Field-Sensitive Program Dependence Analysis

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Joint work with:

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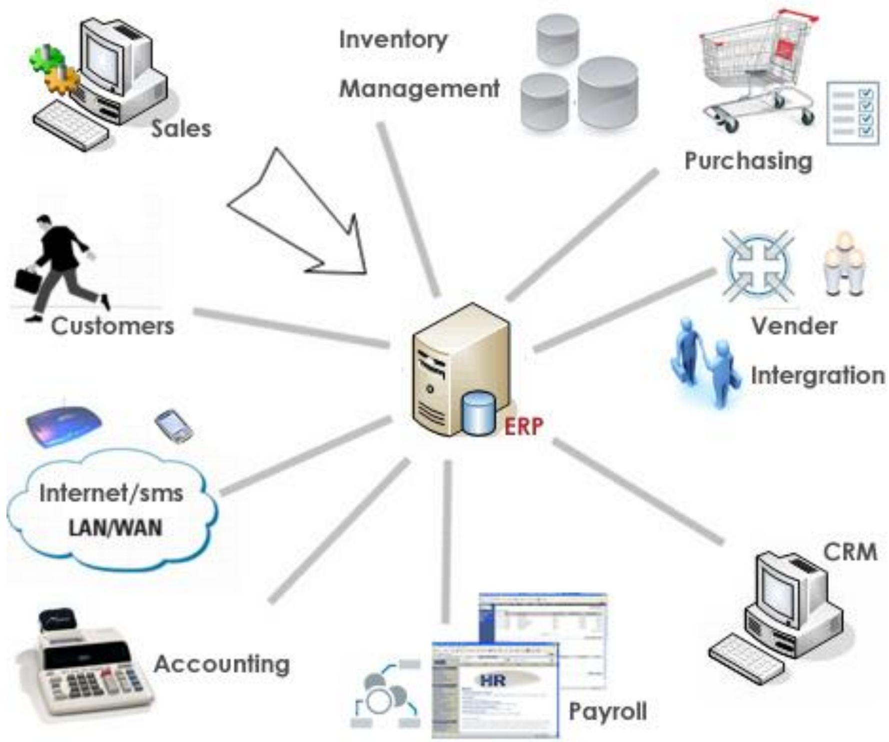
Agenda

- ERP systems
  - The need for tools
  - Challenges
- Field sensitive analysis
  - Algorithm
  - Empirical study
- Architecture
  - Usability
  - Analyzing large programs

ERP Systems

- Critical processes of the organization
- Cross-organization
- Highly integrated
- DataBase centric
- A few vendors
    - SAP
    - Oracle
    - …

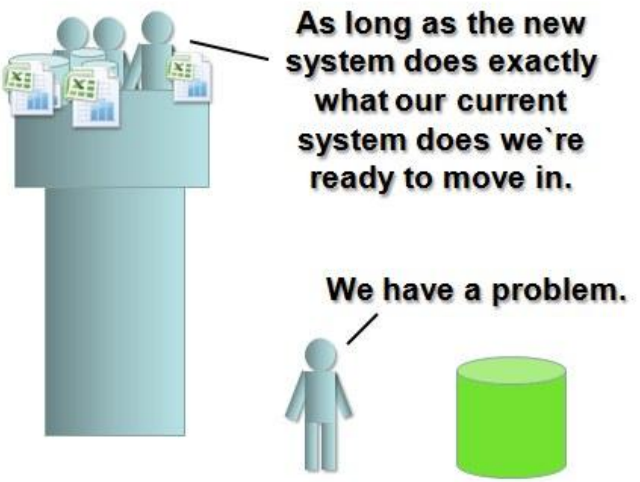


ERP Users

- Higher Education and Research
- Travel and Transportation
- Automotive and defense
- Telecommunications
- Manufacturing
- Public Sector
- Healthcare
- Banking

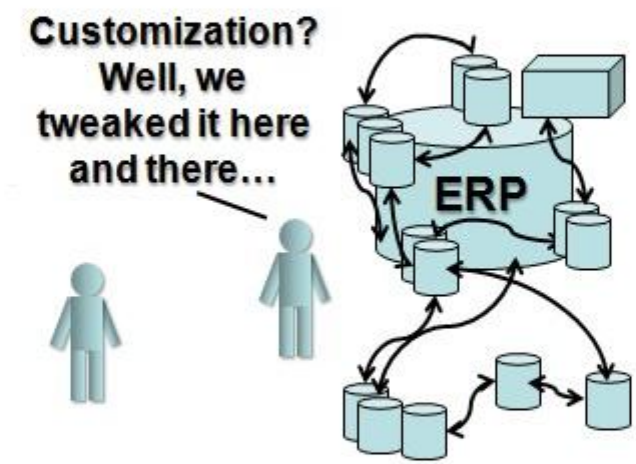
Business Specific Needs

- Packaged Application
  - Standard code base
  - Cannot use as-is
- Recommended Customization
  - Setting properties
  - Interaction with the system
  - Minimal

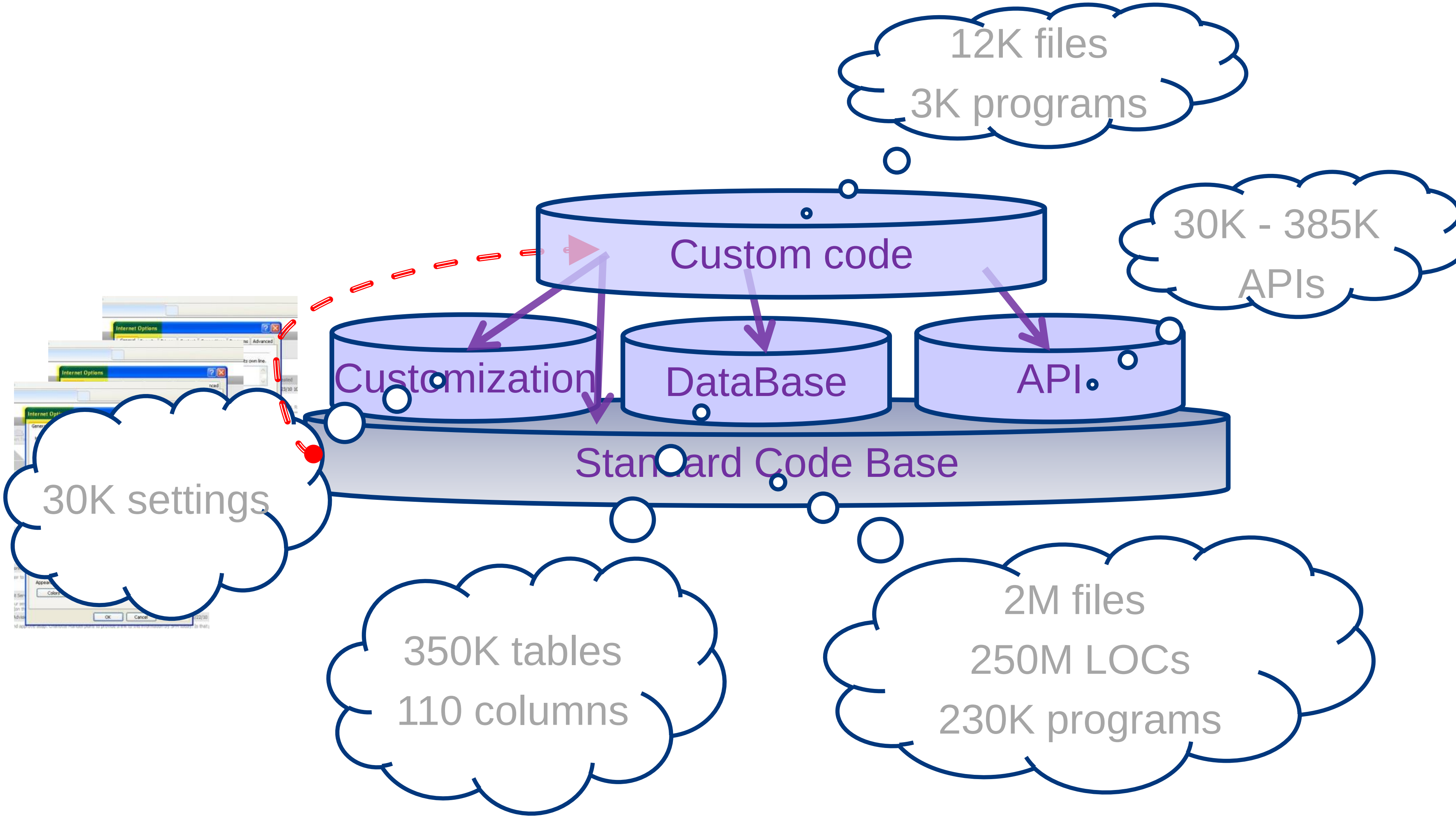


Minimal Customization?

- Customization
  - Adding new features
  - Changing existing features
- Up to hundreds in ERP group:
  - Business analysts
  - Programmers
  - IT + QA
- Go Live
  - Can be few times a month



Typical ERP Installation

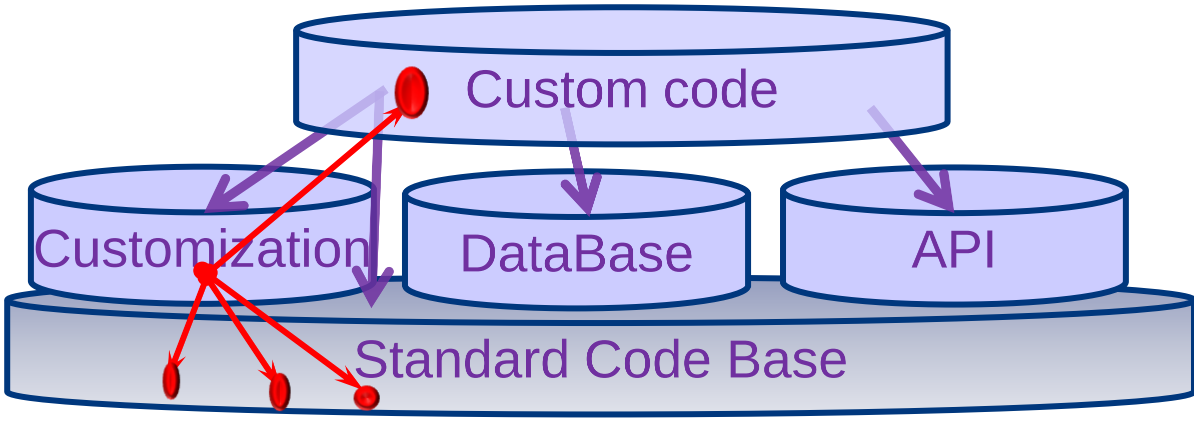


Problems in ERP Maintenance

- Regression testing
  - Replay is not possible
  - Dependent on the database
- System upgrade
  - Massive code change
    - Standard code base
    - API
    - DataBase schema changes
  - Clone finder
- Customization changes

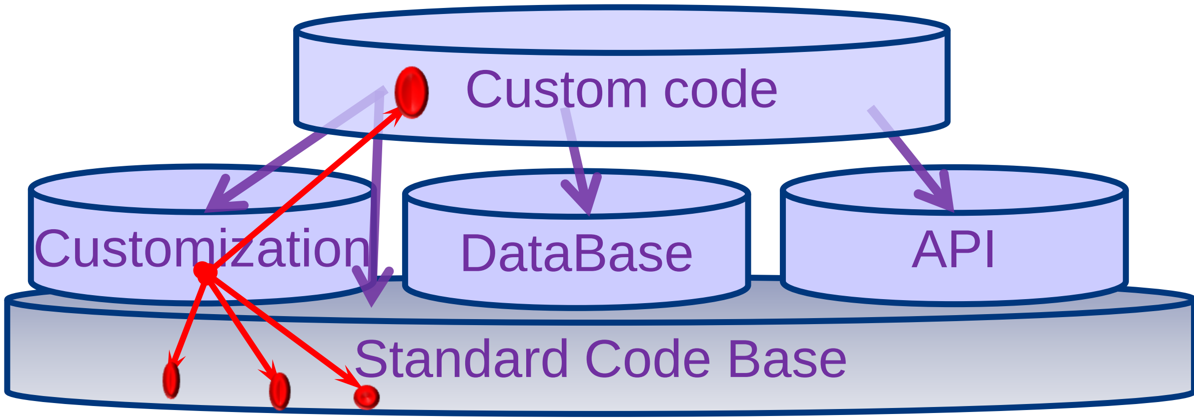
Changing Customization

- Process
    - Need to accommodate some business requirements
    - Change the behavior of programs by external setting
    - What's the impact?
    - What to test?



Changing Customization

- Impact analysis problem
  - A record in the database is changed
  - Find programs that reads this table
  - Is the specific column change impacting the program behavior?



Field Sensitive Dependence

Setting

- Large programs
- Very large aggregate structures

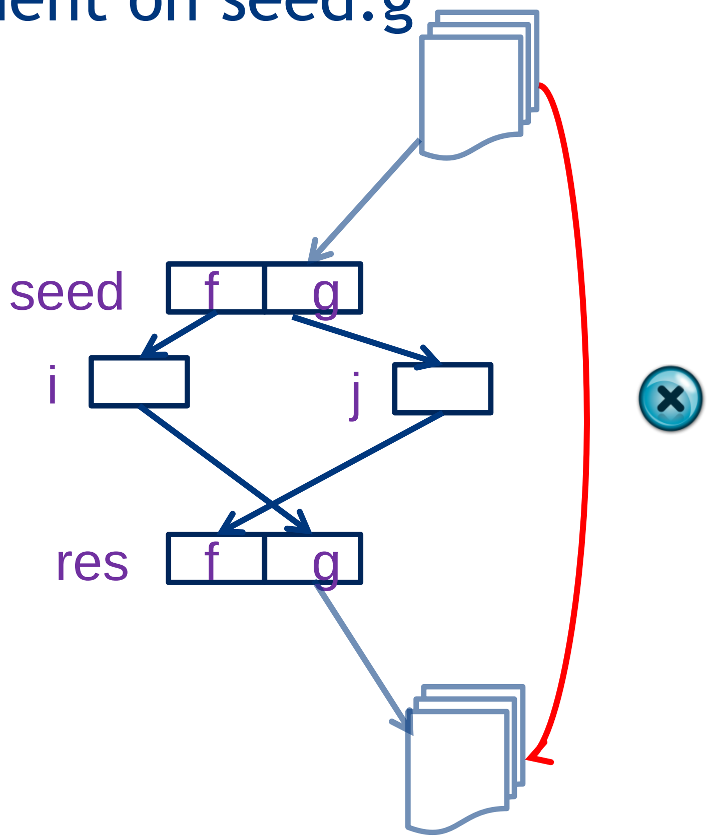
Purpose

- Impact analysis
  - Start point – select from customization table
  - What is impacted?
- Optimizations for other algorithms
  - Flow-insensitive field-sensitive data dependences
  - Constant propagation
  - Control flow analysis

Toy Example

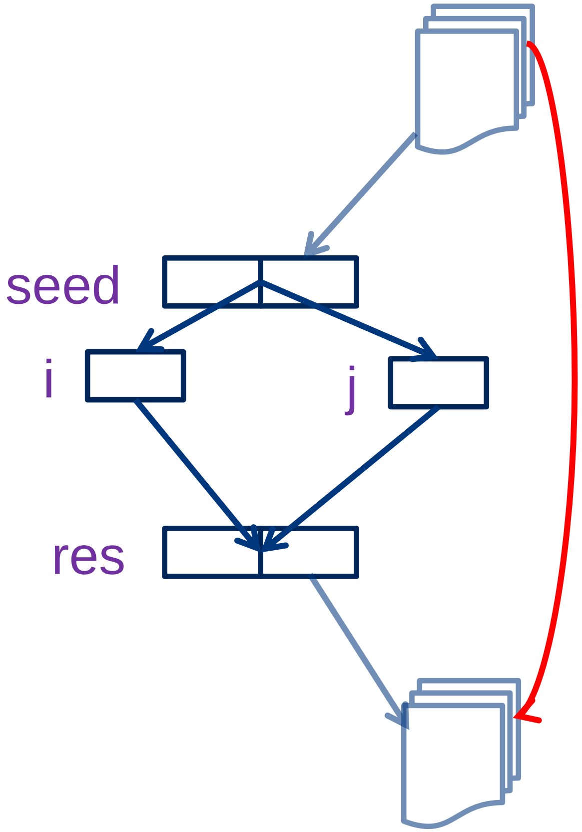
- Field sensitive
  - Infer that res.f is dependent on seed.g
  - Infer that res.g is **not** dependent on seed.g

```
l1: seed := exp
l2: i := seed.f
l3: j := seed.g
l4: res.g := i
l5: res.f := j
l7: return res
```



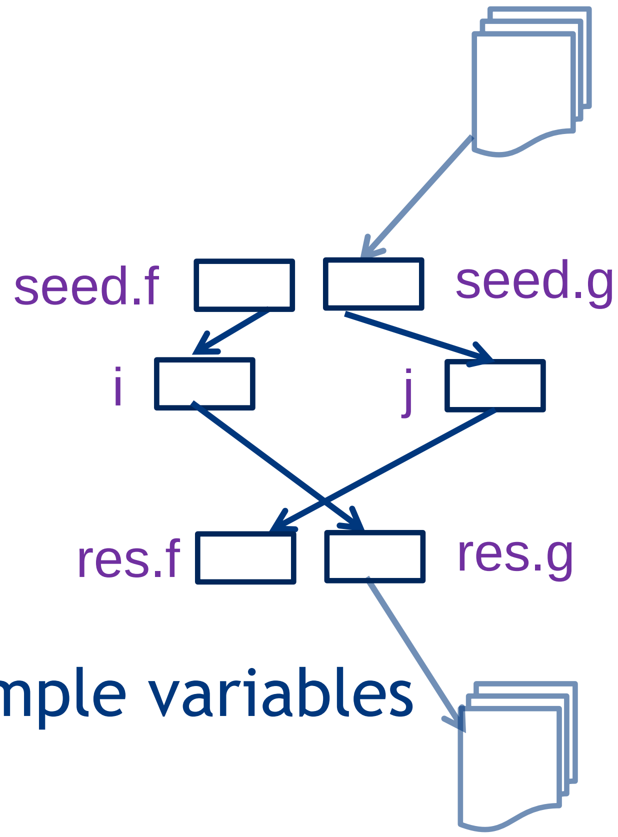
Current approaches

- Whole structure
  - No field sensitive
  - Easy implementation
  - Scalable but not precise



Current approaches

- Whole structure
  - No field sensitive
  - Easy implementation
  - Scalable but not precise
- Atomization
  - Treat structures as many simple variables
  - Field sensitive
  - Precise but not scalable



Transitive Dependences

- Partial kill operations
- Big L-value operation

l_1: s := exp1

l_2: s.f2 := kill

l_3: x := s

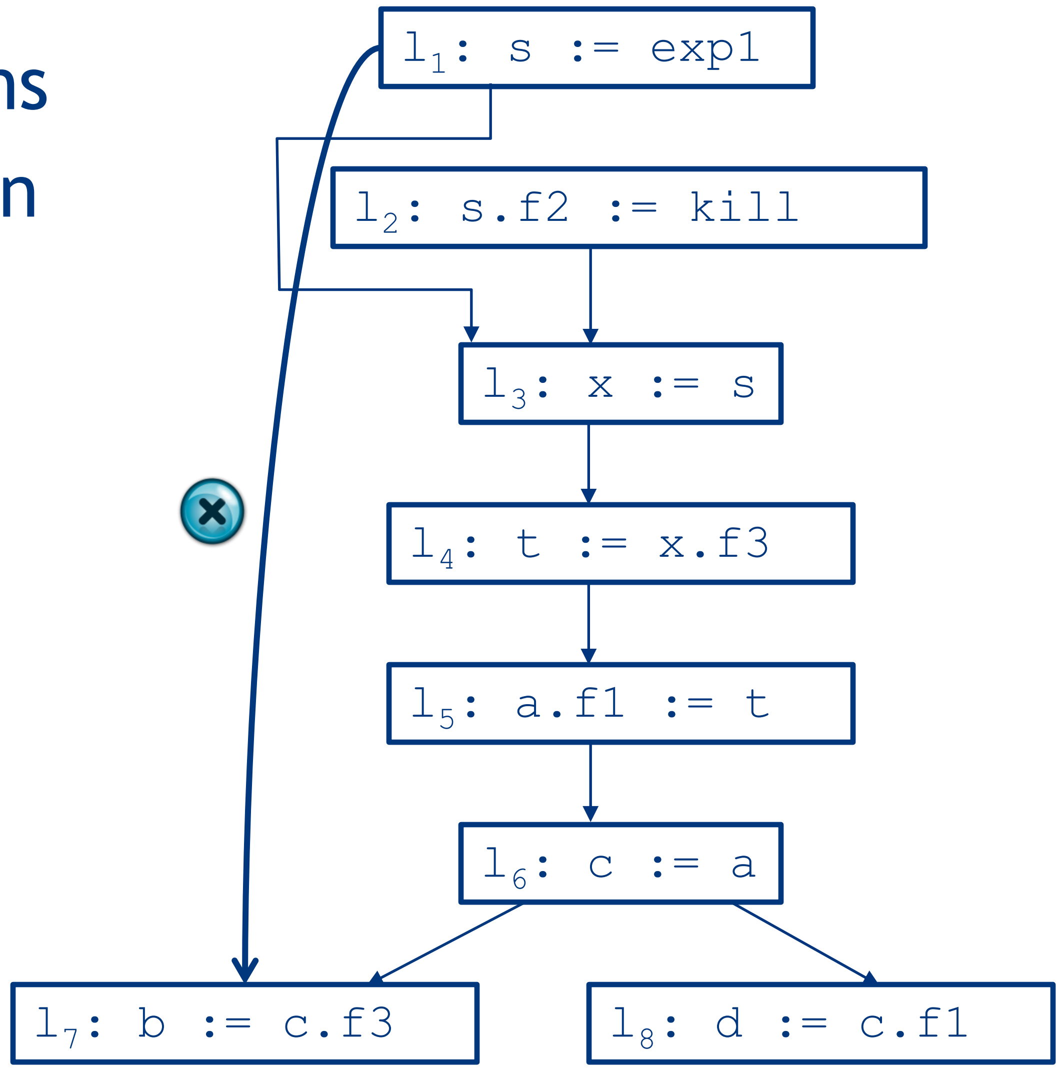
l_4: t := x.f3

l_5: a.f1 := t

l_6: c := a

l_7: b := c.f3

l8: d := c.f1



Algorithm Outline

- Compute interval-based reaching definition
  - Track for each substructure the last definition point
  - Substructure represented by interval (start – end offset)
- Build an interval-labeled Program Dependence Graph (PDG)
  - Records immediate control and data dependencies
- Compute transitive dependences

Interval Based Reaching Definition

l_1: `s := exp1`

l_2: `s.f2 := kill`

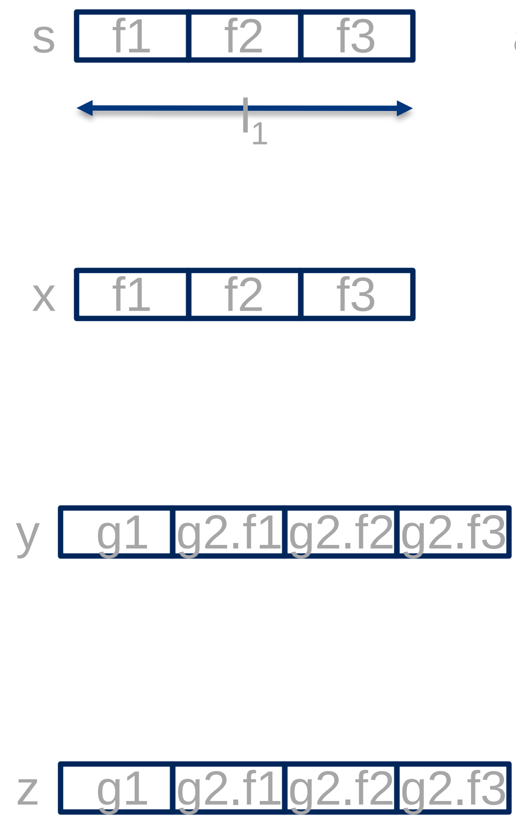
l_3: `x := s`

l_4: `y.g2 := x`

l_5: `z := y`

l_6: `a := z.g2`

l_7: `b := z.g1`



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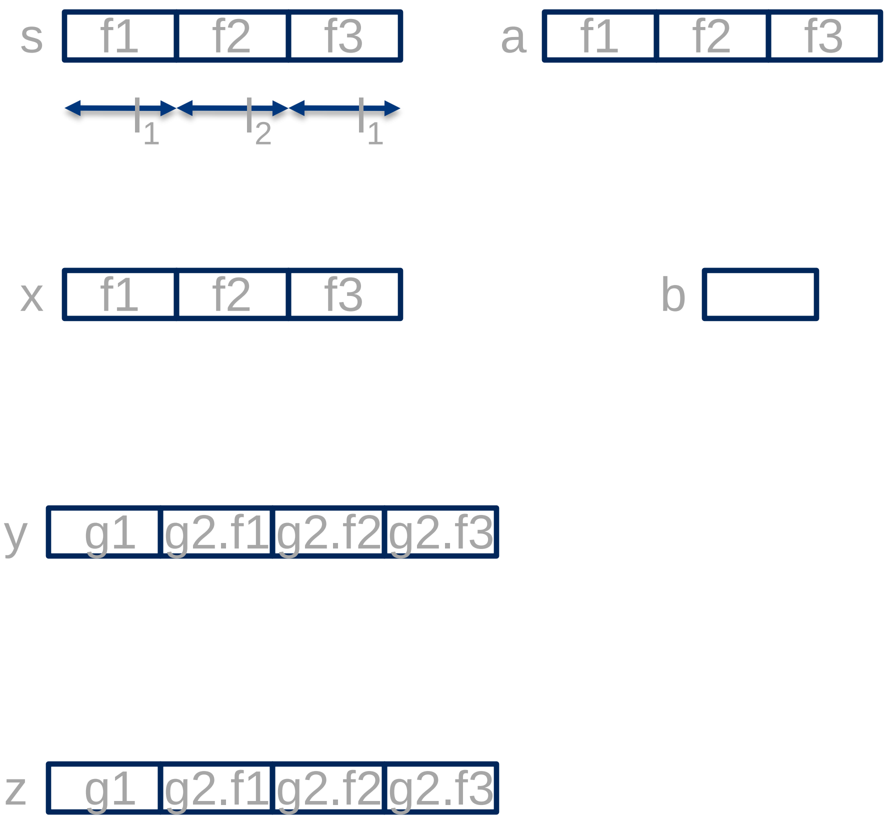

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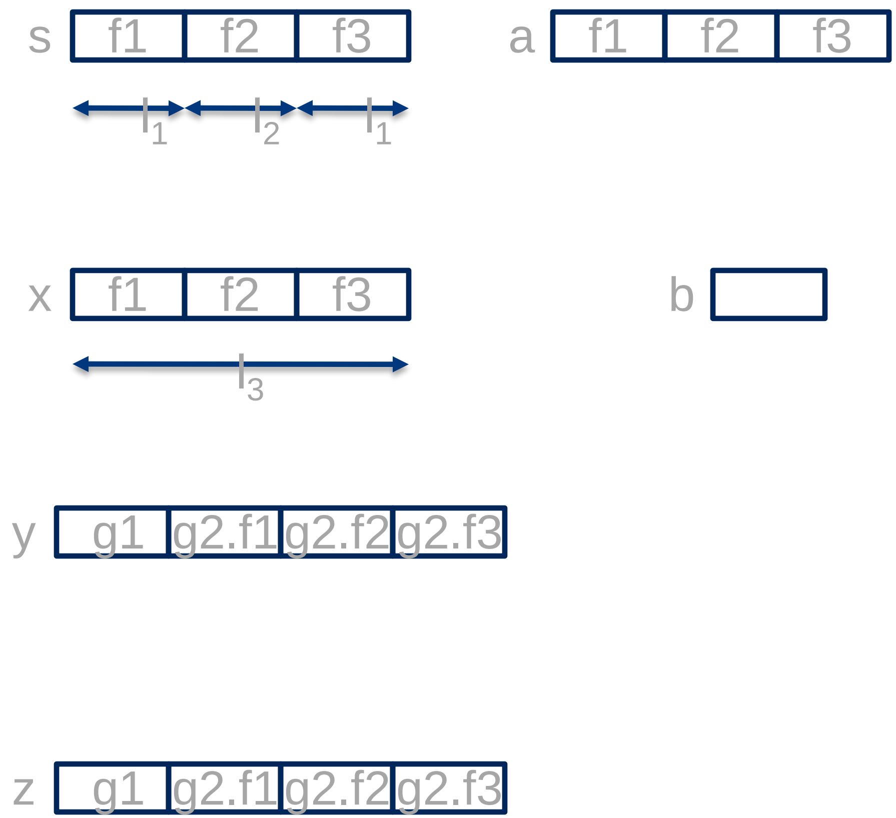

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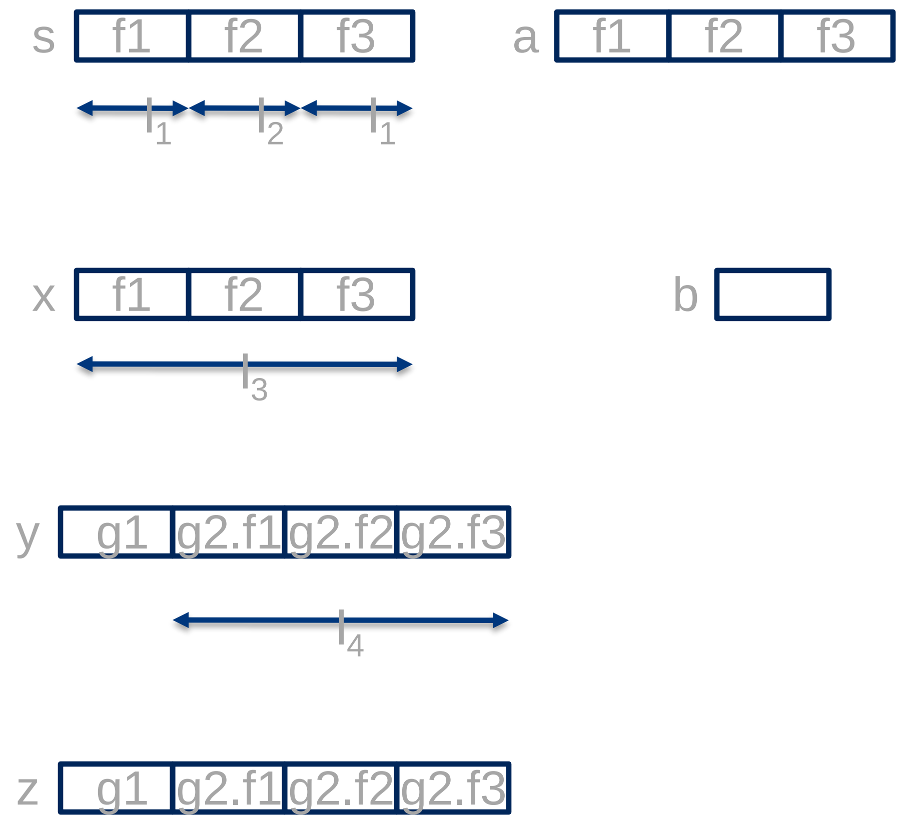

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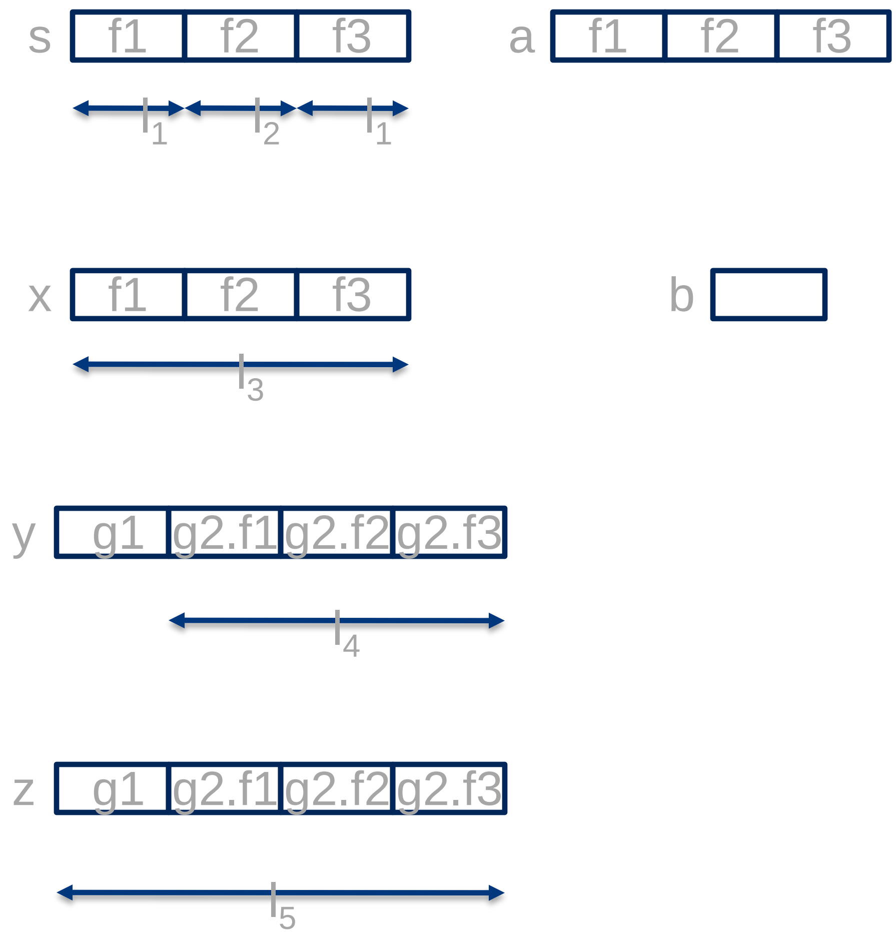

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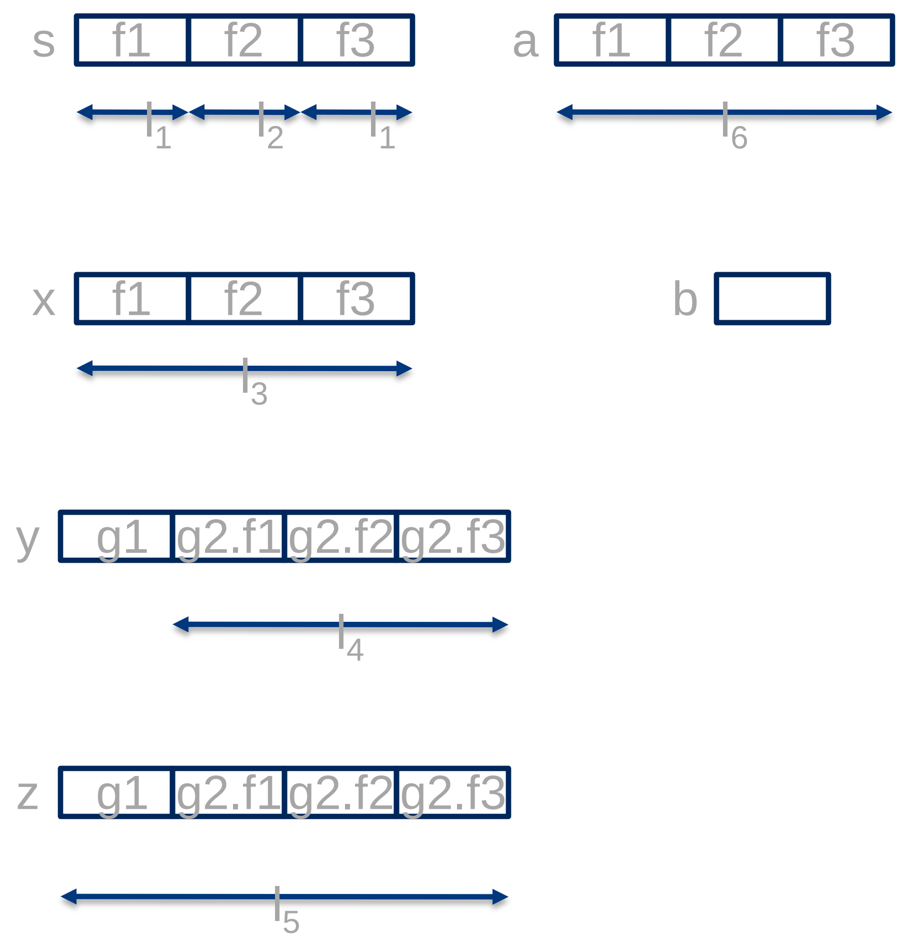

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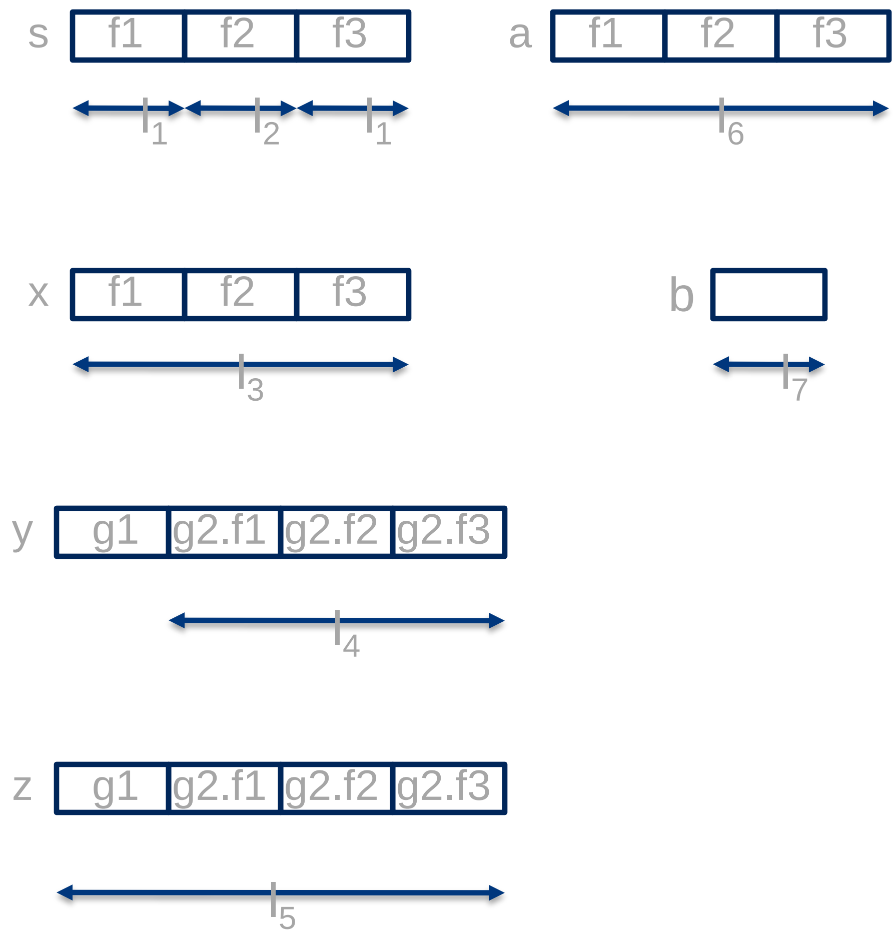

Transitive Dependence

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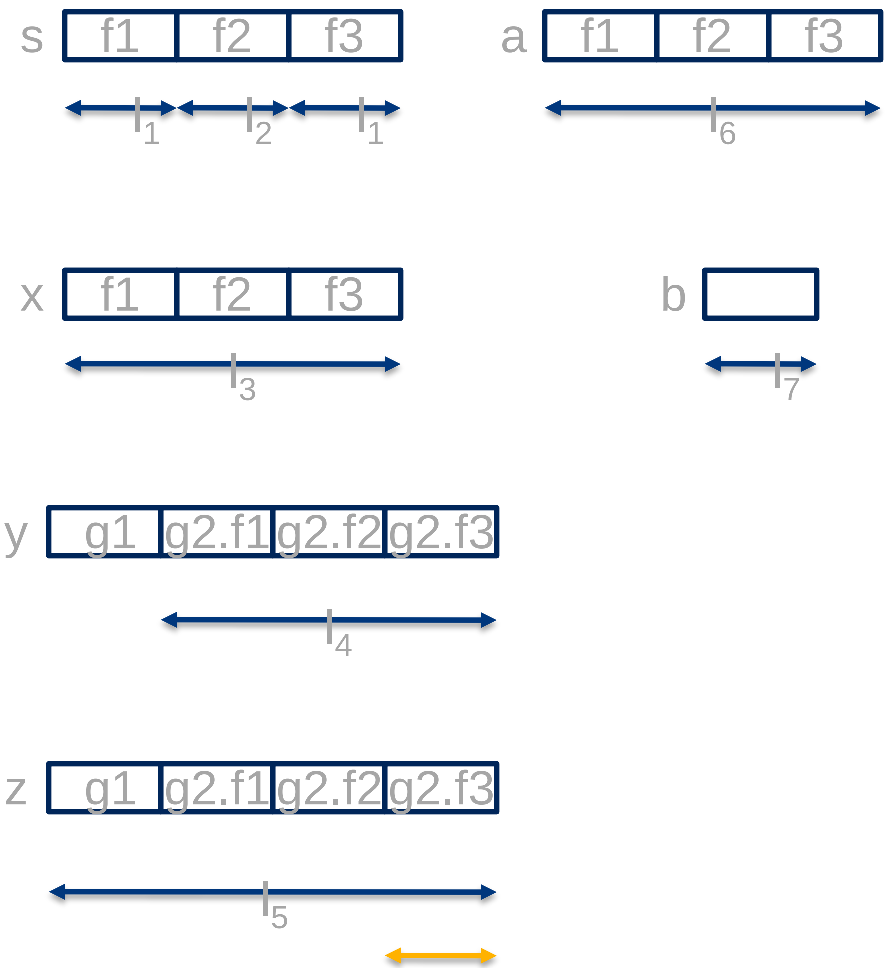


Transitive Dependence

l_1: s := exp1

l_2: s.f2 := kill

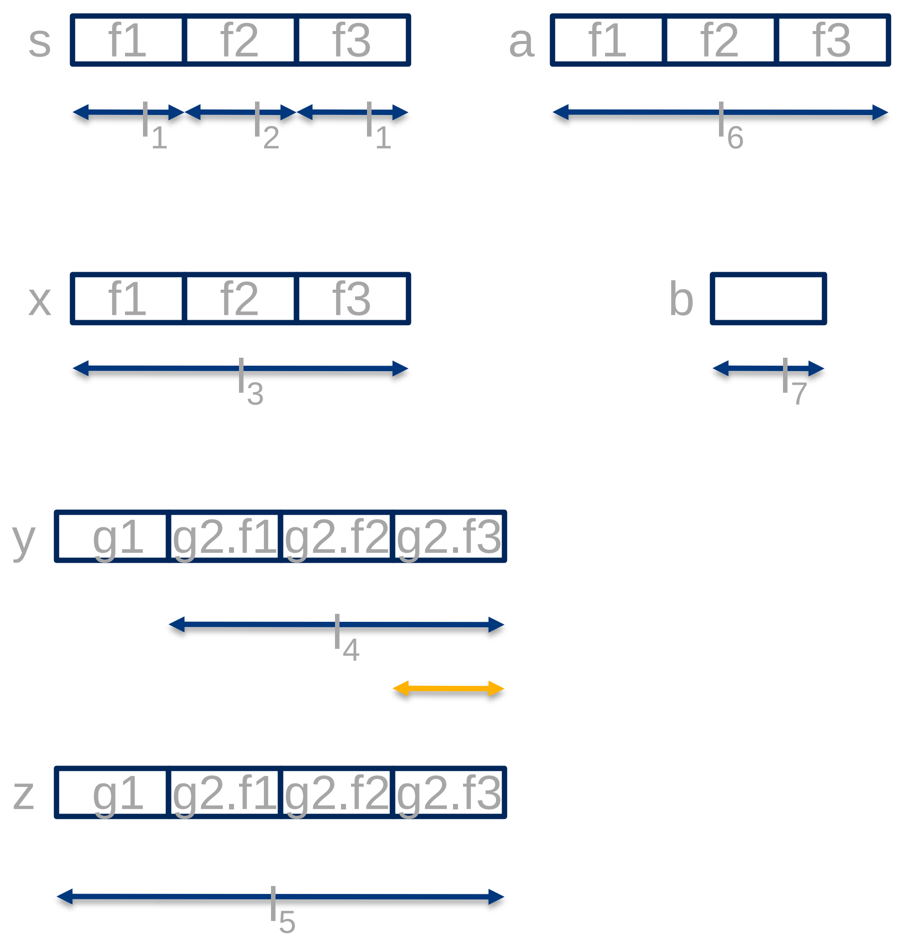
l_3: x := s

l_4: y.g2 := x

$\boxed{l_5\text{: z := y}}$

l_6: a := z.g2

l_7: b := z.g1



Transitive Dependence

l_1: s := exp1

l_2: s.f2 := kill

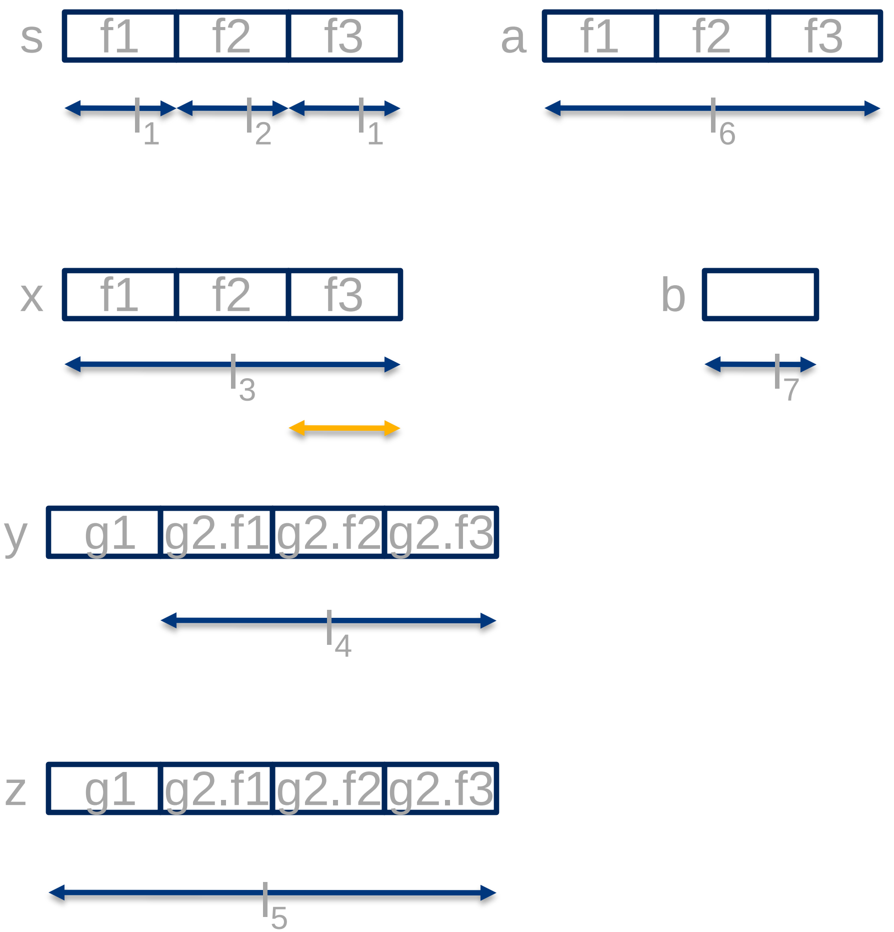
l_3: x := s

$\boxed{l_4\text{: y.g2 := x}}$

l_5: z := y

l_6: a := z.g2

l_7: b := z.g1



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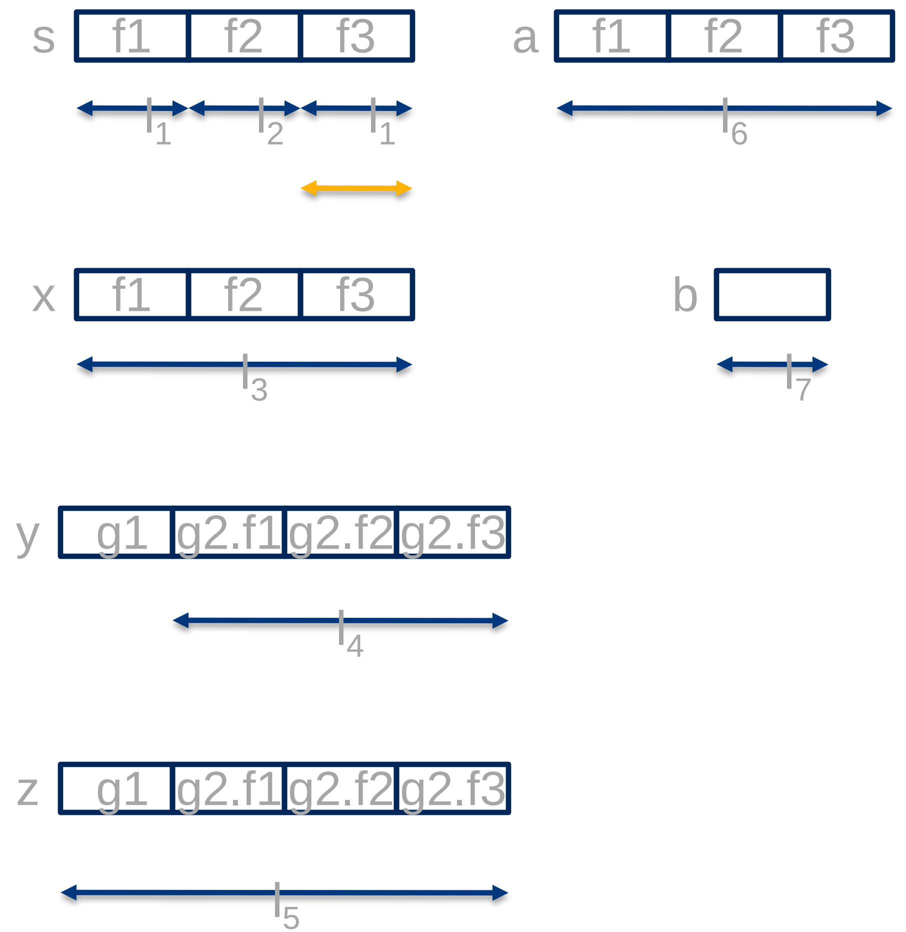

Transitive Dependence

l_1: s := exp1

l_2: s.f2 := kill

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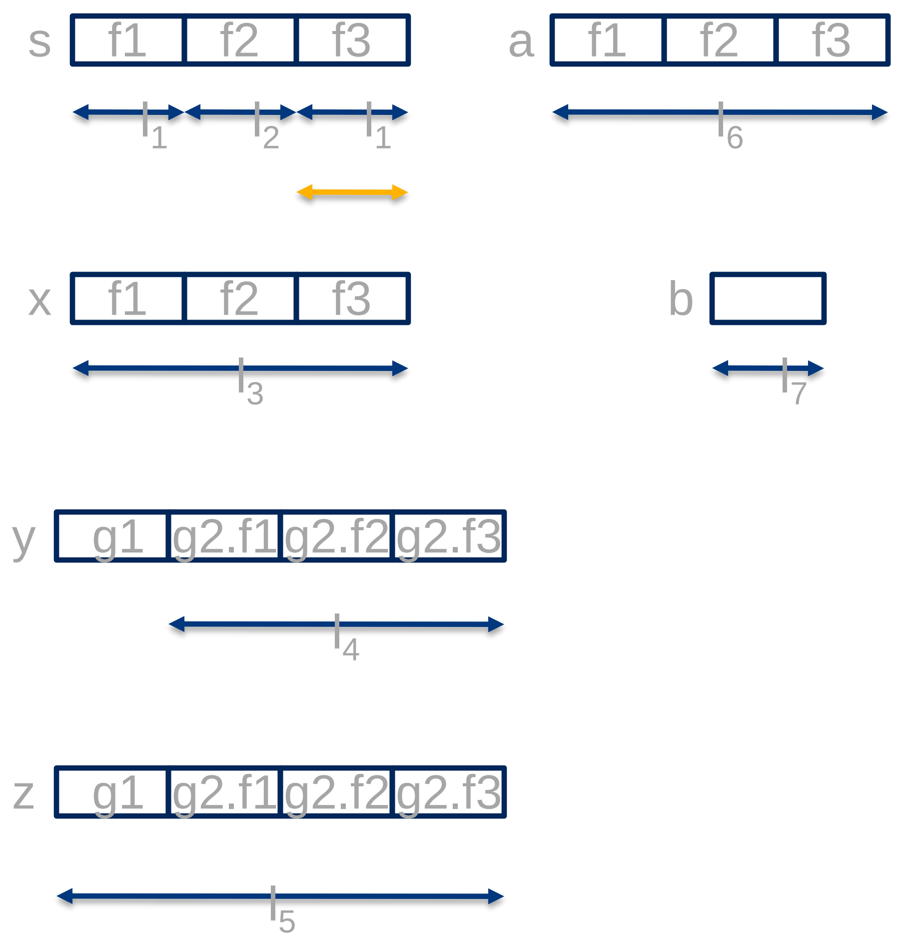


Avoiding Spurious Dependences

l_1: s := exp1

l_2: s.f2 := kill

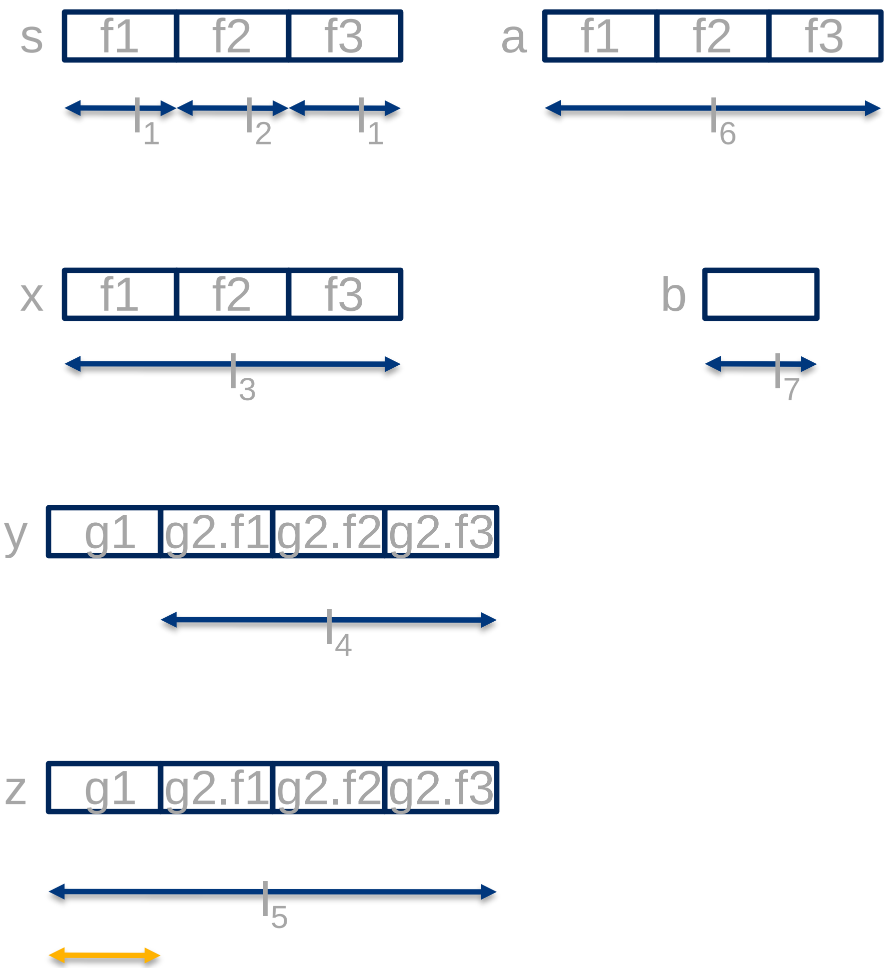
l_3: x := s

l_4: y.g2 := x

l_5: z := y

l_6: a := z.g2

l_7: b := z.g1



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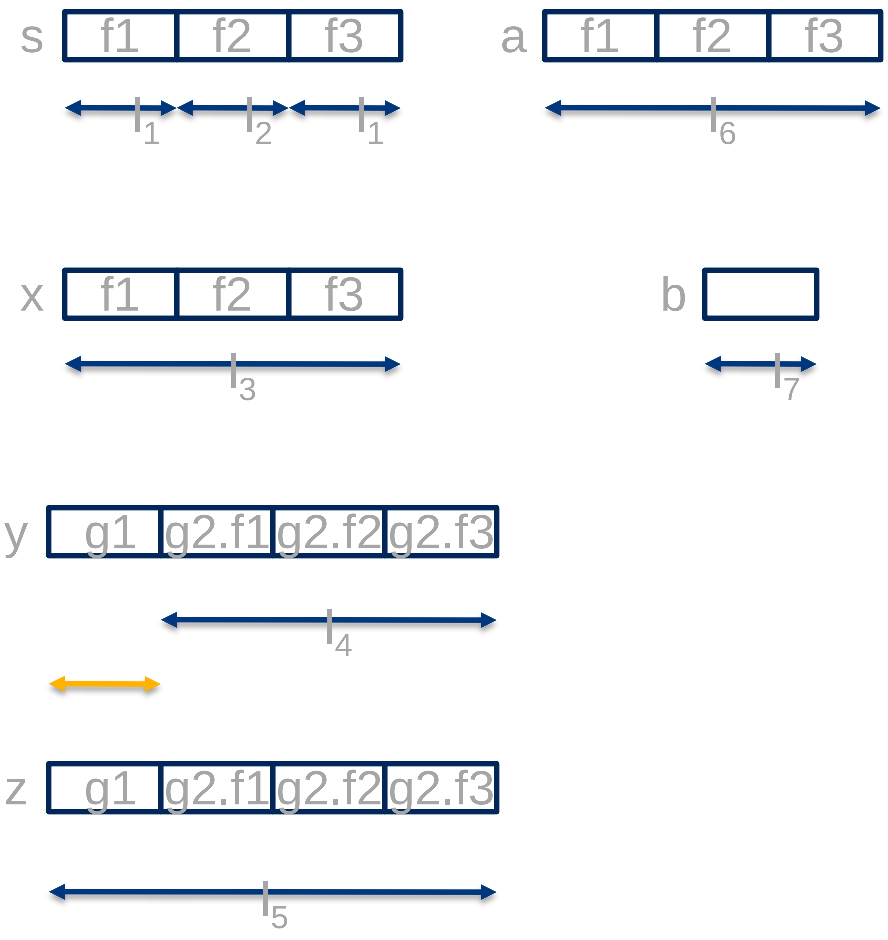
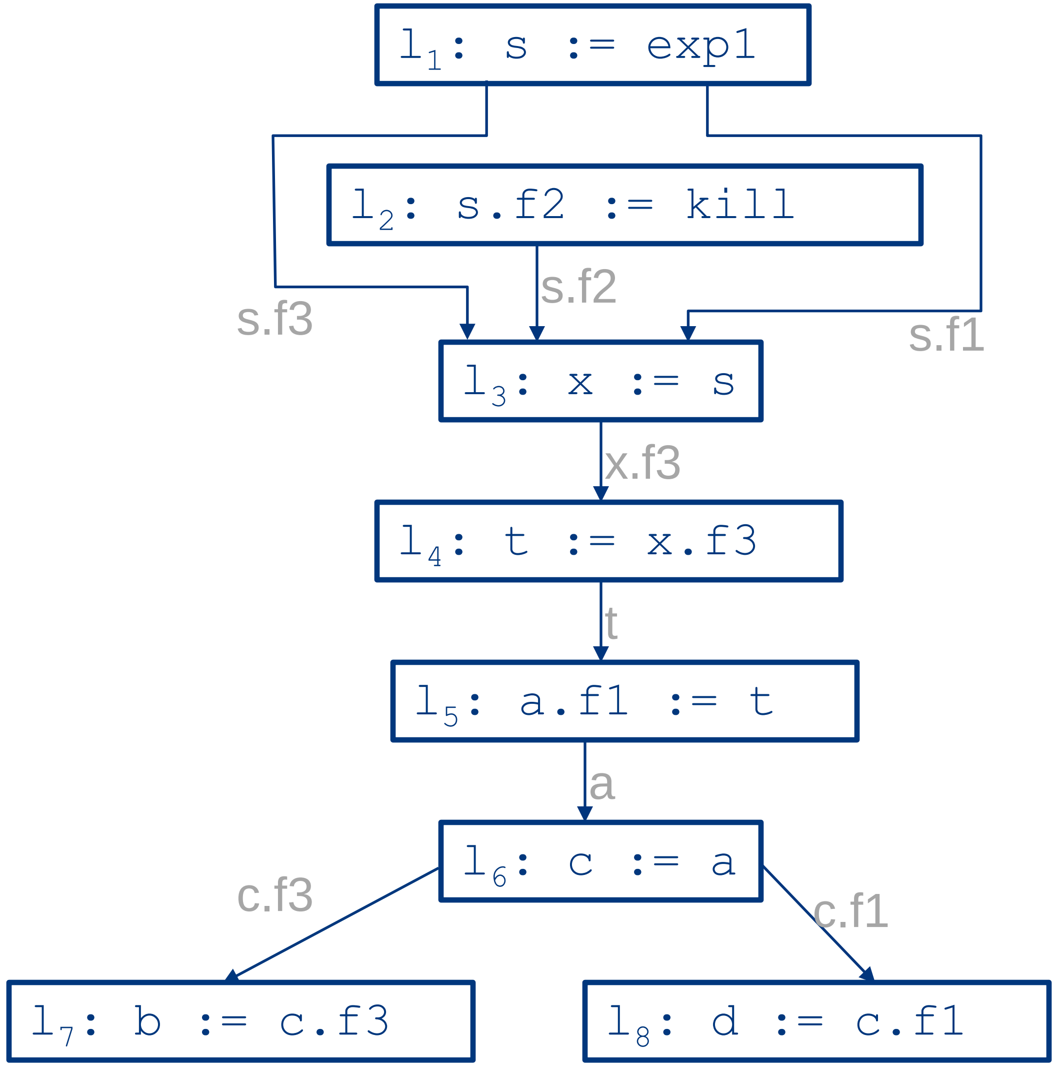


Interval Labeled PDG

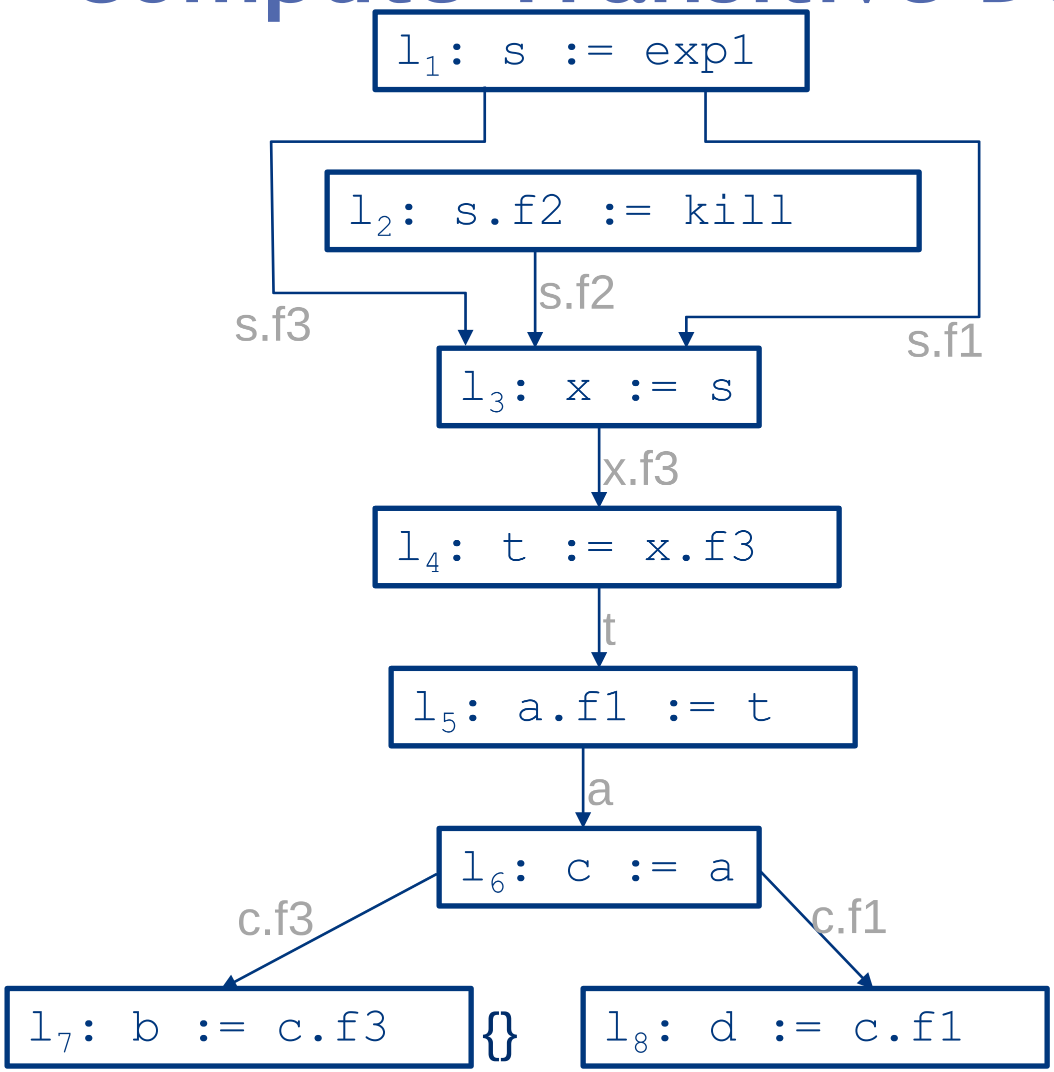
```
l1: s := exp1
l2: s.f2 := kill
l3: x := s
l4: t := x.f3
l5: a.f1 := t
l6: c := a
l7: b := c.f3
l8: d := c.f1
```



Compute Transitive Dependences

- Which segments are dependent on the (partial) definition of seed
- Iterative algorithm over the PDG
- Tracks also the seed interval dependence
  - Which segment of the used variable is dependent on which segment of the seed
- Efficient representation
  - Need to record only according to statement

Compute Transitive Dependences



{<s, s>}

{<s.f1, s.f1>,<s.f3,s.f3>}

{<x.f3,s.f3>}

{<t,s.f3>}

{<a.f1,s.f3>}

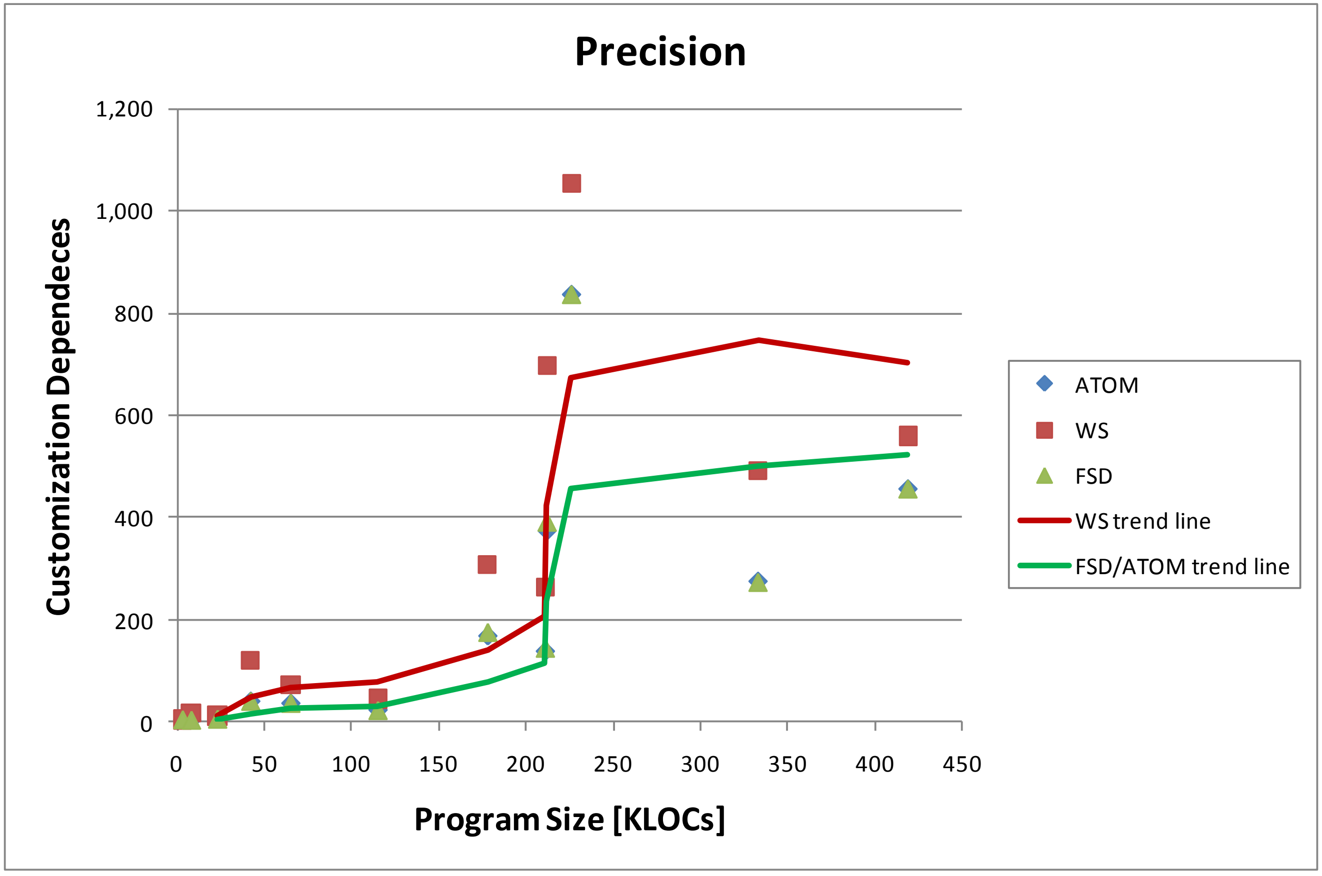
{<c.f1,s.f3>}

Empirical Study

- Compare three algorithms:
  - ATOM – full atomization (code level atomization)
  - WS – whole structure (field insensitive)
  - FSD – field sensitive dependences
- Analyzing 12 Programs (3K - 419K LOCs)
  - ATOM failed on largest one
- Computer grid of 5 Intel Servers
  - Two dual core CPUs, 16GB RAM
  - Window XP 64-bit, Java 5.0

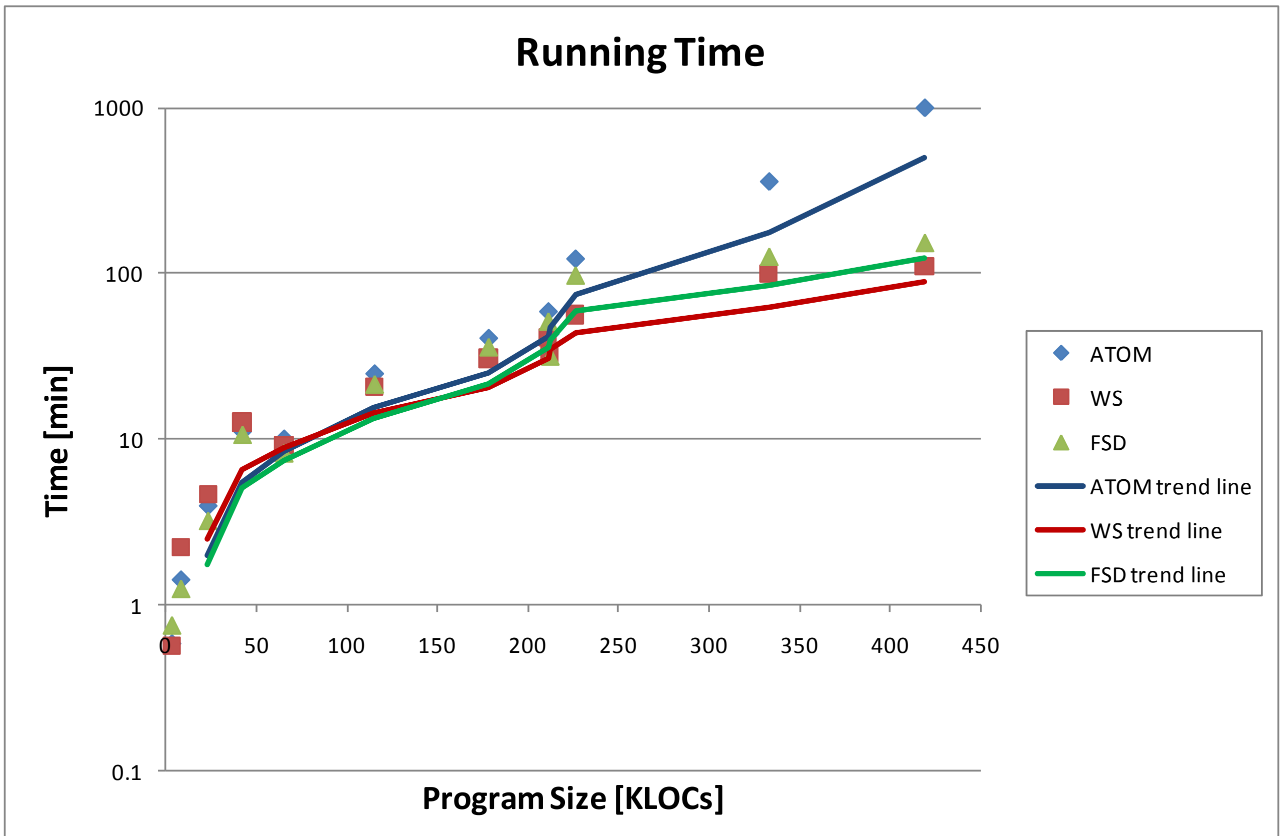
Precision Results

- ATOM and FSD produce the same results
- WS has a false positive rate of 62%



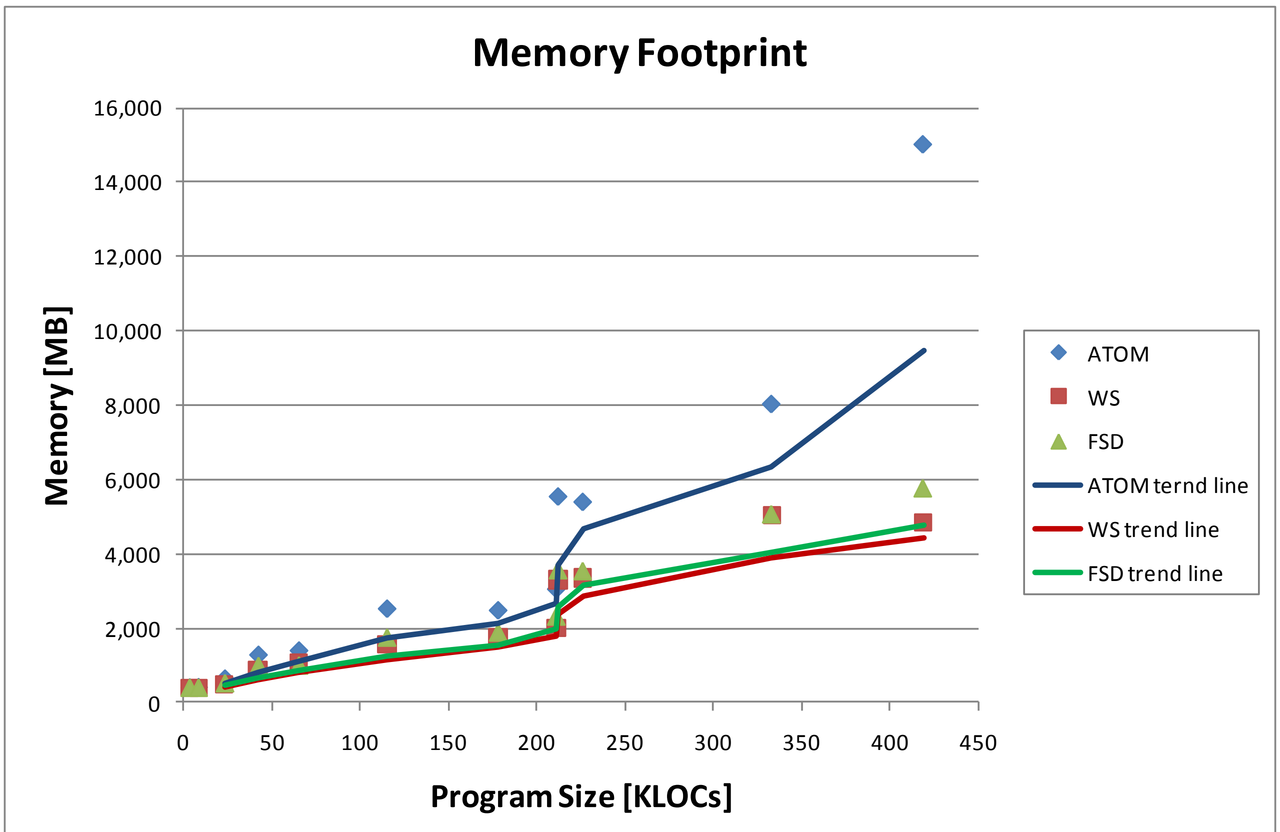
Performance - Running Time

- WS averages at 30 min
- ATOM more than double at 60 min
- FSD shows small increase at 35 min



Performance - Memory

- ATOM footprint 50% larger than WS
  - Failed on the largest program (419K LOCs)
- FSD footprint only 10% larger

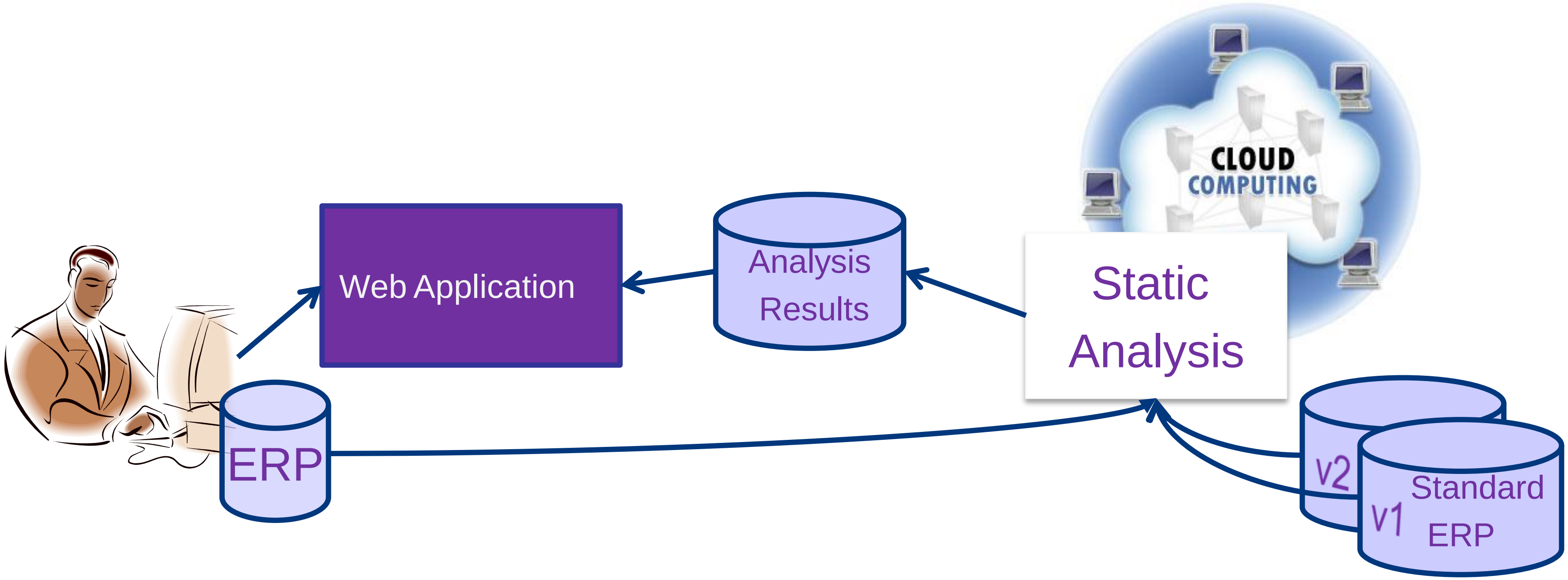


Related work

- Aggregate Structure Identification
  - POPL99: Ramalingam, Field, Tip
    - Avoid atomization for unused parts
  - Only 22% of the fields are unused
  - Almost full atomization
  - Large programs < 15% unused fields
- Procedure summary
  - TOPLAS90: Horwitz, Reps, Binkley
  - FSE94: Horwitz, Reps, Sagiv, Rosay

Architecture

- Software-As-A-Service (SaaS) Application
- Wide and efficient use of cloud computing
  - Multi-process
- Deep static analysis techniques



Analysis Challenges: Control Flow

- Interdependency and sharing of code
  - Modular analysis (assembly – link)
  - Eliminating dead code – saves 30%
- Call by name which is resolved at runtime
  - Find possible targets using constant propagation
- Boundaries of programs are unclear
  - Using heuristics to put logical boundaries
- Programs have large cyclic parts
  - Using procedure cloning for specialization
  - Using SCCs for optimizing chaotic iterations

Analysis Challenges : Data Flow

- Extensive declaration of global variables
  - Localization algorithm eliminates 80%
- Very large aggregate types
  - Field sensitive dependences

Conclusion

- Field sensitive algorithm
  - Importance in the presence of large aggregate structures
- ERP systems
  - Large critical systems
  - In need for solutions
    - Various impact analysis
    - Clone finder
    - Regression testing

Questions?

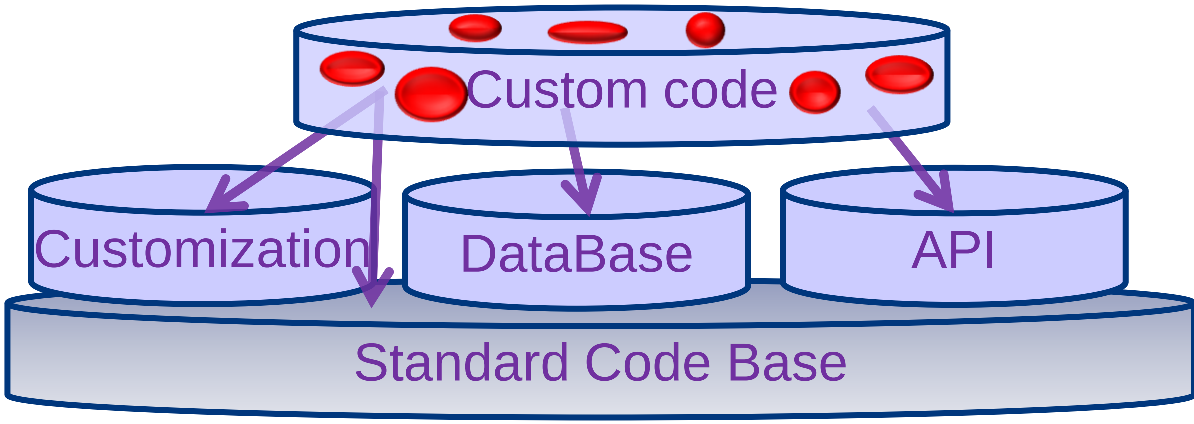
How to Contact Me:

Nurit Dor*, nurit@panayainc.com*

Upgrade

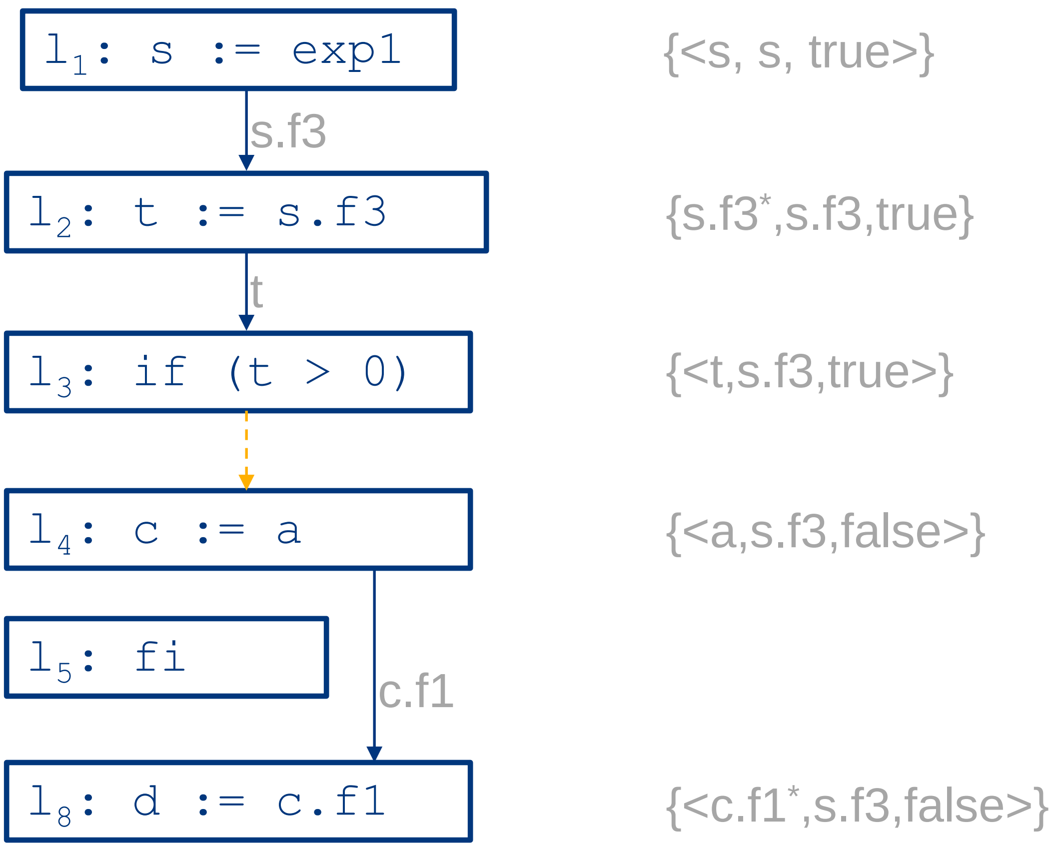
- Massive code change
  - Standard code base
  - API
  - DataBase
- Requirements
  - What needs to be fixed
  - What is used
  - Testing plan

- Example SAP upgrade:
  - 46% of the code changed
  - 5K-7K: API changes



Control dependences

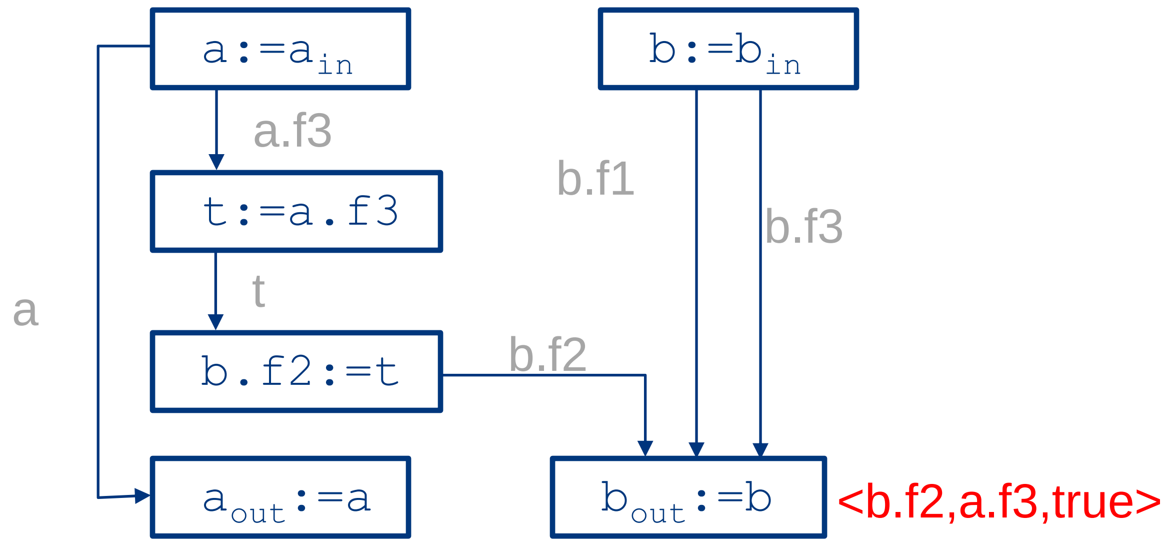
- Using control dependency edges on the PDG
- Non-value dependences
- "Freeze" the seed



Inter-Procedural Analysis

```
procedure bar(a,b)
   t := a.f3
   b.f2 := t
return

procedure foo(s,t)
   x := s
   y := exp
   call bar(x,y)
   t := y
return
```



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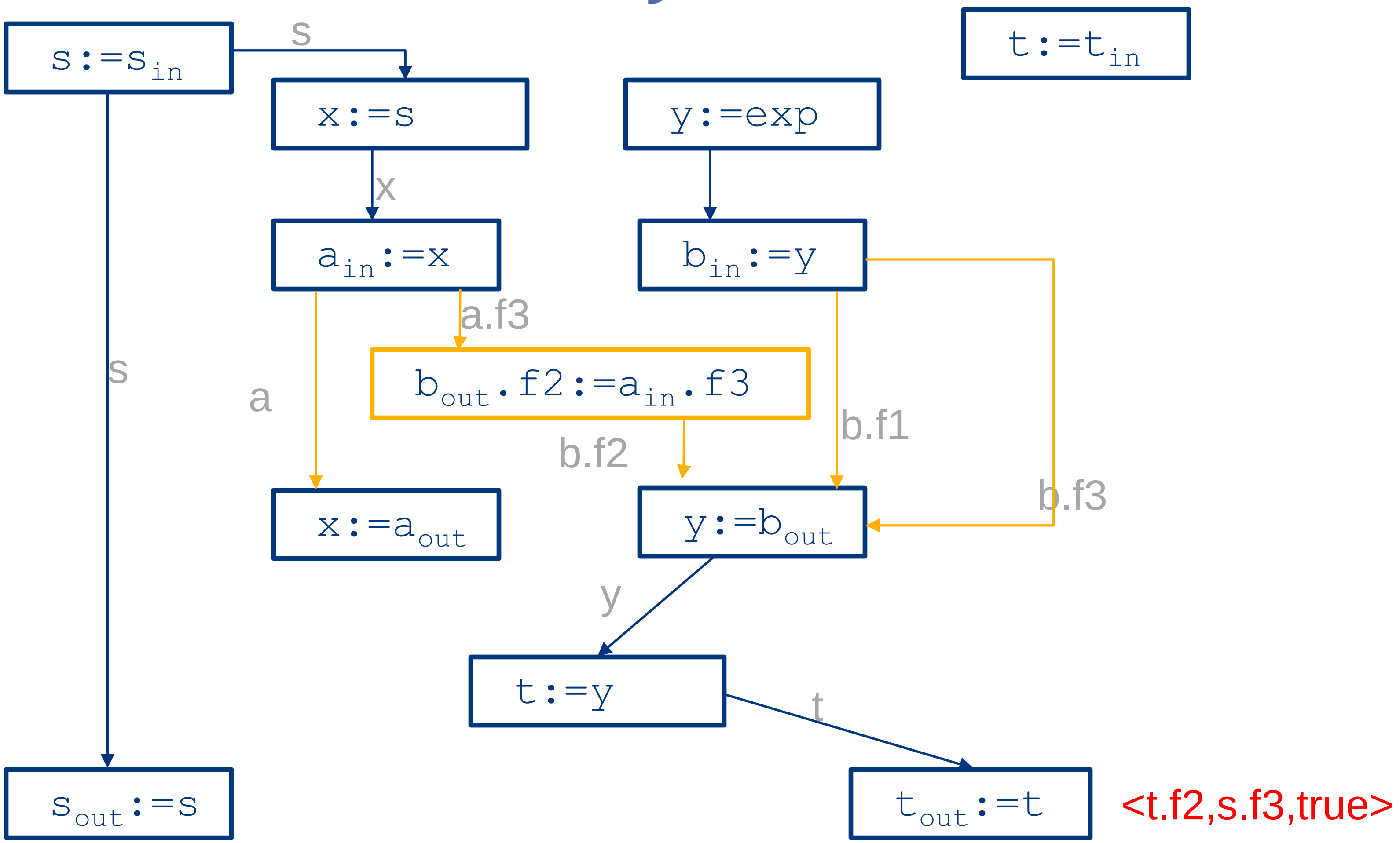
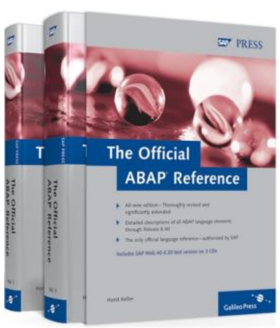
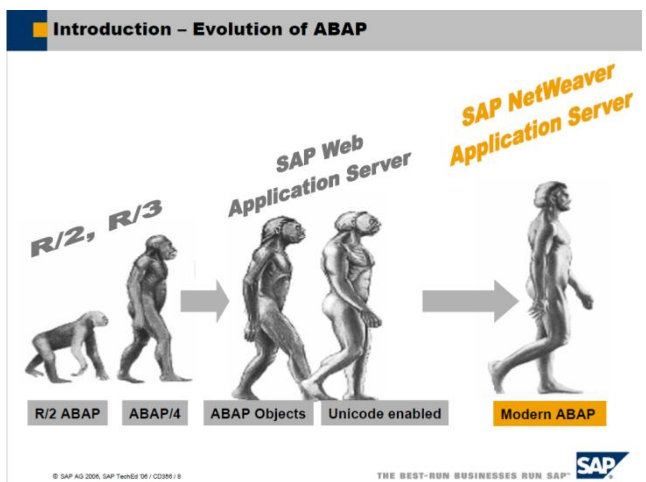


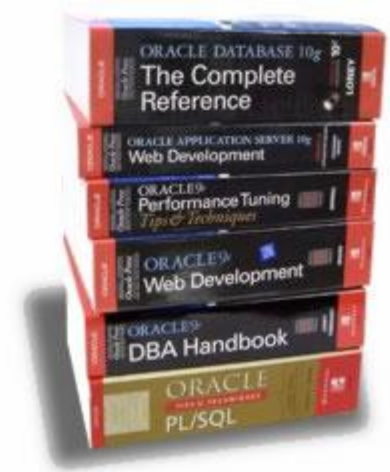
Programming Language

- SAP - ABAP
  - Constantly Developed
  - Started as a report generator in the 70's





- Oracle - PL\SQL
  - Many frameworks for developing programs
    - Reports
    - Forms
    - …
  - Satellites



Clone

```
THEADTAB-TDOBJECT      = 'EINE      '.
THEADTAB-TDID          = 'BT  '.
PERFORM TDNAME_SETZEN
   USING    THEADTAB-TDOBJECT
            THEADTAB-TDNAME.
 READ TABLE THEADTAB.
.
.
.
```

```
FORM TDNAME_SETZEN USING    I_TDOBJECT
                   CHANGING I_TDNAME.
  CLEAR I_TDNAME.
  CASE I_TDOBJECT.
    WHEN 'EINA'.
      IF FC_CALL EQ SPACE OR EINA-INFNR NE SPACE.
        I_TDNAME(10)    = EINA-INFNR.
      ELSE.
        I_TDNAME(1)     = '$'.
        I_TDNAME+1(10) = EINA-LIFNR.
        I_TDNAME+11(18) = EINA-MATNR.
      ENDIF.
    WHEN 'EINE'.
      IF FC_CALL EQ SPACE OR EINA-INFNR NE SPACE.
        I_TDNAME(10)    = EINA-INFNR.
        I_TDNAME+10(4) = EINE-EKORG.
        I_TDNAME+14(1) = EINE-ESOKZ.
        I_TDNAME+15(4) = EINE-WERKS.
      ELSE.
        I_TDNAME(1)     = '$'.
        I_TDNAME+1(10) = EINA-LIFNR.
        I_TDNAME+11(18) = EINA-MATNR.
        I_TDNAME+29(4) = EINE-EKORG.
        I_TDNAME+33(1) = EINE-ESOKZ.
        I_TDNAME+34(4) = EINE-WERKS.
      ENDIF.
  ENDCASE.
ENDFORM.
```

SCC

```
FORM konditionen USING i_kschl
…
IF kond_exit NE space AND fc_call
   EQ space.
    ok-code = endb.
    PERFORM okcode.
  ENDIF.
…
ENDFORM
```

```
FORM okcode.
…
CASE ok-code
…
WHEN endb.
      IF sy-dyngr EQ 'ANFO'.
        IF sy-calld NE space OR sy-binpt NE
   space.
          LEAVE.
        ELSE.
          PERFORM return_to_menu.
        ENDIF.
      ELSE.
        PERFORM info_ende.
      ENDIF.
 WHEN kond.
   PERFORM konditionen USING space.
…
ENDCASE
..
ENDFORM
```

Program Boundaries

- Spaghetti code
  - No clear boundaries
  - One activates another
  - Lots of shared code with multiple behaviors
- We studied 160 programs, with 94,000 procedures
  - On average each procedure is potentially called in 30 programs
  - Half the procedures are only called by a single program
  - Half are called by more than 1/3 of the programs
- Heuristics based on components to decide what to include in which program

Modular Analysis

- Each file is analyzed once independently of calling context
- Whole program is “linked” and analyzed