A Test Adequacy Infrastructure with Database Interaction Awareness

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Motivation

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Jeppesen reports airspace boundary problems

About 350 airspace boundaries contained in Jeppesen NavData are incorrect, the FAA has warned. The error occurred at Jeppesen after a software upgrade when information was pulled from a database containing 20,000 airspace boundaries worldwide for the March NavData update, which takes effect March 20.

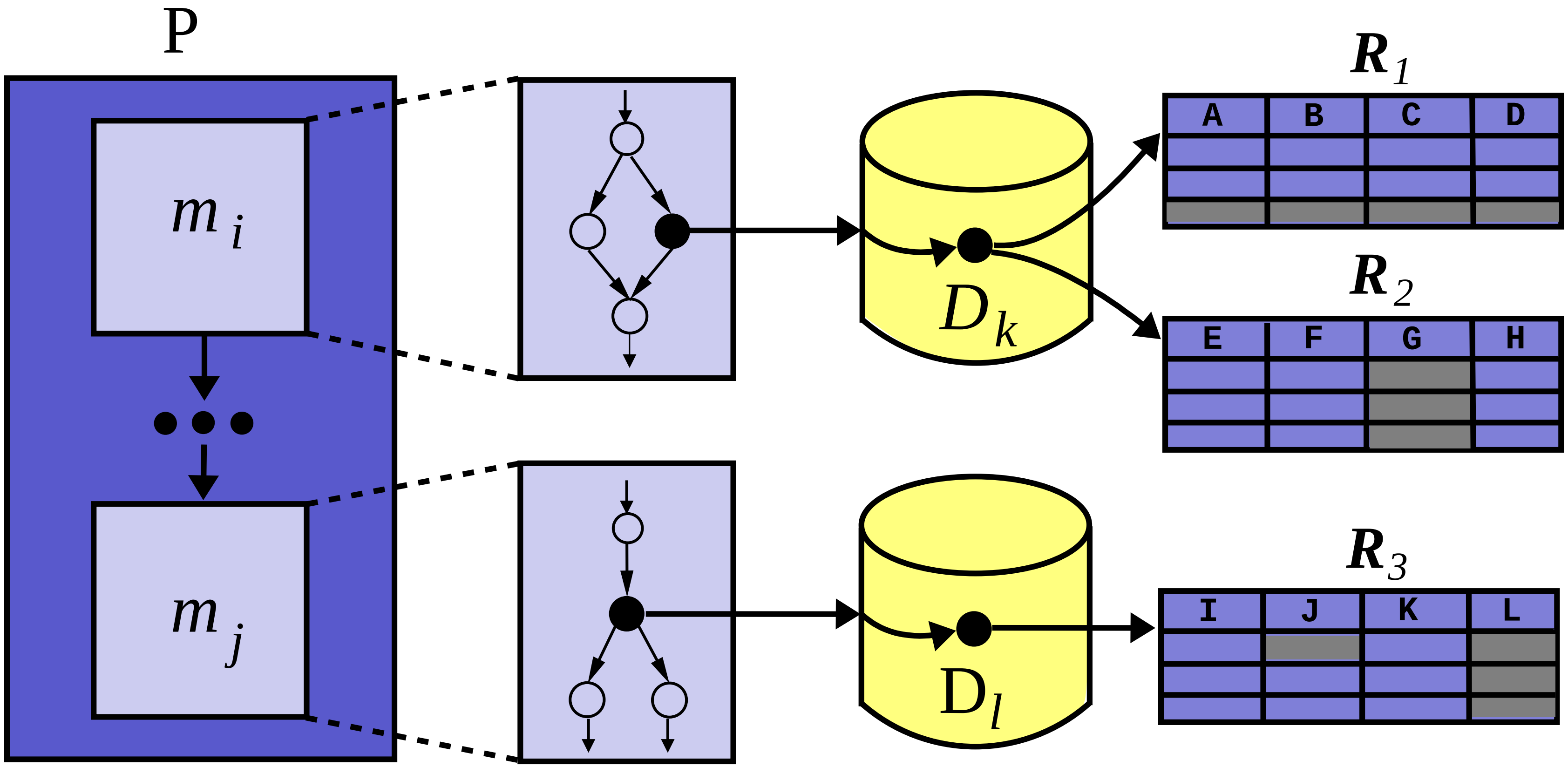
Looking Ahead

- Test adequacy infrastructure that can find faults and establish confidence in the correctness of a database-centric application
  - Model of database interaction faults
  - Unifed application representation
  - Family of test adequacy criteria
- Experiments with real applications that measure the number of test requirements and the time and space overheads incurred by enumeration
  - Foundation for a comprehensive methodology for testing database-centric applications

Testing Challenges

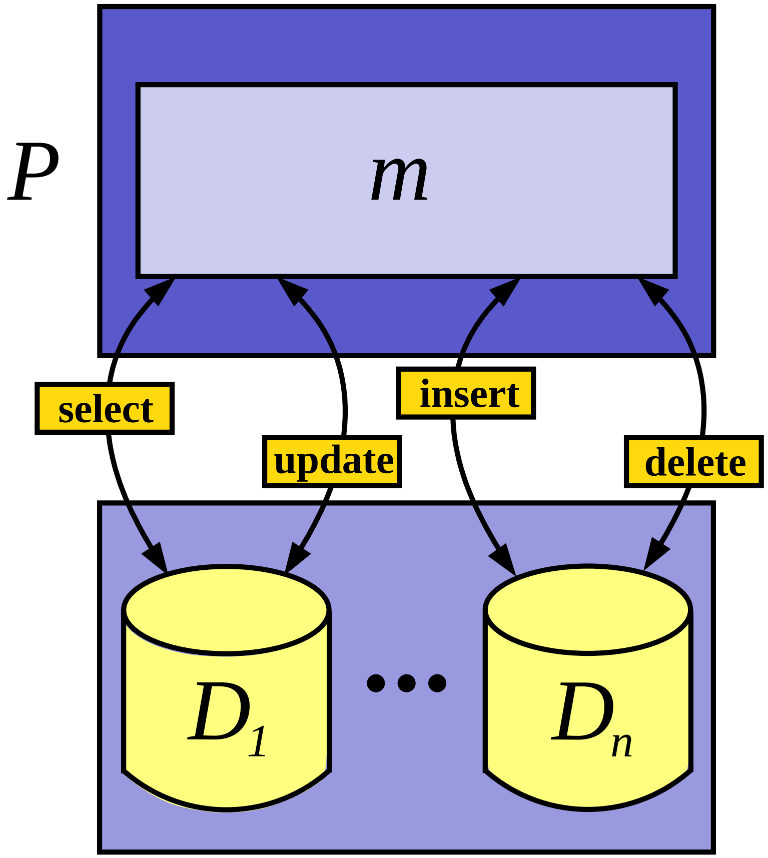
- Must consider the environment in which software applications actually execute
- Should test a program and its interaction with a database
- Database-centric application's state space is well-structured, but essentially infinite (Chays et al.)
- Need to show program does not violate database integrity, where *integrity* = *consistency* + *validity* (Motro)
- Must locate program and database coupling points that vary in granularity

Database-Centric Applications



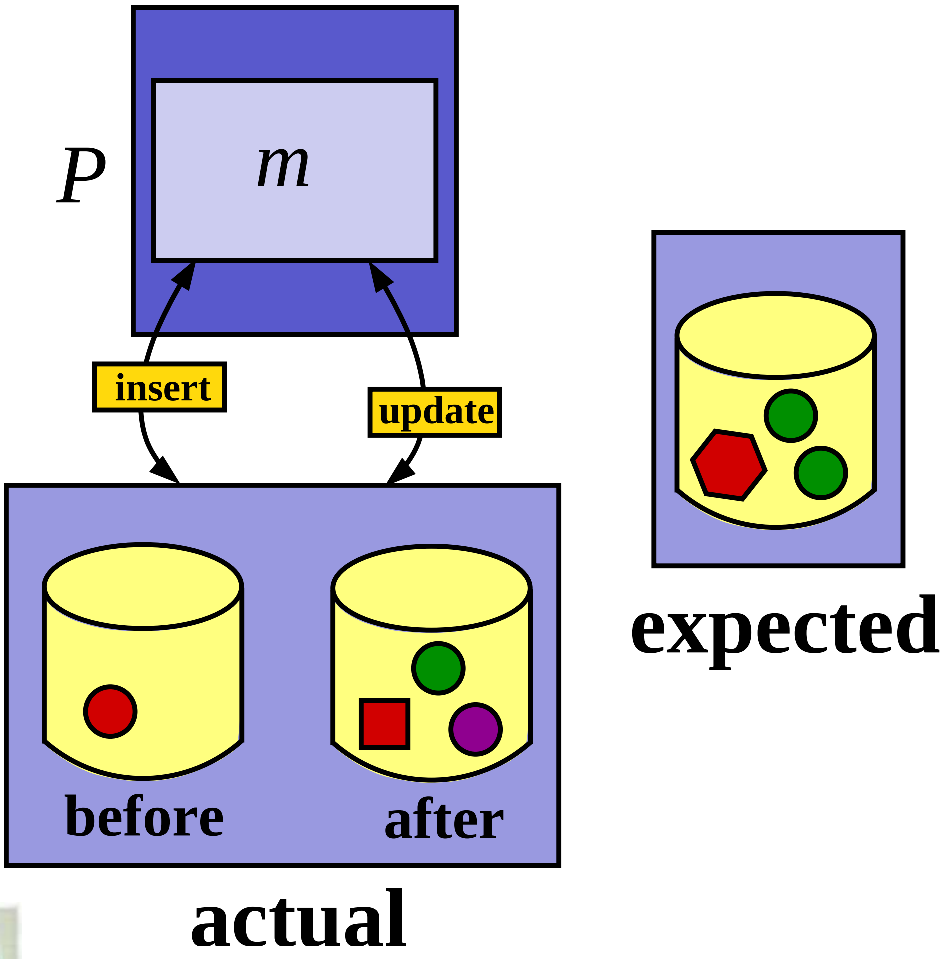
- Program P interacts with two relational databases D_k and D_l

Database Interactions



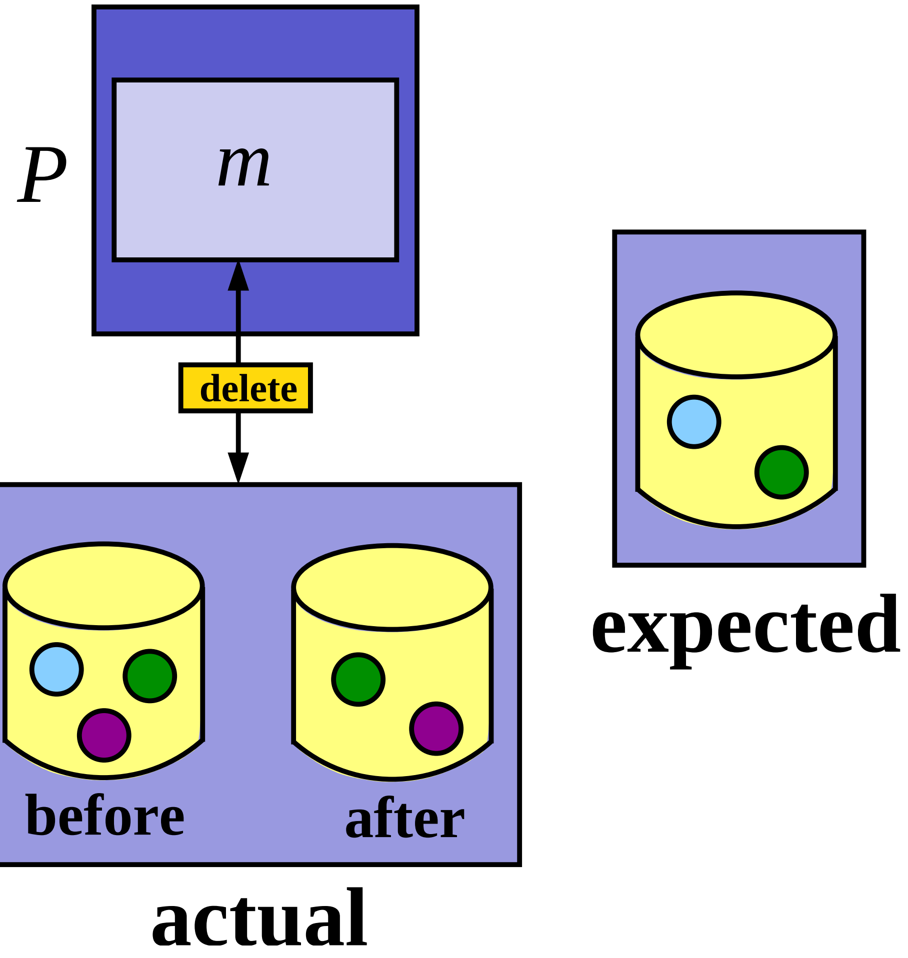
- Program P can view and/or modify the state of the database

Database Interaction Faults: (1-v)



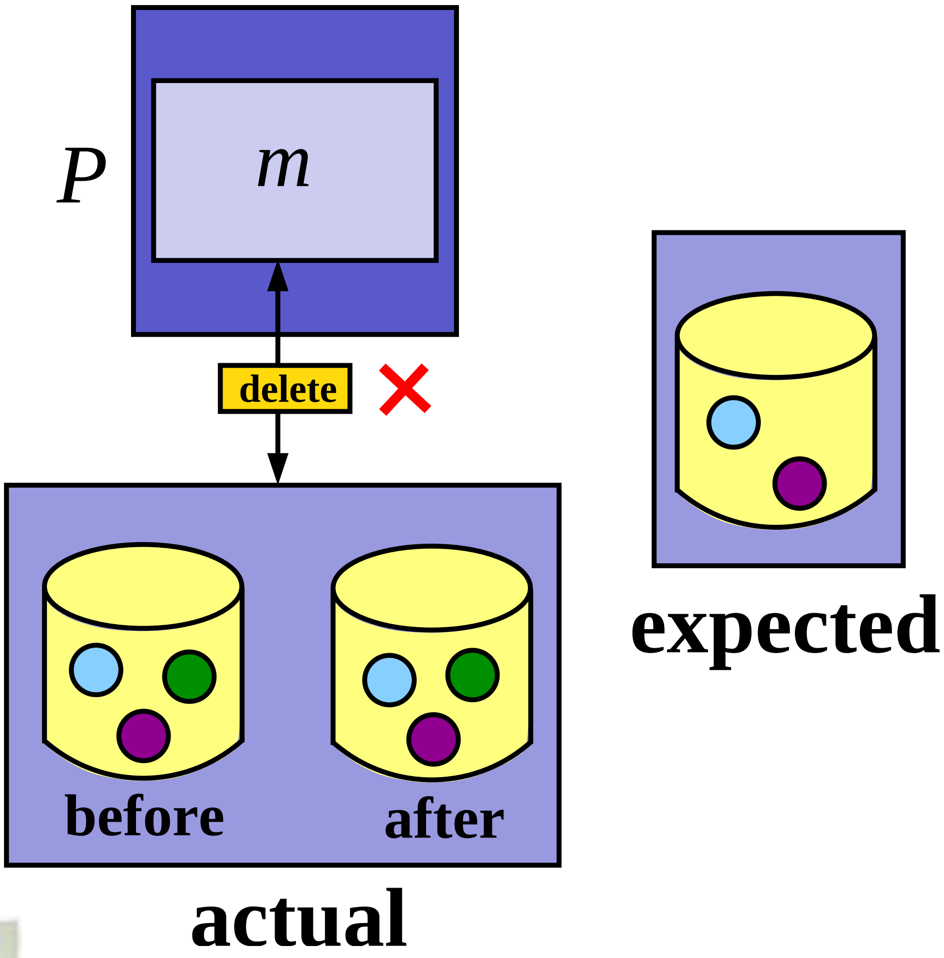
- P uses **update** or **insert** to incorrectly modify items within database
- Commission fault that violates database validity
- Structural adequacy criteria can support fault isolation

Database Interaction Faults: (1-c)



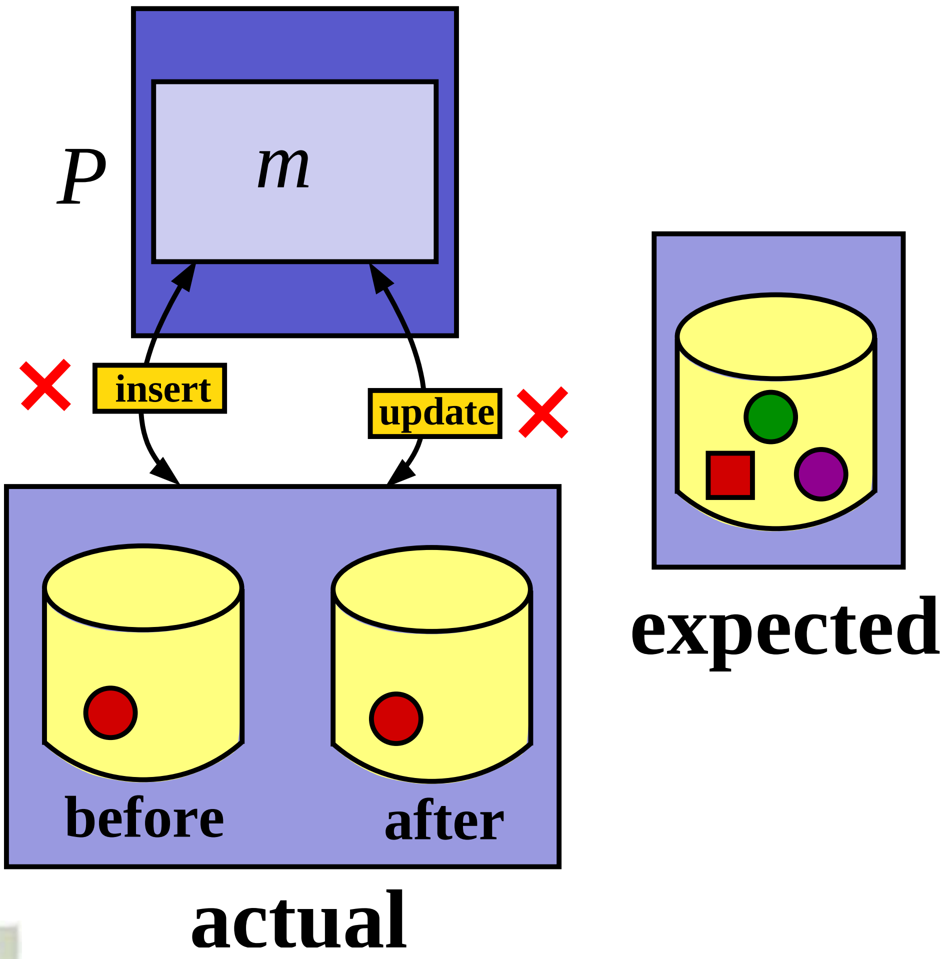
- P uses **delete** to remove incorrect items from database
- Commission fault that violates database completeness
- Structural adequacy criteria can support fault isolation

Database Interaction Faults: (2-v)



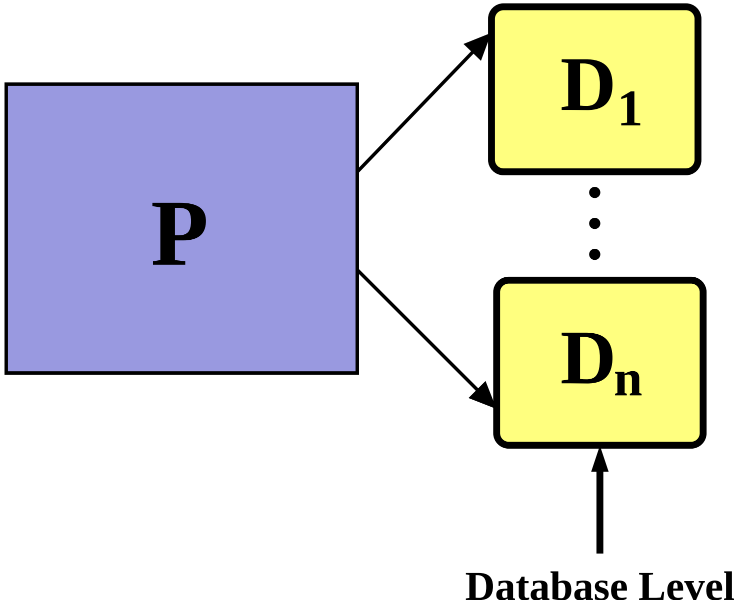
- P does not submit **delete** to remove items from database
- Commission or omission fault that violates database validity
- Structural adequacy criteria cannot easily support omission fault isolation

Database Interaction Faults: (2-c)



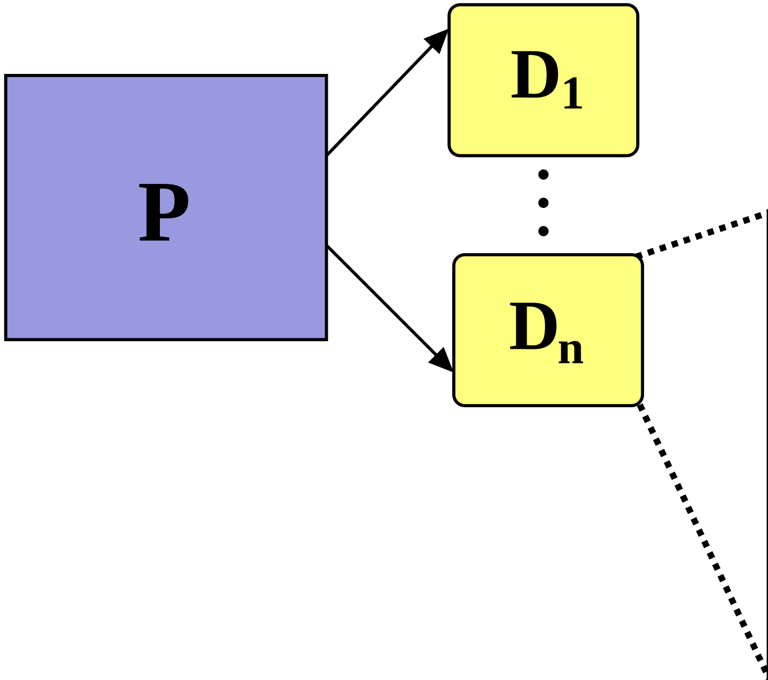
- P does not submit **update** or **insert** to database
- Commission or omission fault that violates database completeness
- Structural adequacy criteria cannot easily support omission fault isolation

Database Interaction Levels



- A program can interact with a relational database at different levels of granularity

Database Interaction Levels

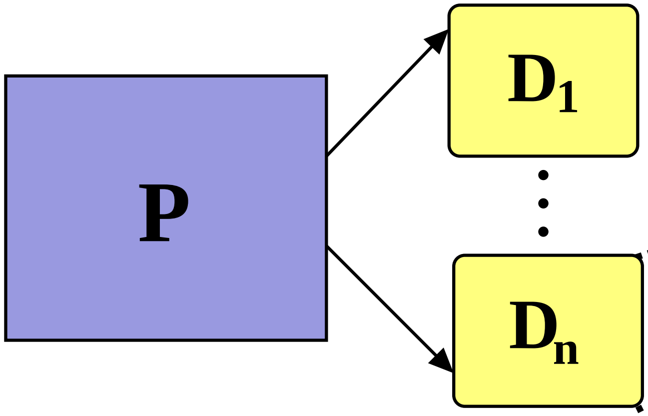


UserInfo

card_number	pin_number	user_name	acct_lock
1	32142	Brian Zorman	0
2	41601	Robert Roos	0
3	45322	Marcus Bittman	0
4	56471	Geoffrey Arnold	0

Relation Level

Database Interaction Levels

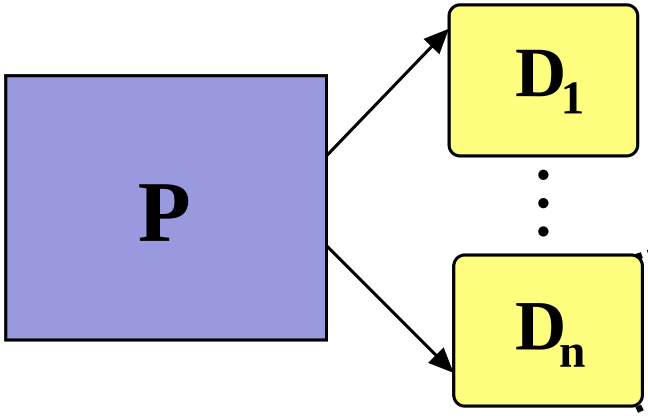


UserInfo

card_number	pin_number	user_name	acct_lock
1	32142	Brian Zorman	0
2	41601	Robert Roos	0
3	45322	Marcus Bittman	0
4	56471	Geoffrey Arnold	0

Record Level

Database Interaction Levels

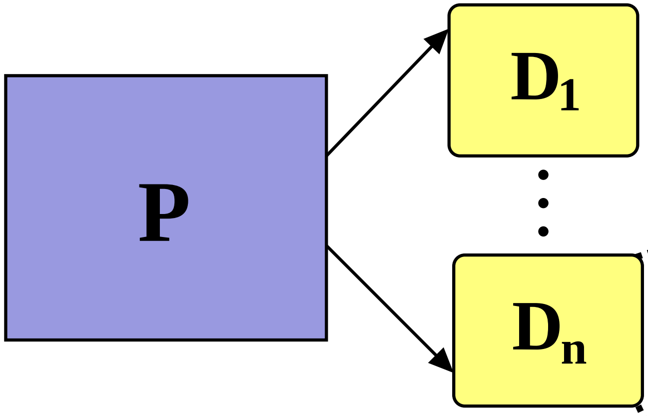


UserInfo

card_number	pin_number	user_name	acct_lock
1	32142	Brian Zorman	0
2	41601	Robert Roos	0
3	45322	Marcus Bittman	0
4	56471	Geoffrey Arnold	0

Attribute Level

Database Interaction Levels



UserInfo

card_number	pin_number	user_name	acct_lock
1	32142	Brian Zorman	0
2	41601	Robert Roos	0
3	45322	**Marcus Bittman**	0
4	56471	Geoffrey Arnold	0

Attribute Value Level

Database Interaction Points: DML

select $A_1, A_2, \ldots, A_q$
from $r_1, r_2, \ldots, r_m$
where Q

delete from r
where Q

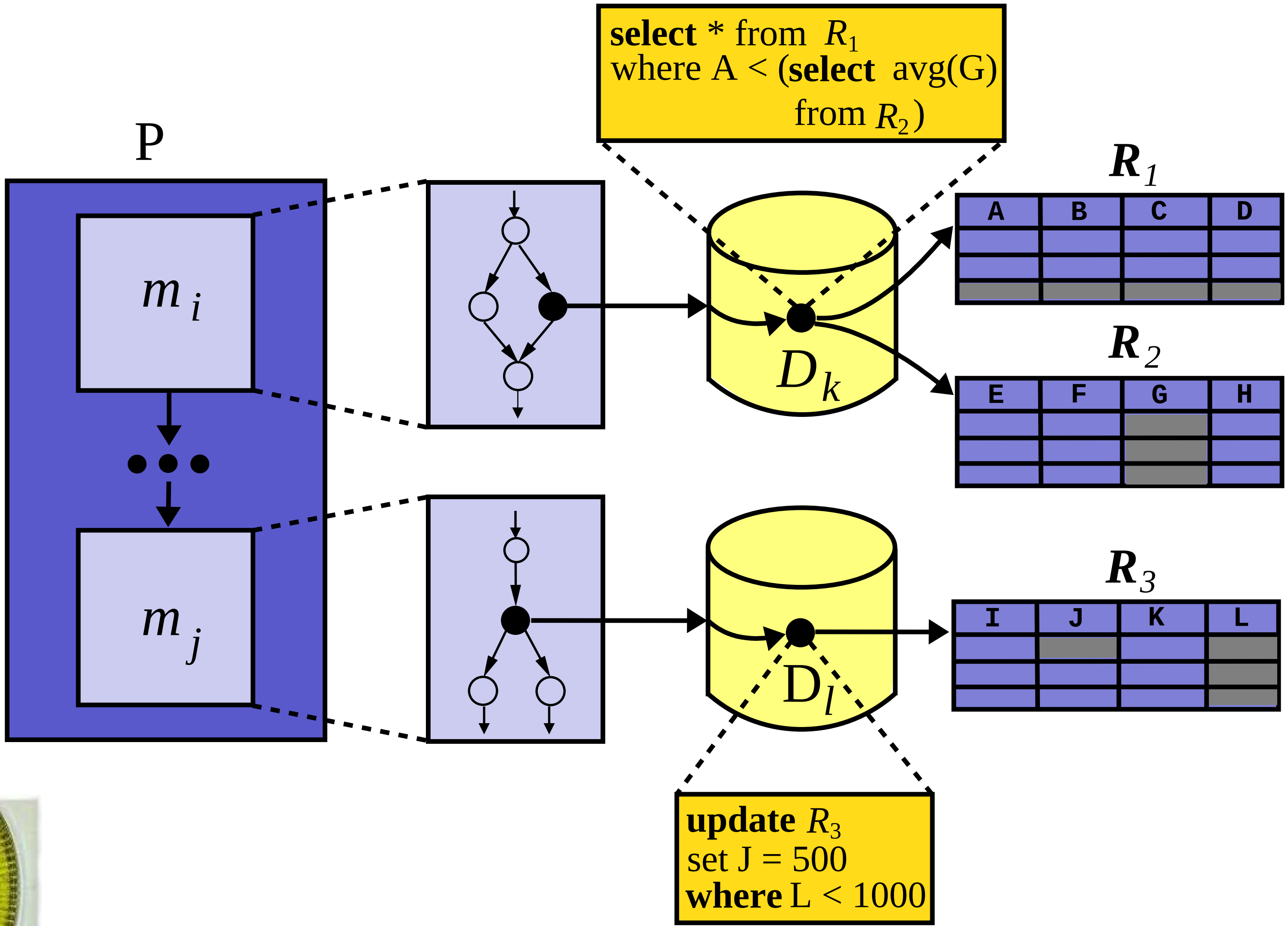
insert into $r(A_1, A_2, \ldots, A_q)$
values$(v_1, v_2, \ldots, v_q)$

update r
set $A_l = F(A_l)$
where Q

Analyzing Database Interaction Points

- Database interaction point $I_r \in I$ corresponds to the execution of a SQL DML statement
- Consider the relevant portions of SQL that are parsed by HSQLDB ($\mathtt{http://hsqldb.sf.net}$)
- Interaction points are normally encoded within Java programs as dynamically constructed `String`s
- **select** uses D_k, **delete** defines D_k, **insert** defines D_k, **update** defines and/or uses D_k

Refined Database-Centric Application



Test Adequacy Concepts

- P violates a database D_k's validity when it:
  - **(1-v)** inserts entities into D_k that do not reflect real world
- P violates a database D_k's completeness when it:
  - **(1-c)** deletes entities from D_k that still reflect real world
- In order to verify **(1-v)** and **(1-c)**, T must cause P to define and then use entities within $D_1, \ldots, D_n$!

Data Flow Information

- Interaction point:
  “UPDATE UserInfo SET acct_lock = 1 WHERE card_number =” + card_number + “;”;
  - Database Level: *define(BankDB)*
  - Attribute Level: *define(acct_lock)* and *use(card_number)*
- Data fbw information varies with respect to the granularity of the database interaction

Database Entities

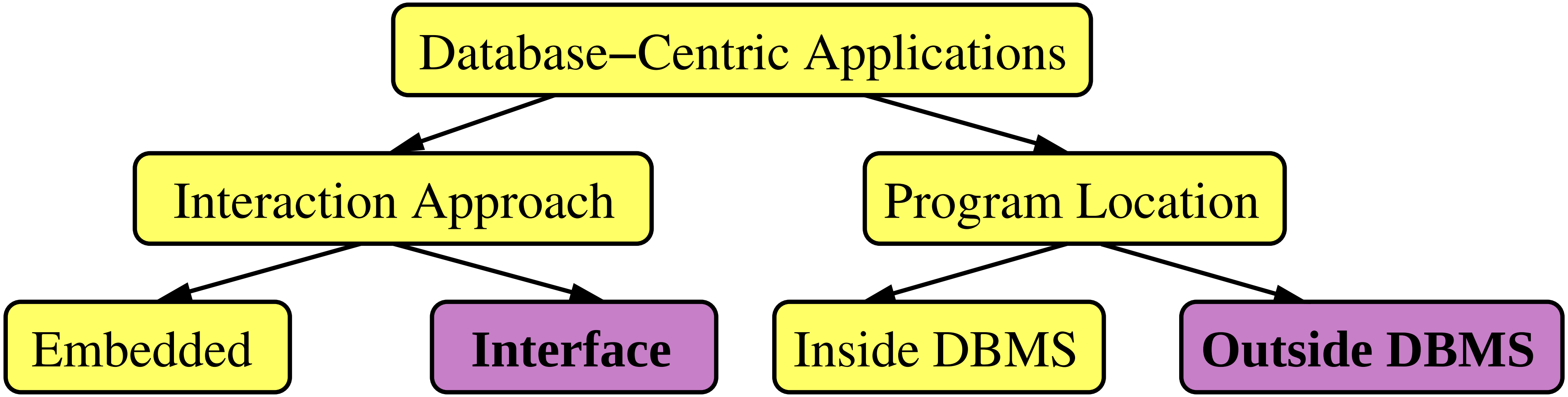
UserInfo

card_number	pin_number	user_name	acct_lock
1	32142	Brian Zorman	0
2	41601	Robert Roos	0
3	45322	Marcus Bittman	0
4	56471	Geoffrey Arnold	0

$$A_v(I_r) = \{ \boxed{1}, \boxed{32142}, \ldots, \boxed{\text{Geoffrey Arnold}}, \boxed{0} \}$$

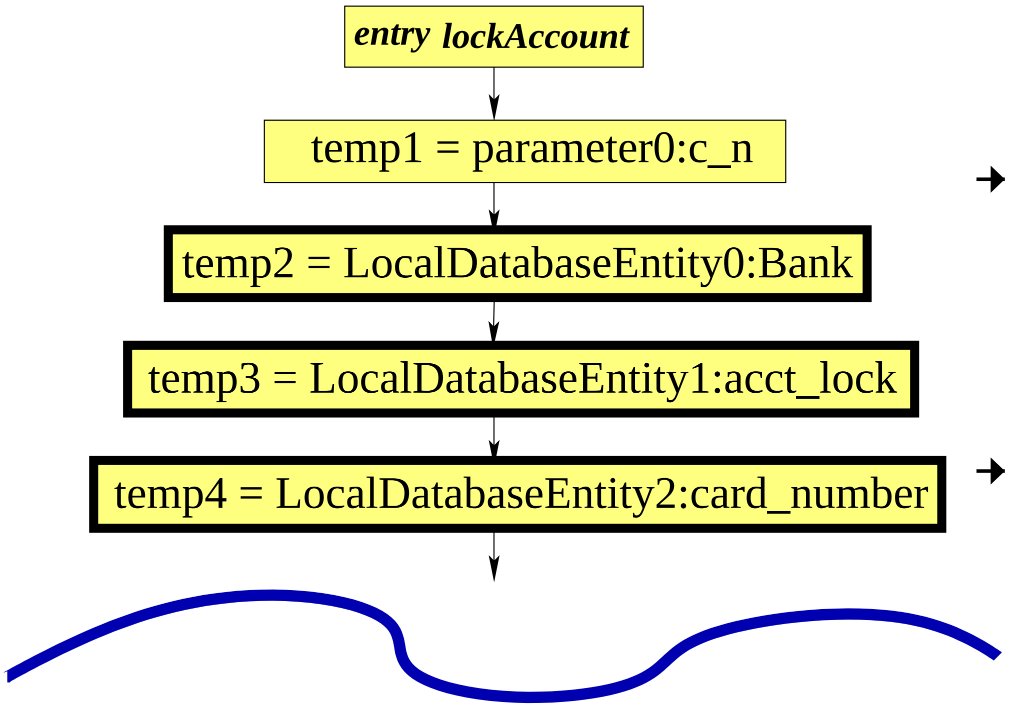
- Enumerate database entities at the attribute value level

Application Types



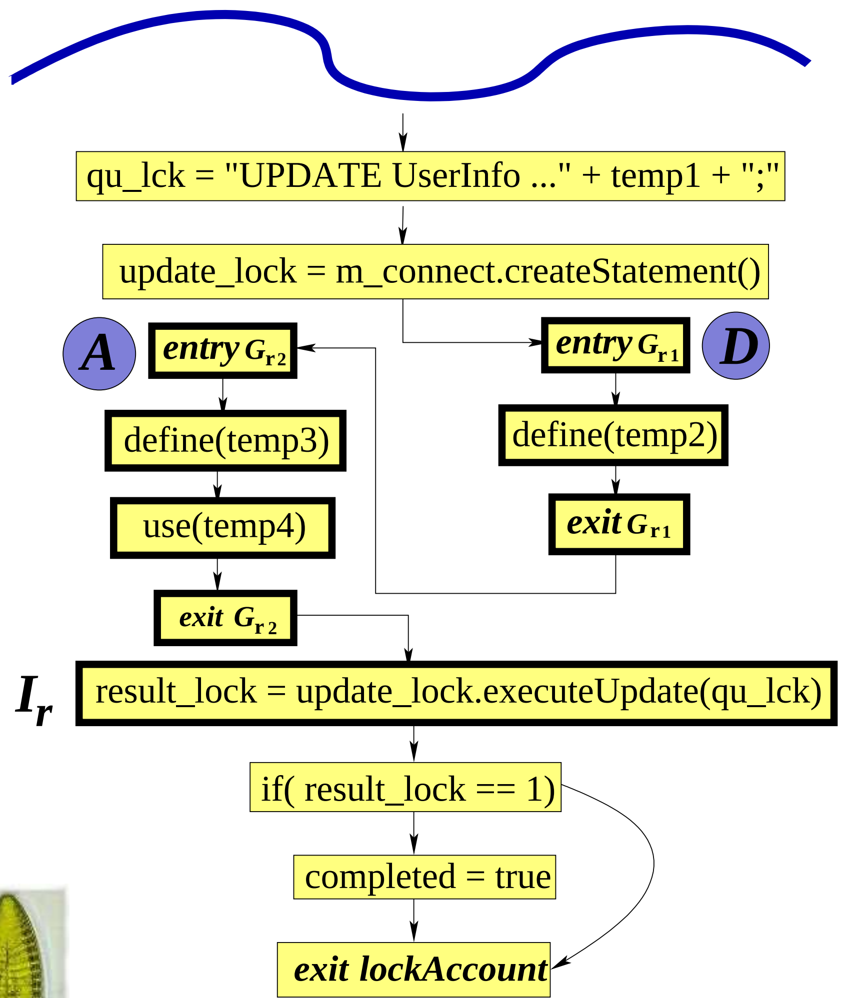
- Testing methodology relevant to all types of applications
- Current tool support focuses on Interface-Outside applications
- **Example:** Java application that submits SQL `Strings` to HSQLDB relational database using JDBC drivers

The DICFG: A Unified Representation



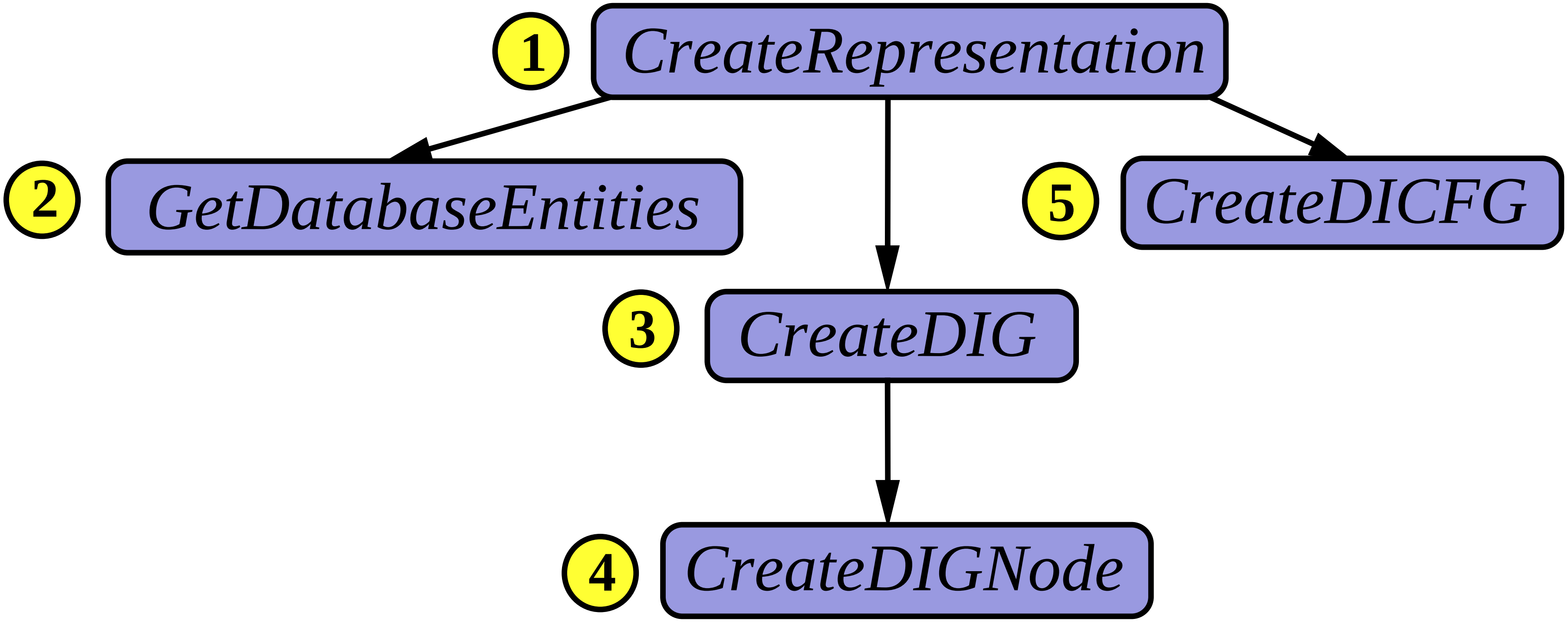
- "Database-enhanced" CFG for `lockAccount`
- Automatically constructed with tool support
- Define temporaries to represent the program's interaction at the levels of database and attribute

The DICFG: A Unified Representation



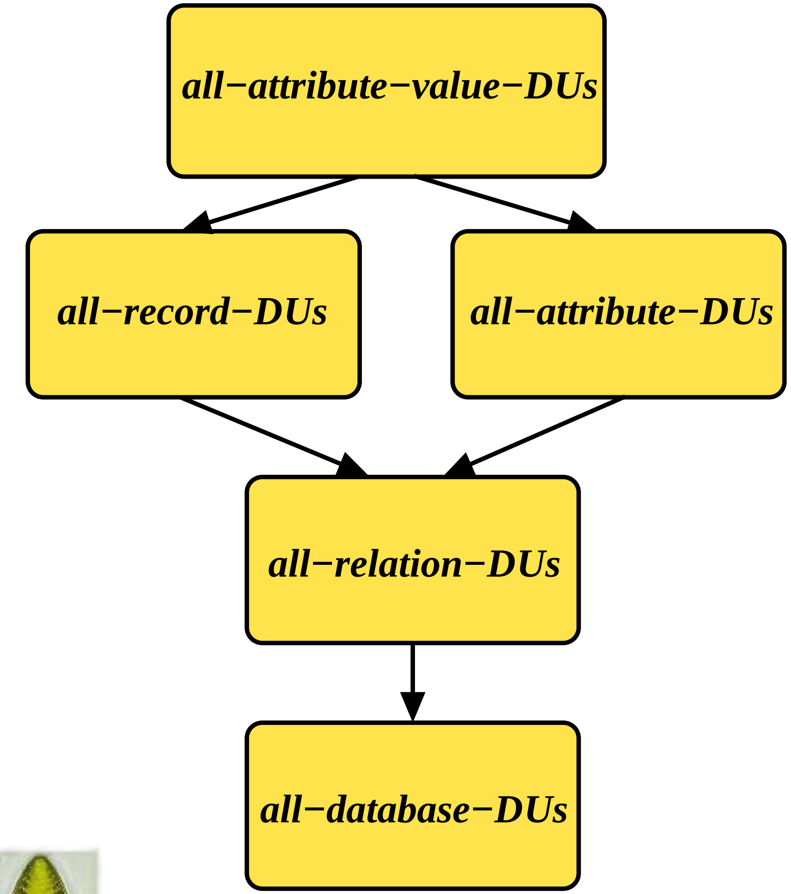
- Database interaction graphs (DIGs) are placed before interaction point I_r
- Multiple DIGs can be integrated into a single CFG
- `String` at I_r is determined in a control-fbw sensitive fashion using enhanced BRICS JSA

DICFG Construction Algorithms



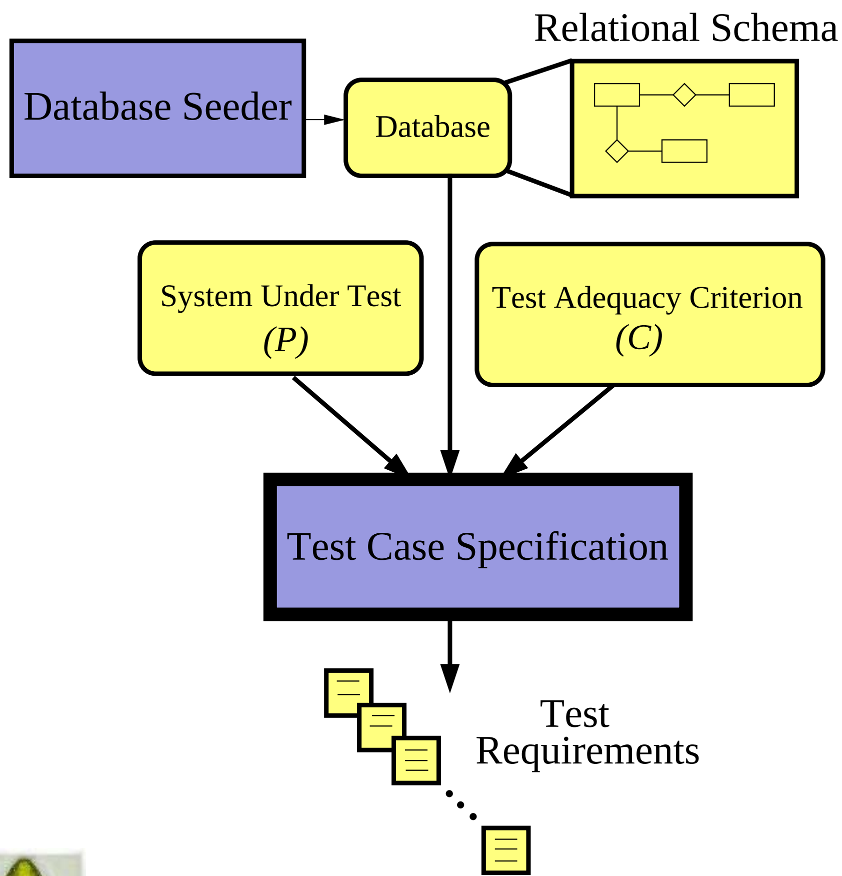
- Iteratively construct a database aware CFG to support data flow analysis and enumerate test requirements

Test Adequacy Criteria



- Database interaction association (DIA) involves the *def* and *use* of a database entity
- DIAs can be located in the DICFG with data flow analysis
- *all-database-DUs* requires tests to exercise all DIAs for all of the accessed databases

Generating Test Requirements

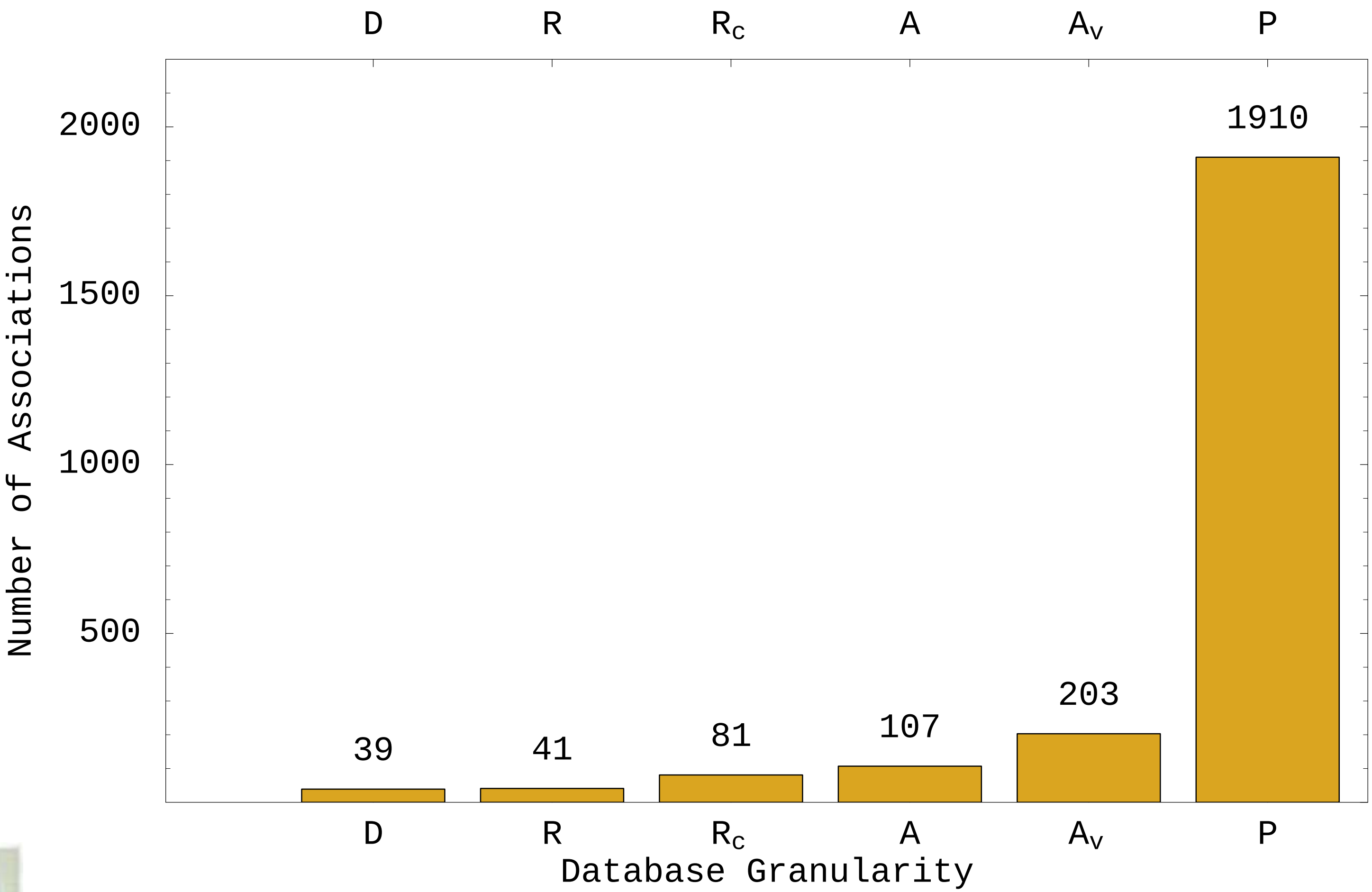


- Measured time and space overhead when computing family of test adequacy criteria
- Modifi ed `ATM` and `mp3cd` to contain appropriate database interaction points
- Soot 1.2.5 to calculate intraprocedural associations
- GNU/Linux workstation with kernel 2.4.18-smp and dual 1 GHz Pentium III Xeon processors

Experiment Goals and Design

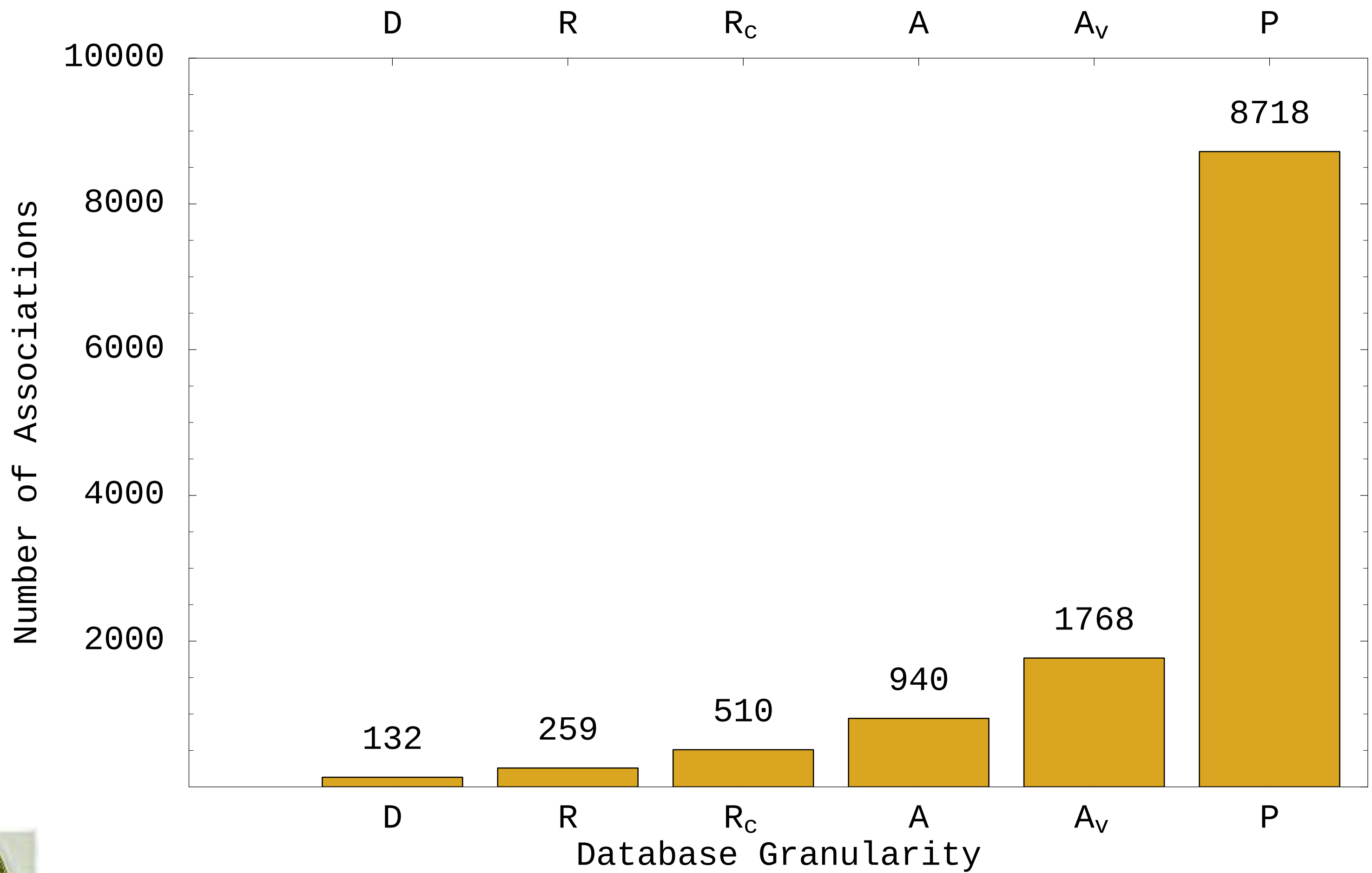
- **Reseach Question One:** Does the incorporation of database interactions yield more test requirements?
- **Reseach Question Two:** Can test requirement enumeration be performed efficiently if database interactions are included?
- **Experiment Metrics:** Number of test requirements ($\mathcal{TR}$), time overhead ($\mathcal{T}$), and space overhead ($\mathcal{S}$)
- Applications: `ATM` (1732 NCSS and 136 methods) and `mp3cd` (2913 NCSS and 452 methods)

Number of Test Requirements: ATM



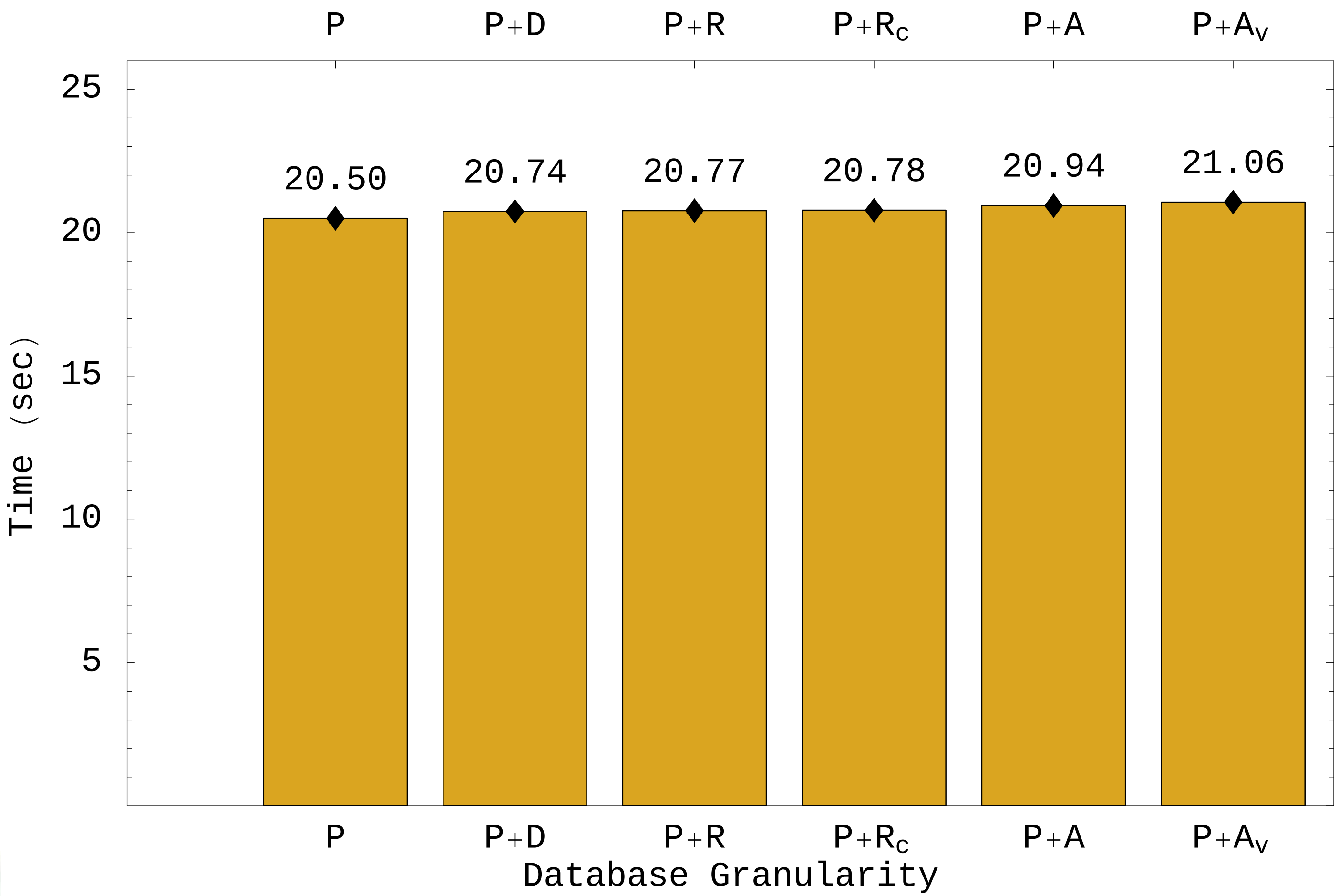
- 80.7% increase in number of test requirements from D to A_v

Number of Test Requirements: `mp3cd`



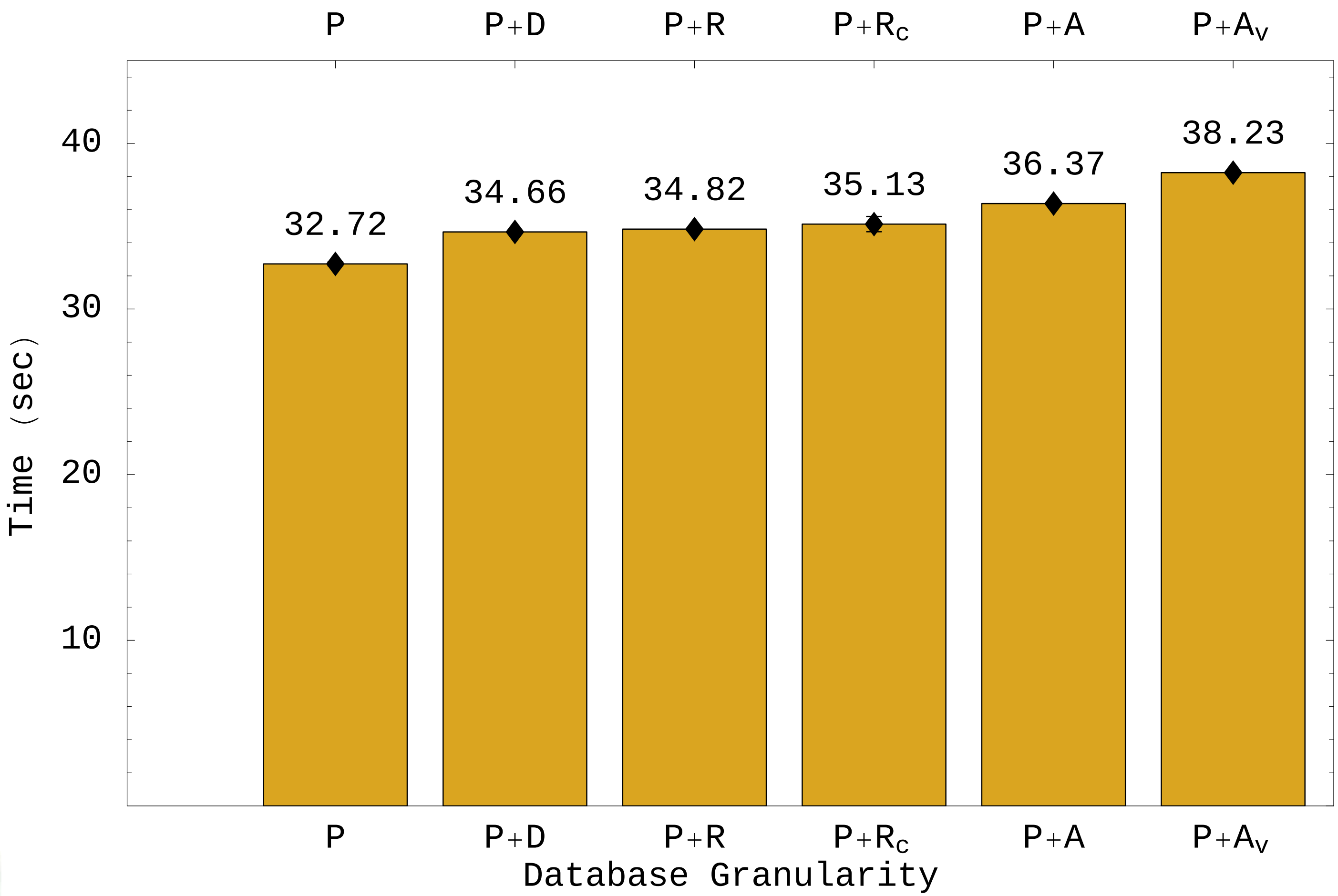
- 92.5% increase in number of test requirements from D to A_v

Time Overhead: ATM



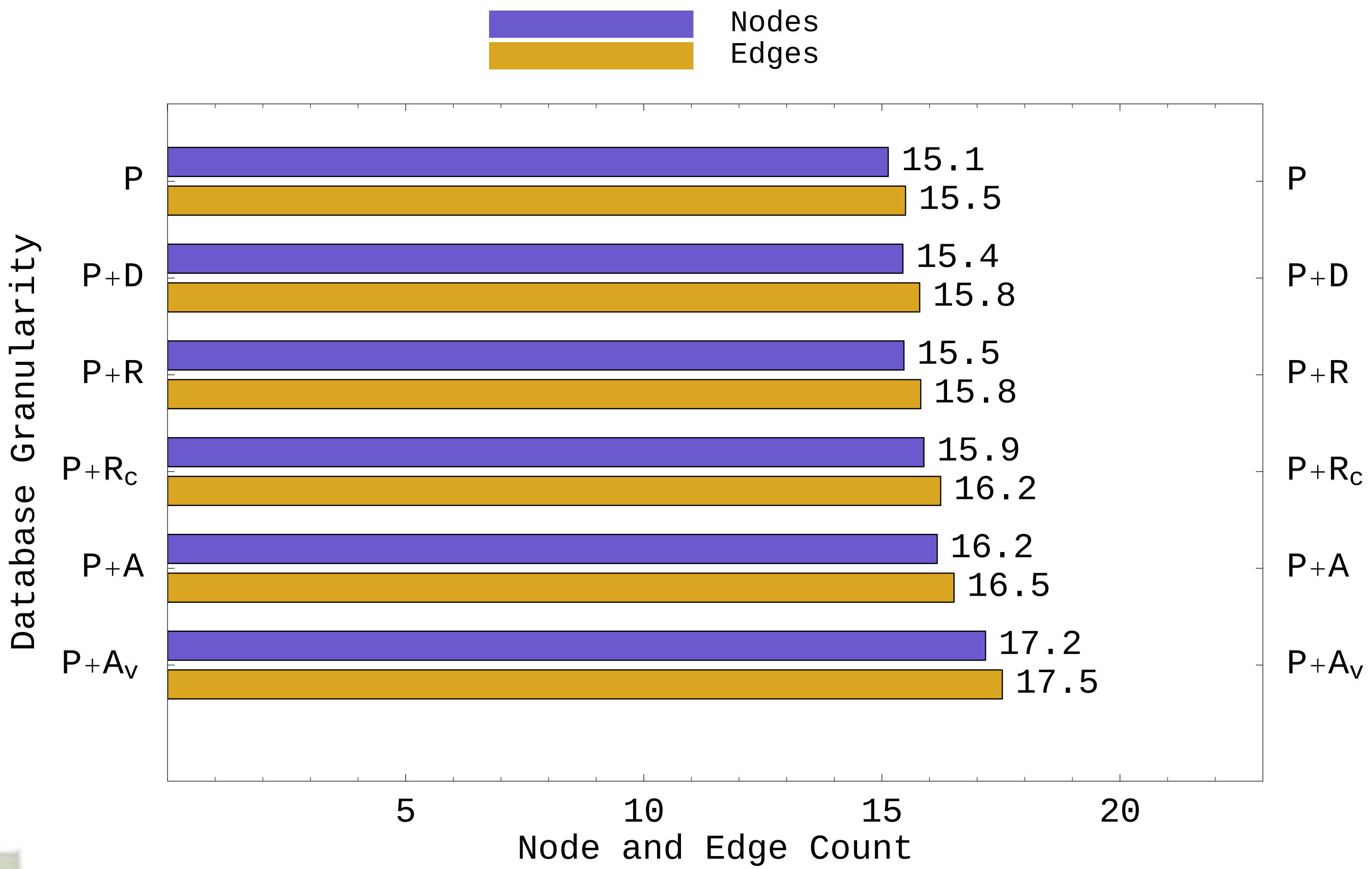
- 2.7% increase in time overhead from P to $P + A_v$

Time Overhead: `mp3cd`



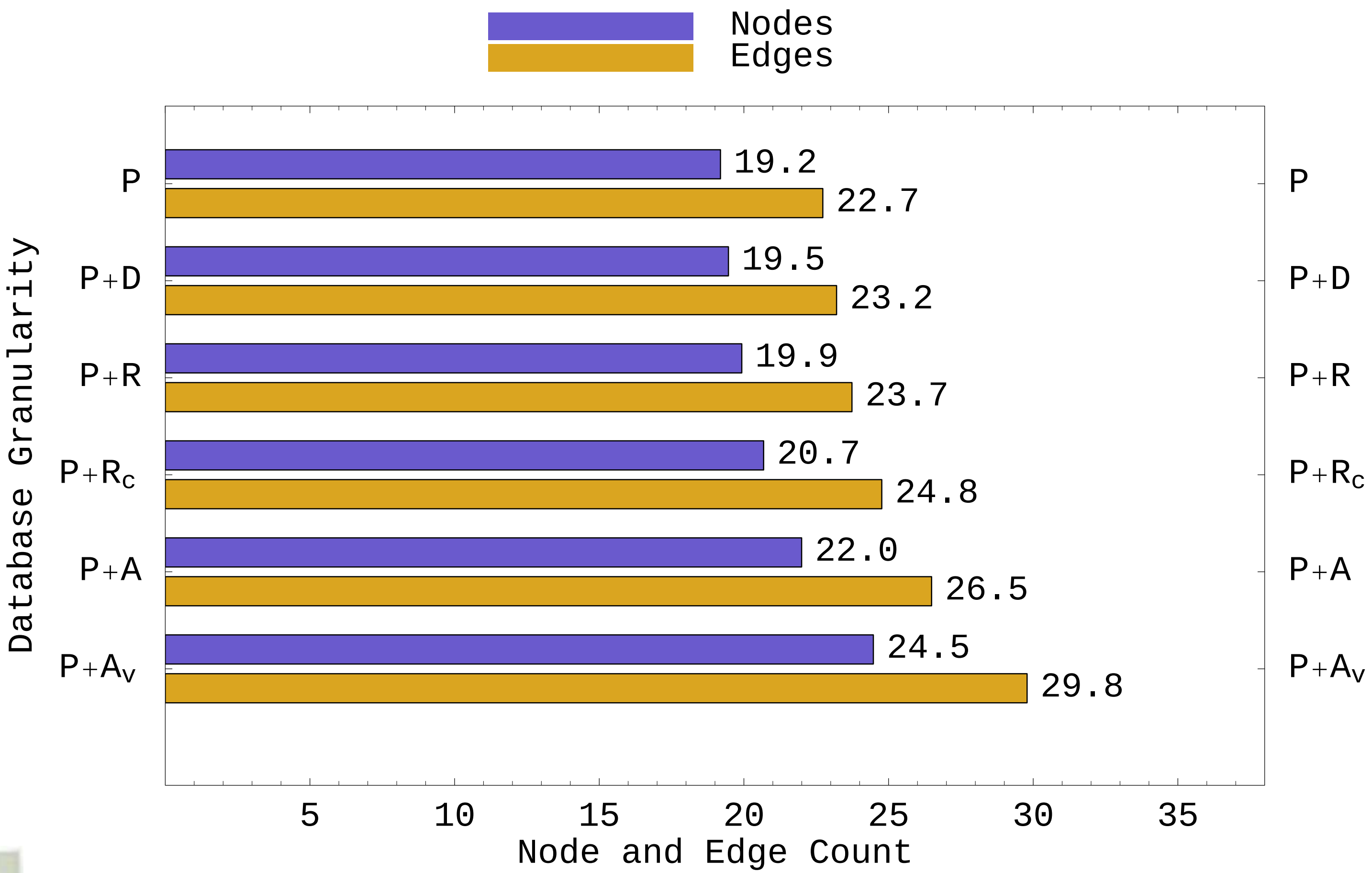
- 14.4% increase in time overhead from P to $P + A_v$

Space Overhead: ATM



- Average number of {DI}CFG nodes and edges is stable

Space Overhead: `mp3cd`



- `mp3cd` has more database interactions and larger database

Average Increase in CFG Nodes

	$\mathcal{SN}^{\%}_{\mathcal{I}}(R, D)$	$\mathcal{SN}^{\%}_{\mathcal{I}}(R_c, R)$	$\mathcal{SN}^{\%}_{\mathcal{I}}(A, R)$
`ATM`	.6	2.5	4.3
`mp3cd`	2.0	3.8	9.5

	$\mathcal{SN}^{\%}_{\mathcal{I}}(A_v, R_c)$	$\mathcal{SN}^{\%}_{\mathcal{I}}(A_v, A)$	$\mathcal{SN}^{\%}_{\mathcal{I}}(A_v, D)$	$\mathcal{SN}^{\%}_{\mathcal{I}}(A_v, P)$
`ATM`	7.5	5.8	10.4	12.2
`mp3cd`	15.5	10.2	20.4	21.6

Average Increase in CFG Edges

	$\mathcal{SE}_{\mathcal{I}}^{\%}(R, D)$	$\mathcal{SE}_{\mathcal{I}}^{\%}(R_c, R)$	$\mathcal{SE}_{\mathcal{I}}^{\%}(A, R)$
`ATM`	0.0	2.4	4.2
`mp3cd`	2.1	4.4	10.5

	$\mathcal{SE}_{\mathcal{I}}^{\%}(A_v, R_c)$	$\mathcal{SE}_{\mathcal{I}}^{\%}(A_v, A)$	$\mathcal{SE}_{\mathcal{I}}^{\%}(A_v, D)$	$\mathcal{SE}_{\mathcal{I}}^{\%}(A_v, P)$
`ATM`	7.4	5.7	9.7	11.4
`mp3cd`	16.7	11.0	22.1	23.8

Related Work

- Jin and Offutt and Whittaker and Voas have suggested that the environment of a software system is important
- Chan and Cheung transform SQL statements into C code segments
- Chays et al. and Chays and Deng have created the category-partition inspired AGENDA tool suite
- Neufeld et al. and Zhang et al. have proposed techniques for database state generation
- Dauo et al. focused on the regression testing of database-driven applications

Ongoing Research

- Test suite execution that minimizes number of costly database restarts and initializations
- Test coverage monitoring through a database interaction calling context tree (DICCT)
- Regression test suite reduction and prioritization that incorporates database aware adequacy and test case cost
- Detailed empirical studies with ten case study applications of varying code and database size
- Comprehensive tool support to assist the testing of database-centric applications

Conclusions

- Must test the program’s interaction with the database
- Test adequacy infrastructure provides : (i) database interaction fault model, (ii) unifi ed application representation, (iii) family of test adequacy criteria
- Unique family of test adequacy criteria to detect all type (1) and some type (2) violations of database validity and completeness
- Intraprocedural database interactions can be computed from a DICFG with minimal time and space overhead
- Foundation for a complete testing methodology

Further Resources

Gregory M. Kapfhammer and Mary Lou Soffa. A Family of Test Adequacy Criteria for Database-Driven Applications. In *ESEC/FSE 2003*.

Gregory M. Kapfhammer. Software Testing. CRC Press Computer Science Handbook. June, 2004.

http://cs.allegheny.edu/~gkapfham/research/diatoms/