
    ):statement
    =  "\t += \s;" ? "\t = \t + \s;".
public data flow pattern MatrixMultiply
    <i: Implementation,
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     rc: Representation, oc: Order>
    (n: IDENTIFIER <~, -- in: matrix size parameter
     m: IDENTIFIER <~, -- in: matrix size parameter
     p: IDENTIFIER <~, -- in: matrix size parameter
     a: IDENTIFIER <~, -- in: source matrix
     b: IDENTIFIER <~, -- in: source matrix
     c: IDENTIFIER ~> -- out: target matrix
    ):statement
    = case
        when i == `Explicit Code` then
            [i: IDENTIFIER, j: IDENTIFIER, k: IDENTIFER,
             s: IDENTIFIER,
             ta: IDENTIFIER, tb: IDENTIFIER, tc: IDENTIFIER.
             "for (\i=0; \i<\n; \i++)
                for (\j=0; \j<\p; \j++) {
                   \s=0;
                   for (\k=0; \k<\m; \k++) {
             \ReadElement\<ra,oa>\(\a\,\n\,\m\,\i\,\k\,\ta\)
             \ReadElement\<rb,ob>\(\b\,\m\,\p\,\k\,\j\,\tb\)
             \tc = \ta * \tb;
             \AddInto\(\s\,tc\)
                                              }
             \WriteElement\<rc,oc>\(\c\,\n\,\p\,\i\,\j\,\s\)
             }"
            ]
        when i == `BLAS` then
            ...
        esac.
```
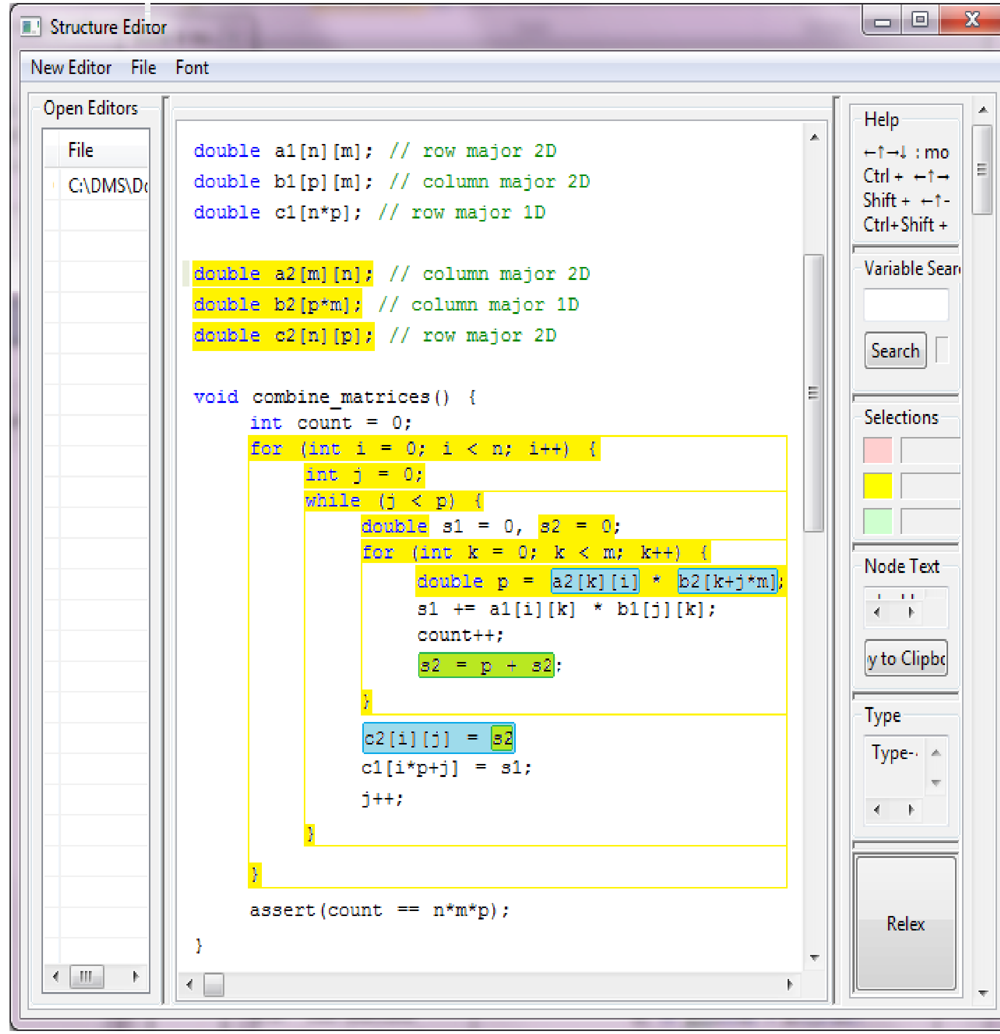

Dataflow Pattern for MatrixMultiply in C (2)
Represents 3456 variants with decisions

Matching abstract concepts using dataflow instead of syntax

```
private data flow pattern AddInto
     (t: IDENTIFIER, -- target being updated
      s: IDENTIFIER  -- value to add to target
     ):statement
     = "\t += \s;" ? "\t = \t + \s;".
public data flow pattern MatrixMultiply
     <i: Implementation,
      ra: Representation, oa: Order,
      rb: Representation, ob: Order,
      rc: Representation, oc: Order>
     (n: IDENTIFIER <~, -- in: matrix size parameter
      m: IDENTIFIER <~, -- in: matrix size parameter
      p: IDENTIFIER <~, -- in: matrix size parameter
      a: IDENTIFIER <~, -- in: source matrix
      b: IDENTIFIER <~, -- in: source matrix
      c: IDENTIFIER ~> -- out: target matrix
     ):statement
   = case
       when i == `Explicit Code` then
          [i: IDENTIFIER, j: IDENTIFIER, k: IDENTIFIFER,
           s: IDENTIFIER,
           ta: IDENTIFIER, tb: IDENTIFIER, tc: IDENTIFIER.
             "for (\i=0; \i<\n; \i++)
                for (\j=0; \j<\p; \j++) {
                  \s=0;
                  for (\k=0; \k<\m; \k++) {
\ReadElement\<ra,oa>\(\a\,\n\,\m\,\i\,\k\,\ta\)
\ReadElement\<rb,ob>\(\b\,\m\,\p\,\k\,\j\,\tb\)
\tc = \ta * \tb;
\AddInto\(\s\,tc\)
                  }
\WriteElement\<rc,oc>\(\c\,\n\,\p\,\i\,\j\,\s\)
                }"
          ]
       when i == `BLAS` then
          …
    esac.
```

Dataflow Pattern for MatrixMultiply for C (1)



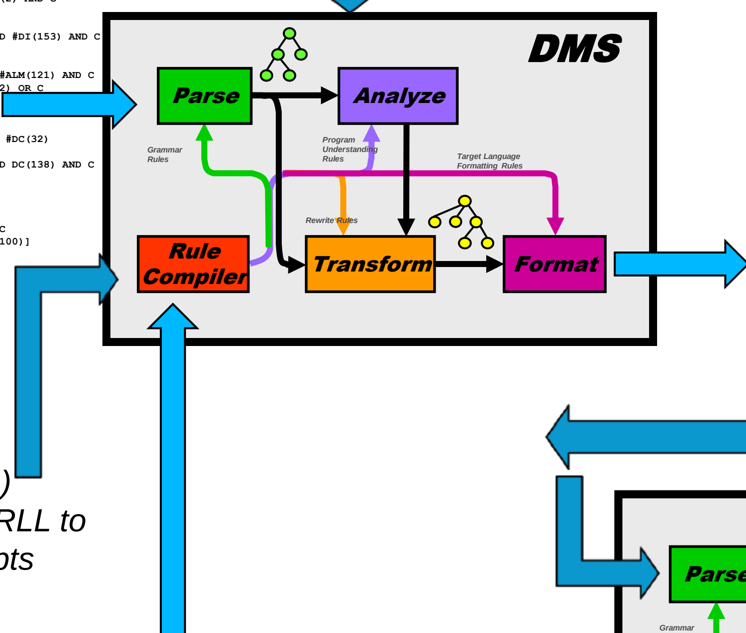
Matrix multiply abstraction found in code

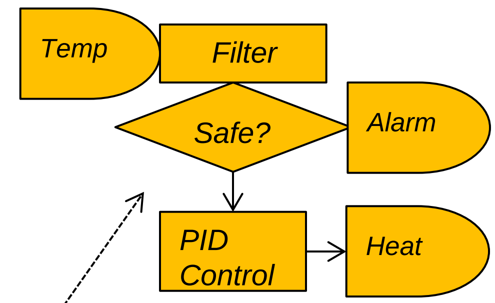
Model/Abstraction Based Migration (Dow Chemical)

Guidance

AS-IS

```
DO(252) IF STEP(255) AND #STEP(288)

DO(152) IF #DI(123) AND AI(1) GT AP(2) AND #DI(153) C
AND DC(144)

DO(152) IF #DI(123) AND AI(1) GT AP(2) AND C
[DO(153) AND #DI(153)] AND DC(144)

DO(152) IF #DI(123) AND DOT(153) AND #DI(153) AND C
AI(1) GT AP(2) AND DC(144)

DC(31) IF DO(101) AND #DI(101) AND #ALM(121) AND C
AI(121) GT AP(1) AND AI(121) LT AP(2) OR C
[DR(1) OR DR(2)]


DO(121) IF STEP(152) AND DC(31) AND #DC(32)

DO(166) IF STEP(155) AND DC(137) AND DC(138) AND C
#DC(139) AND #DC(140) AND #ALM(110)

DO(165) IF DO(166) AND #DI(166)

DO(195) IF AI(125) GT AP(3,80,100) C
OR [DO(195) AND AI(125) GT AP(4,25,100)]
…
```





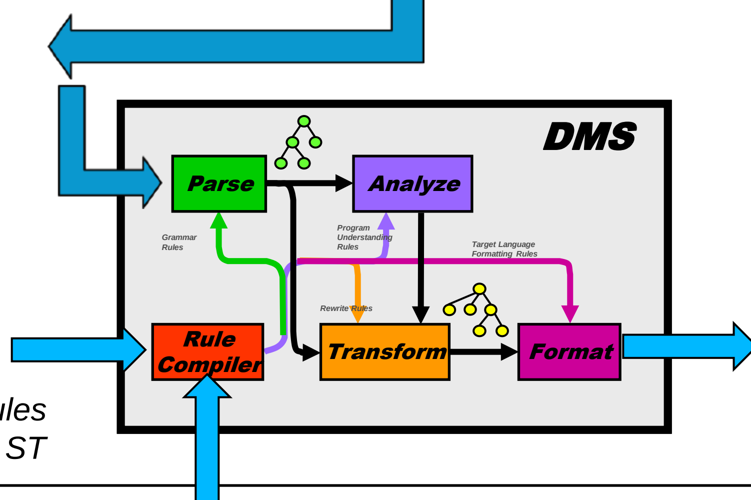
DCS Model: Process Control Concepts applied to specific factory

TO BE

Modern Controller Code (ST)

Translation (Abstraction) Rules from RLL to DCS concepts

Description of RLL
Description of Model



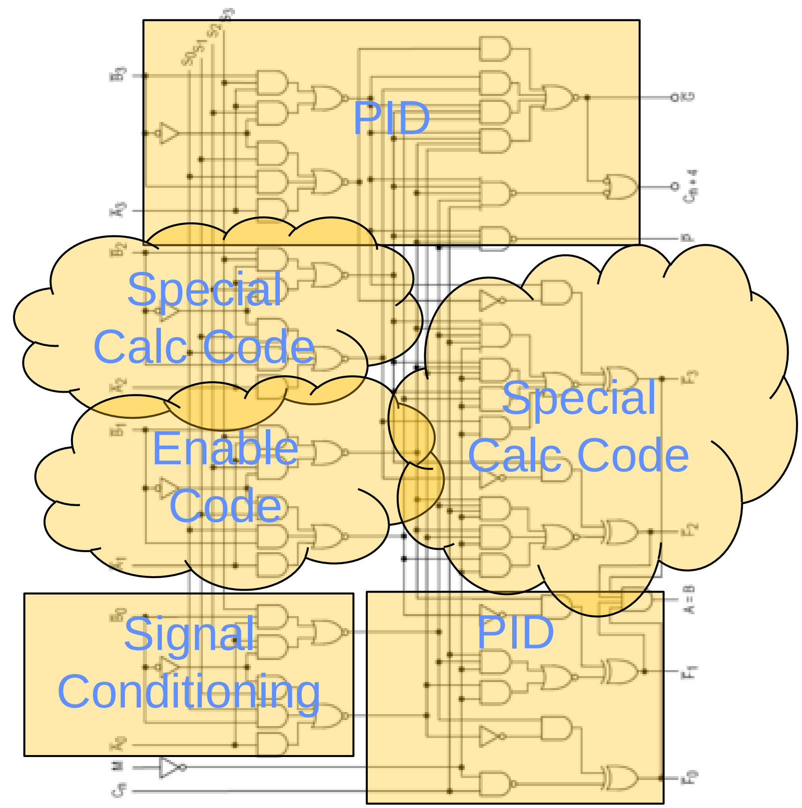

```
if(ST4)
then Timer(T42,4sec);
if(ST2)
then Timer(t41,4sec);
ST1X :=
   (ST1 ! ST4 & T42.dn)
    & (~ST1 ! ~ S1 ~ S2)
   ! first_scan );
ST2X :=
   ( ST2 ! ST1 & S1 & ~S2 )
   & ( ~ST2 ! T41.DN );
ST3X :=
   ( ST3 ! ST2 & T41.DN)
   & ( ~ST3 ! S1 ! ~S2 )
ST4X :=
   ( ST4 ! ST3 & ~S1 & S2 )
   & ( ~ST4 | T42.DN );
```

Translation Rules from Model to ST

Description of Model
Description of ST

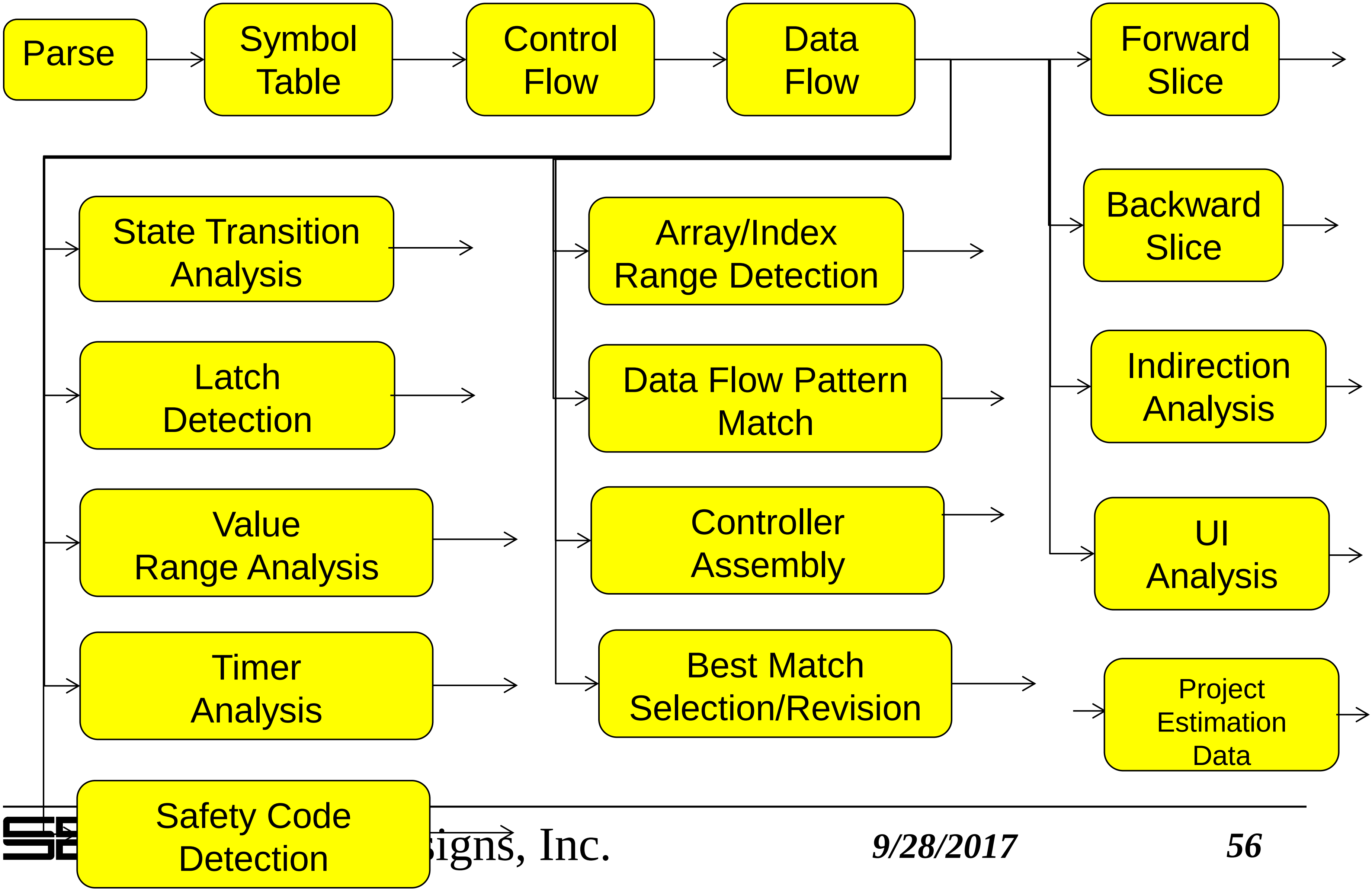
Dowtran interpreted as Dataflow

```
DO(252) IF STEP(255) AND #STEP(288)

DO(152) IF #DI(123) AND AI(1) GT AP(2) AND #DI(153) C
AND DC(144)

DO(152) IF #DI(123) AND AI(1) GT AP(2) AND C
[DO(153) AND #DI(153)] AND DC(144)

DO(152) IF #DI(123) AND DOT(153) AND #DI(153) AND C
AI(1) GT AP(2) AND DC(144)

DC(31) IF DO(101) AND #DI(101) AND #ALM(121) AND C
AI(121) GT AP(1) AND AI(121) LT AP(2) OR C
[DR(1) OR DR(2)]


DO(121) IF STEP(152) AND DC(31) AND #DC(32)

DO(166) IF STEP(155) AND DC(137) AND DC(138) AND C
#DC(139) AND #DC(140) AND #ALM(110)

DO(165) IF DO(166) AND #DI(166)

DO(195) IF AI(125) GT AP(3,80,100) C
OR [DO(195) AND AI(125) GT AP(4,25,100)]

DC(120) IF STEP(125) AND DM(120) C
OR [DC(120) AND #STEP(120)]

DO(150) IF 'LOGIC' AND DC(120)

DC(2) IF ALM(101) OR ALM(121) OR STEP(4) OR STEP(8)
DO(104) IF #DC(2)

DC(121) IF #DC(121) FOR DT(1,30,10)

DO(125) IF DC(121) AND ALM(125)
```

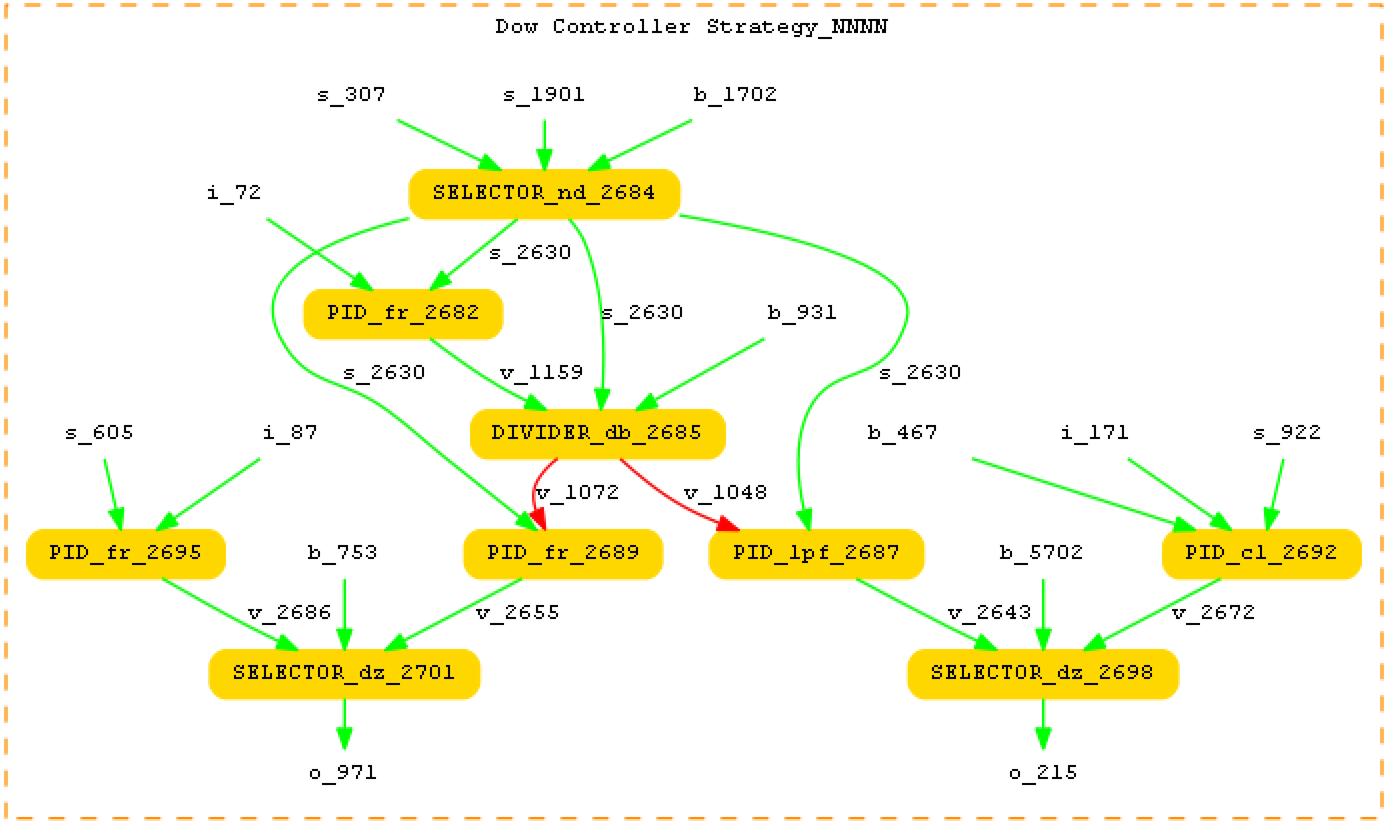


then matched by Dataflow Patterns

Various Dowtran Analyzers



Connecting Matched Dataflow Patterns using intervening dataflows



Dow Controller Strategy_NNNN

Lessons

- Program Transformation is better model than MDE
  - Perspective and theory enable us to understand and improve
- We throw away the design. Price is really high.
  - *STOP THAT*
- Clean design capture starts with new program
  - We have a theory about how to capture it
  - Can revise transformational designs
    - **Gives continuous maintenance model preserving design!**
- Apply reverse engineering to legacy software
  - Reconstruct the part of the design you need
  - Switch to continuous maintenance model
- Dataflow patterns provide one kind of RE
  - Proven in practice on real code (Dow Chemical)

Speaker Biography

Dr. Baxter has been building system software since 1969, when he built a timesharing system on Data General Nova serial #3. In the mid-seventies, he built real-time, single user, multi-user systems and locally distributed OSes on 8 bit CPUs.

Realizing that software engineering was largely enhancement of existing code rather than building new code, and that the OS architectures were conceptually similar but shared no code, he went back to graduate school to learn more about reuse of knowledge in software maintenance. He studied program transformation tools for code generation and modification, obtaining a PhD from UC Irvine in 1990.

At the Schlumberger Computer Science lab, he worked on generation of parallel CM-5 Fortran code for sonic wave models from PDEs. He spent several years as consulting scientist for Rockwell Automation working on automating factory control.

In 1996, he founded Semantic Designs, where he is now CEO and CTO. At SD, he architected DMS, a general purpose program transformation engine, used in commercial software reengineering tasks, and he designed and implemented PARLANSE, a task-parallel, work-stealing programming language in which DMS is implemented.

He has been project lead on applying DMS to re-architect large C++ applications. Recent work includes automated recovery of chemical factory process control models from low-level industrial controller software to enable migrations to new process control platforms.

Abstract: Supporting Forward and Reverse Engineering with Multiple Types of Models

Many model-based tools work with single models, which capture some abstraction of a target software system of interest, with intent to convert the abstract description into a runnable computer program somehow. These tools usually provide some type of model-to-model transforms to carry out operations appropriate for the abstraction level of "the" model, and model-to-text transforms to generate low-level program source code. The model-to-model and model-to-text transforms are treated differently; one difference is that model-to-model transforms (may) compose, but model-to-text transforms by definition do not compose.

We have found it practical to mix high level models of programs with low-level models of source code, using domain-specific notations for each, and applying composable transformations (both reifying and abstracting) to both.

This talk will provide an intuitive unified view of how "models" and "code" can be treated consistently, and how transforms between them may be harnessed for both forward and reverse engineering.

A practical version of such a tool must be able to (meta)model a variety of models and source code, and allow specification and execution of transformations across these.

We will describe an effective tool for reverse engineering "assembly code" for running large-scale chemical plants back to abstract process control models, and then forward engineer those models to a completely different industrial control language, preserving the critical elements of factory control. This realizes the vision of (ADM/MDA) of "architecture-driven modeling of legacy applications into reifiable models. The implementation uses a combination of abstract syntax trees, data-flow graphs, and what amounts to graph-grammars, and mixes the analysis and transformation of these. Special support for reverse engineering low level code is provided by data flow pattern graphs. This reverse/forward engineering tool is realized using a commercial program transformation (DMS).

The resulting tool is being used by a Fortune 100 company to re-engineer the process control code for roughly 1000 factories.