Inlining Control-Flow Jumps in Library Usage Graphs of Legacy Code

Presentation Abstract

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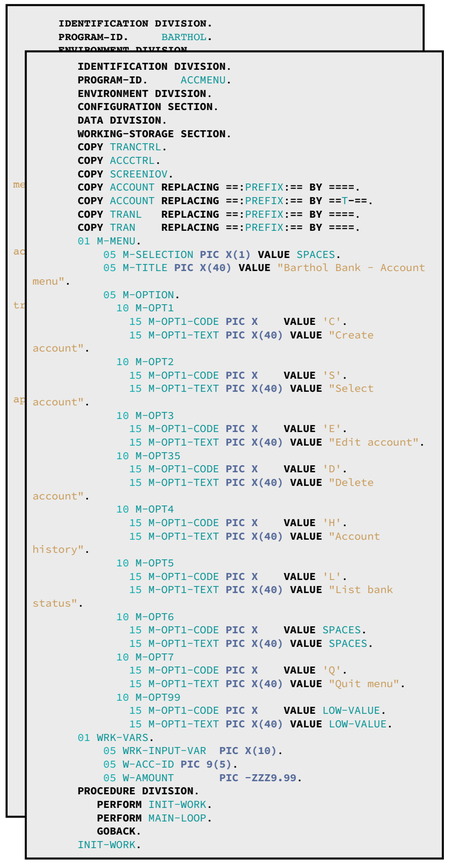
VRIJE UNIVERSITEIT BRUSSEL

Software Languages Lab

raincode LABS compiler experts

INTiMALS

COBOL Library Usage Pattern Mining



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       ENVIRONMENT DIVISION.
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Case 1	305	662.2
Case 2	3926	22889

Goal: Understand library usages
to estimate modernisation effort

COBOL Library Usage Pattern Mining

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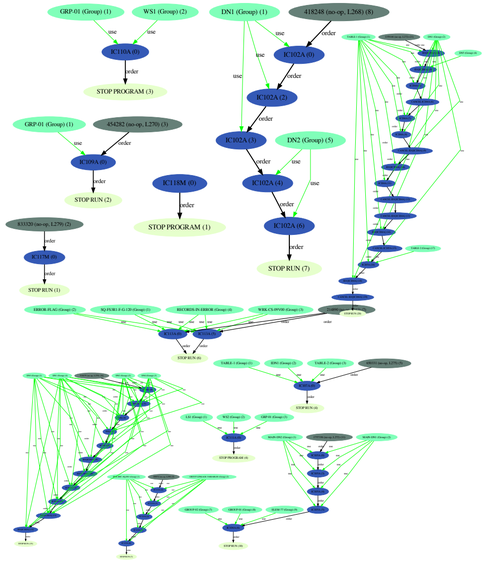
Library Usages



Case	Time (s)	# Groums	Avg. size	Max. size
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Case 2 (limited)	N/A	3573	125	9644

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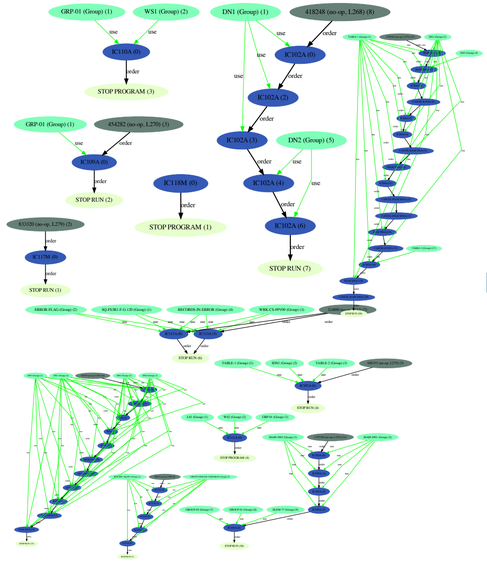

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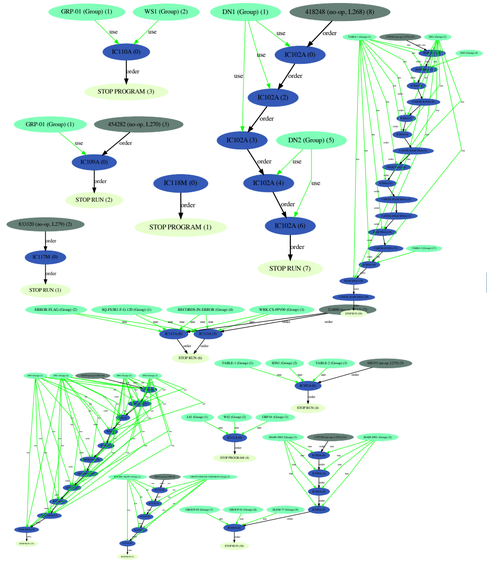

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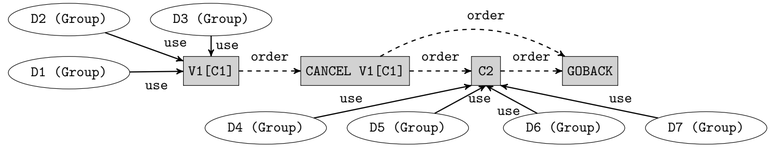

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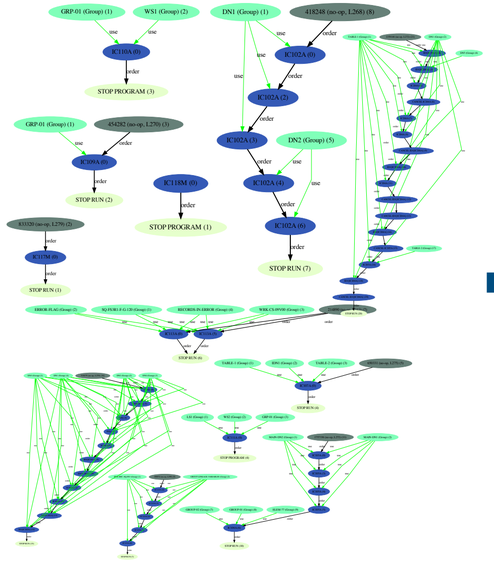

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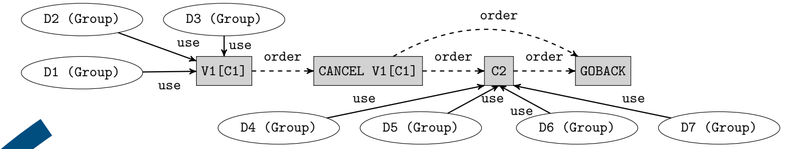

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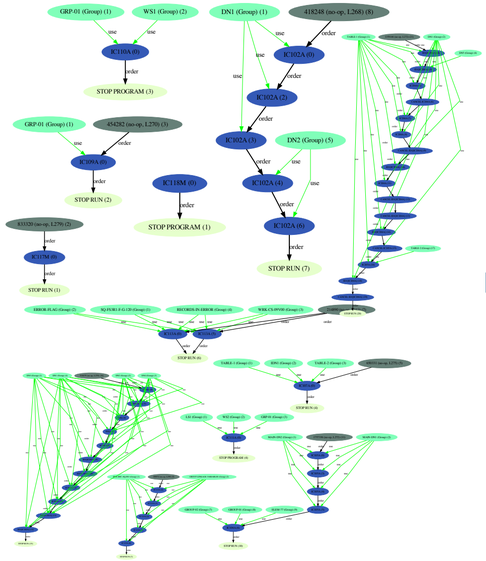

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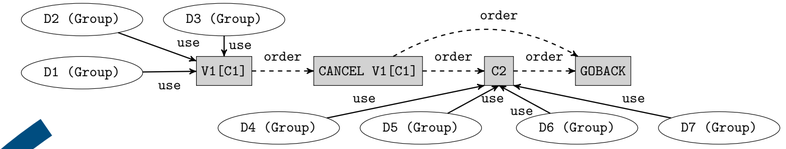

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    return lst.stream()
        .filter(s -> s.startsWith("test_"))
        .count();
}
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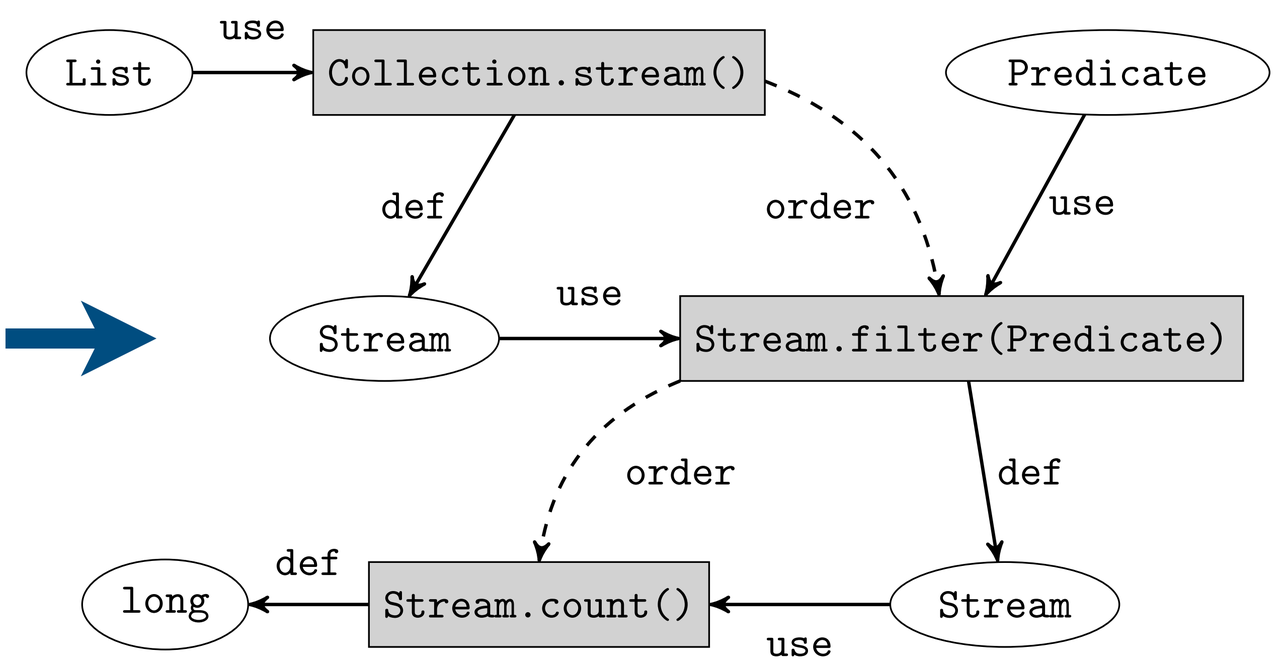

Java snippet using Collection API

Graph-based object usage model

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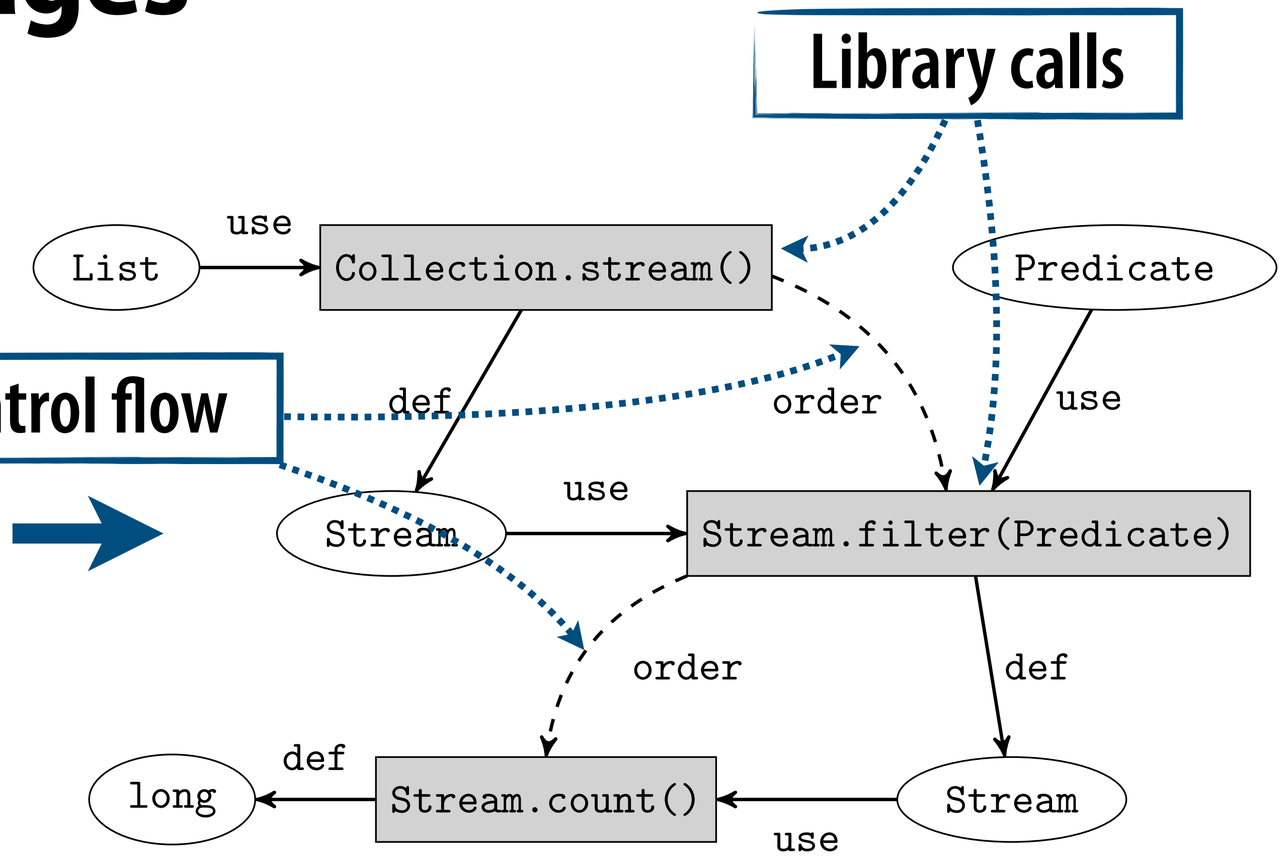

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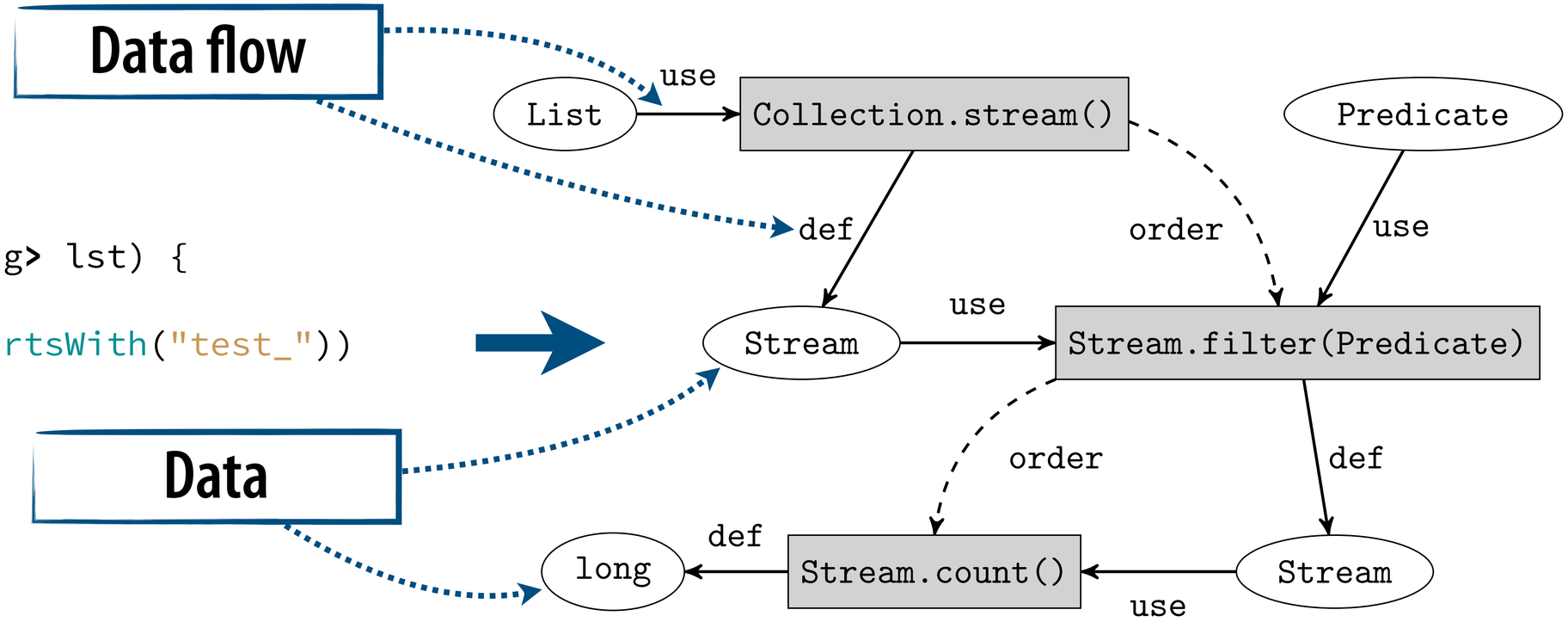

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Graph-based object usage model

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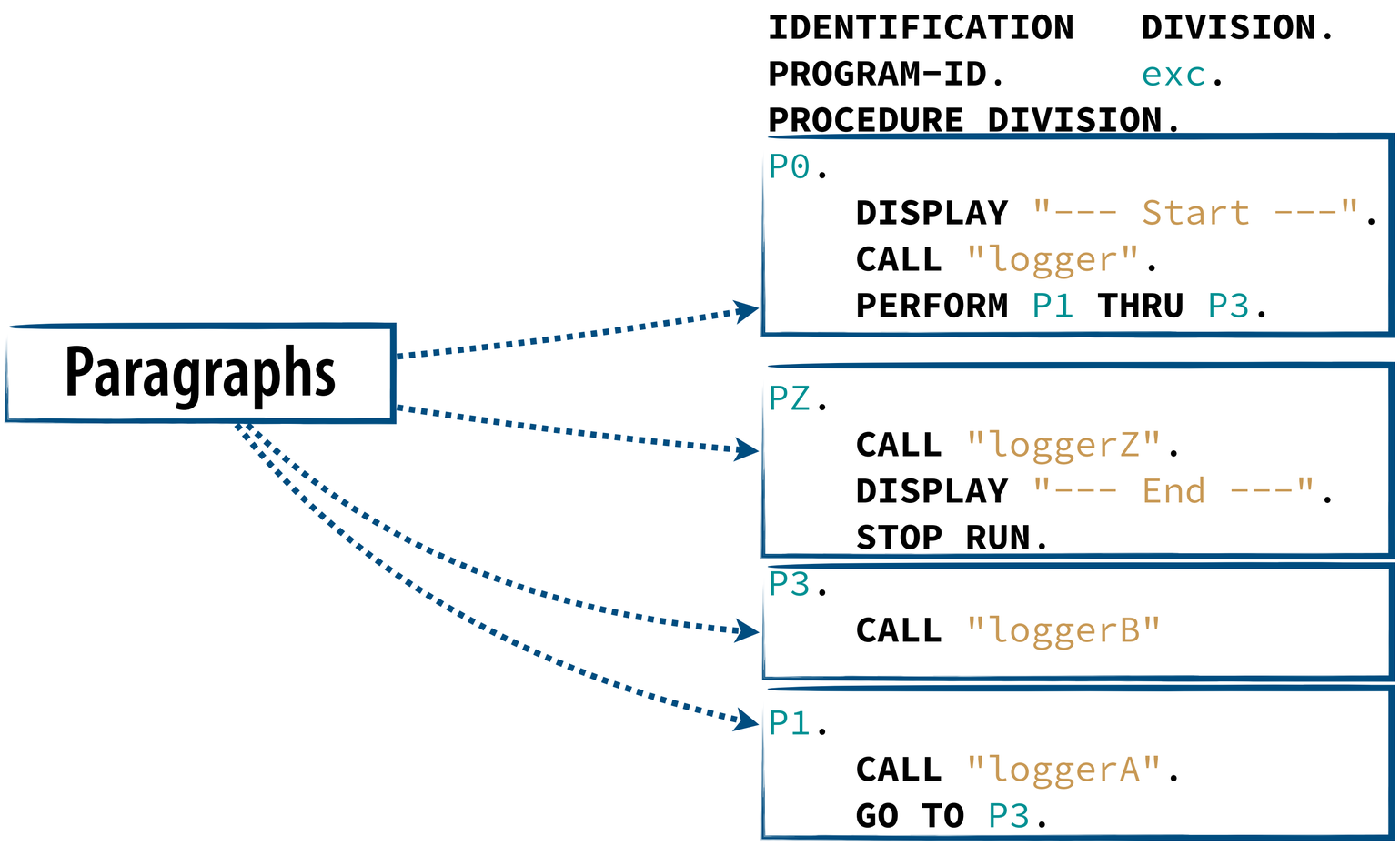
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```

COBOL Primer



COBOL Primer

Call statement
Calls an external program.
“Library call”

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P1.
    CALL "loggerA".
    GO TO P3.
```
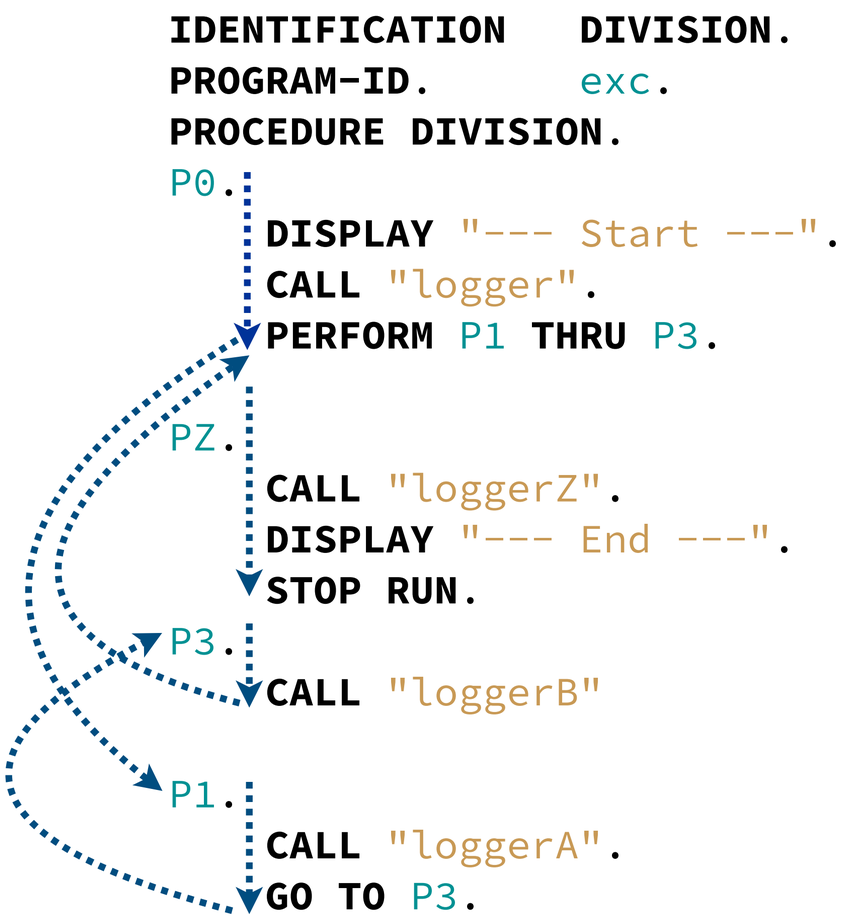

Perform statement
Jump to `P1`, execute until `P3`, jump back

Go to statement
Jump to `P3` and continue execution

COBOL Primer



Jumping leads to complex control flow

Groums for COBOL

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```

Single paragraph (often) too small

Groums for COBOL

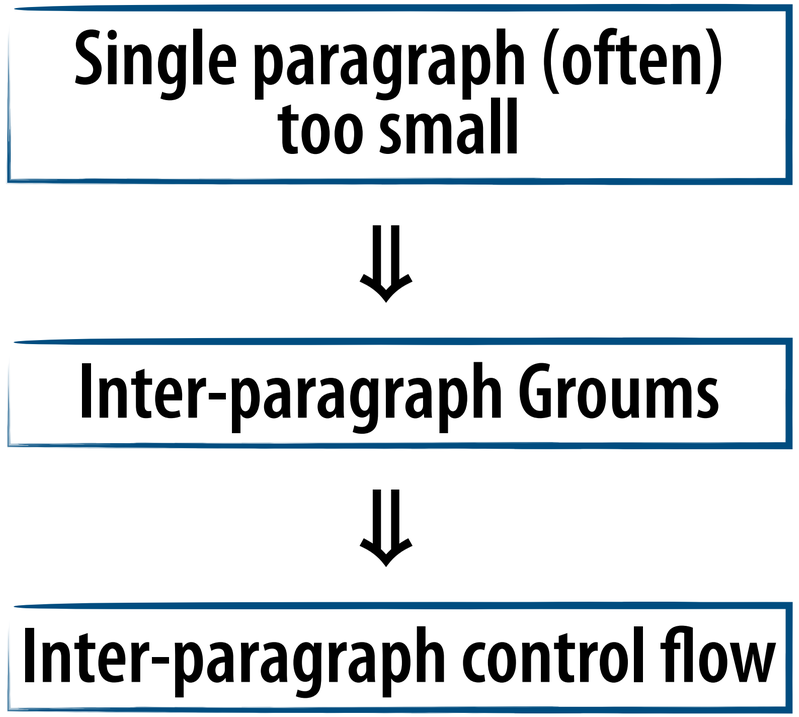
```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```

Single paragraph (often) too small

Inter-paragraph Groums

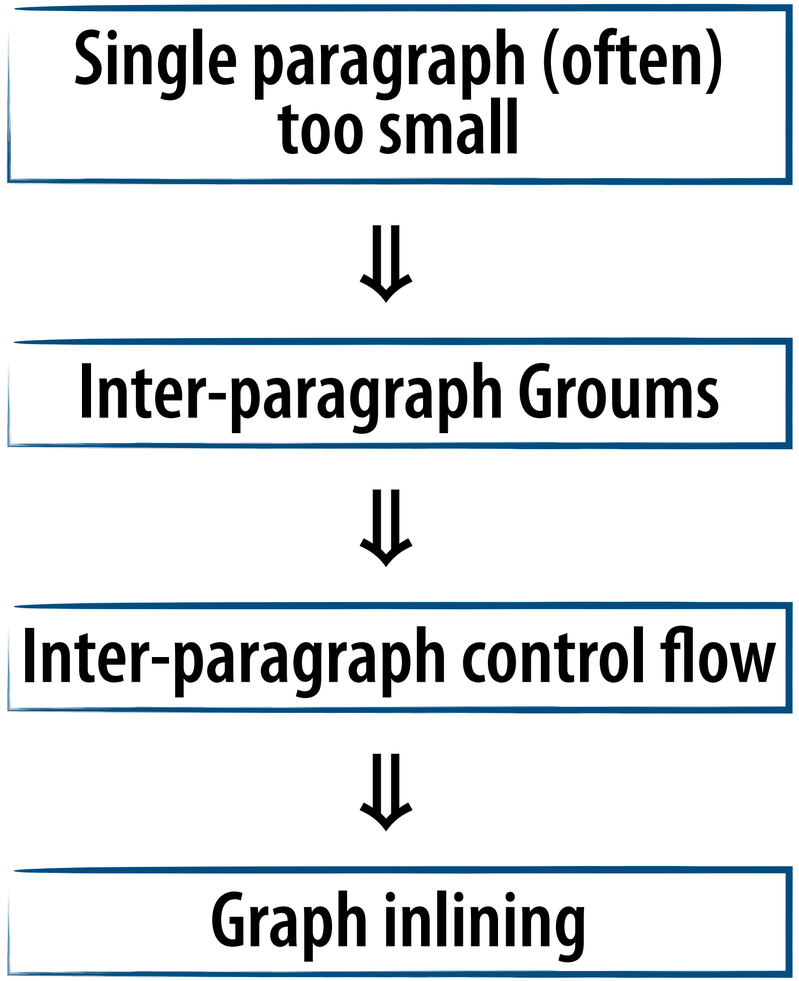
Groums for COBOL

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```



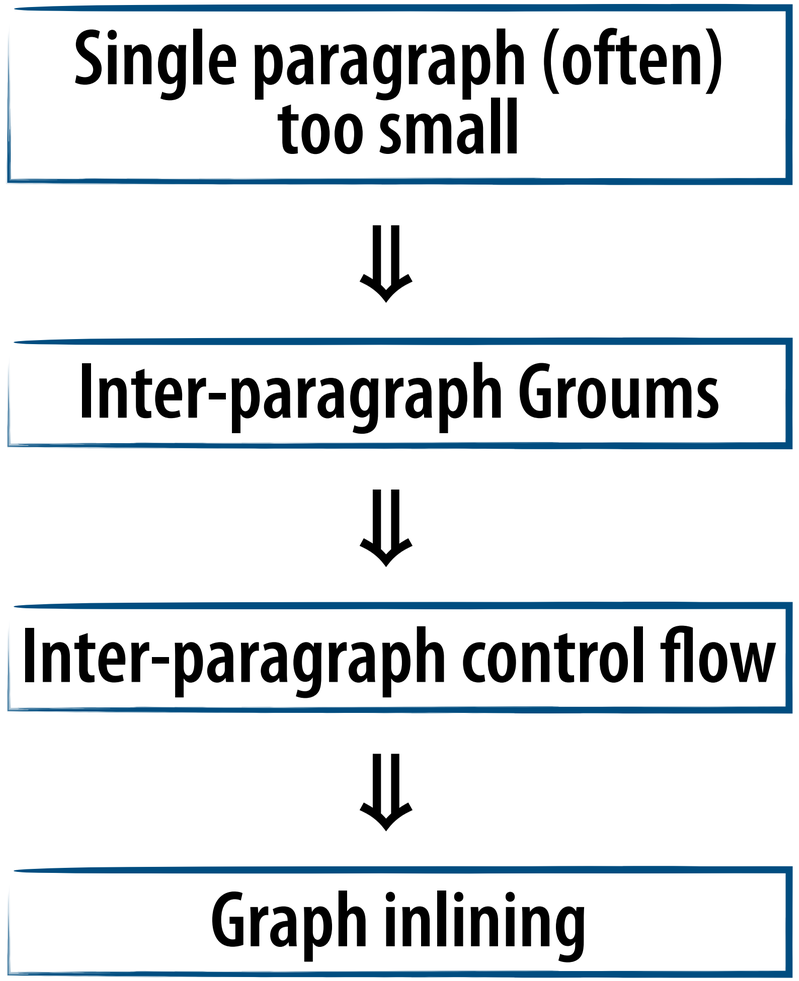
Groums for COBOL

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```



Groums for COBOL

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```



Other challenges
- Definition of library calls
- Absence of “def” edges
- Iteration through jumps
- Exit calls
- ...

Phase 1: Intermediate Groum Construction

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```

Phase 1: Intermediate Groum Construction

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IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
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    DISPLAY "--- Start ---".
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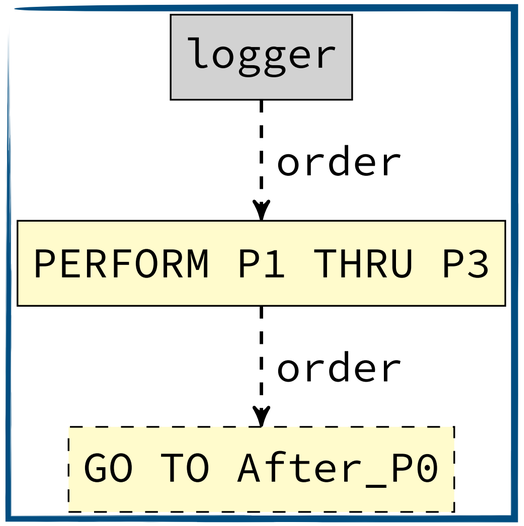
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```

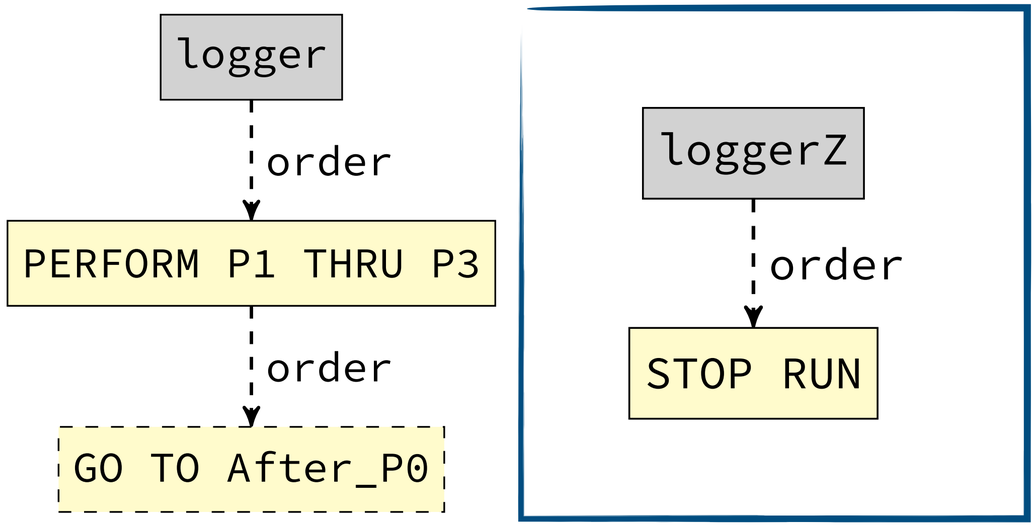


Phase 1: Intermediate Groum Construction

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```

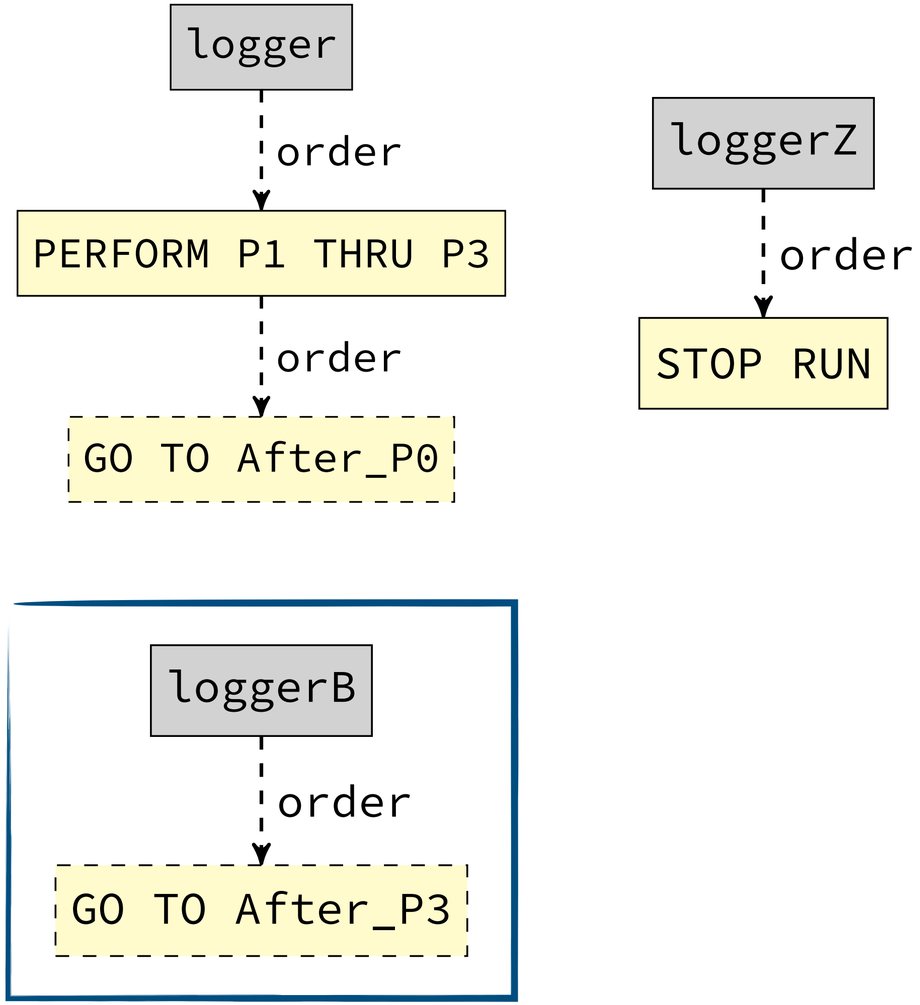


Phase 1: Intermediate Groum Construction

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```



Phase 1: Intermediate Groum Construction

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
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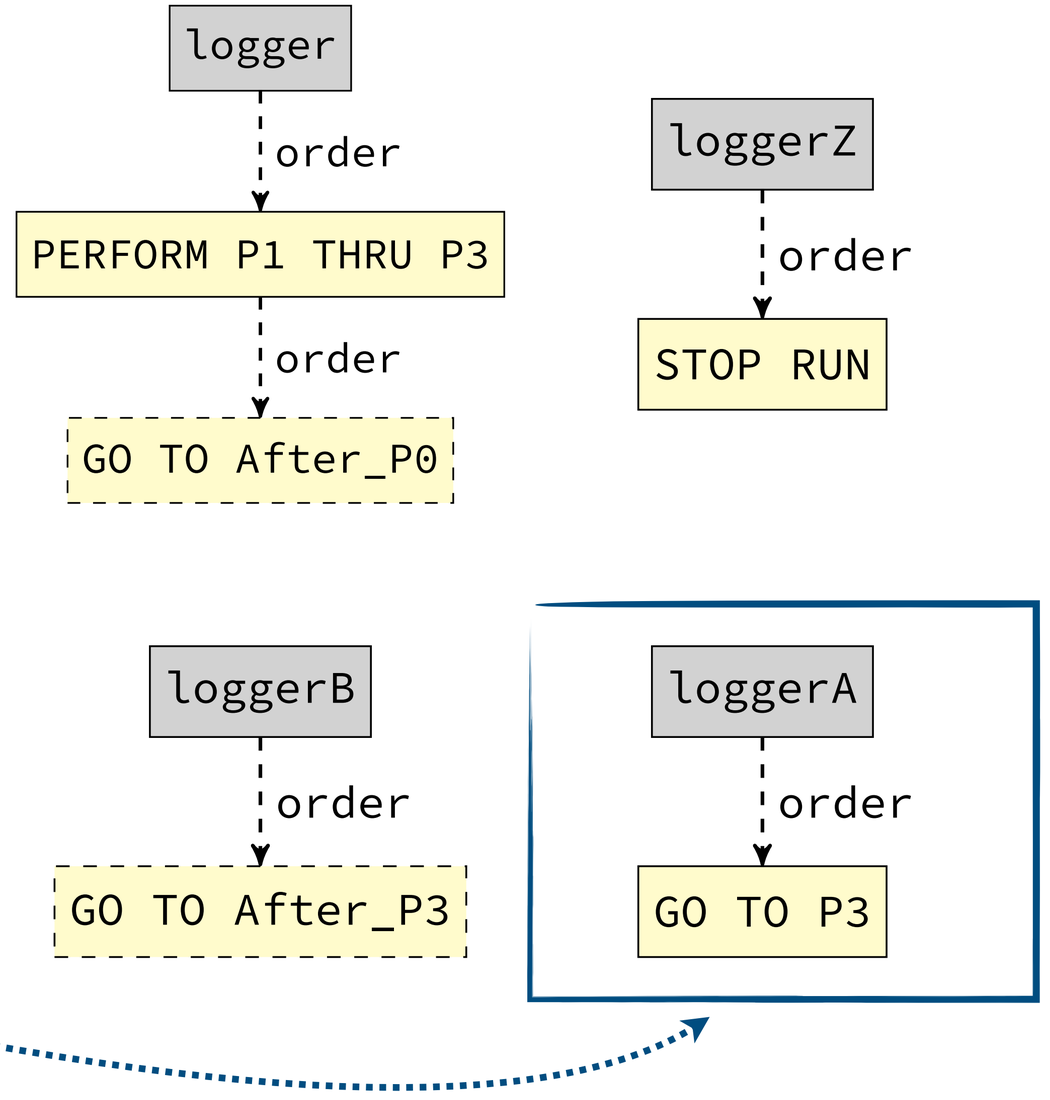
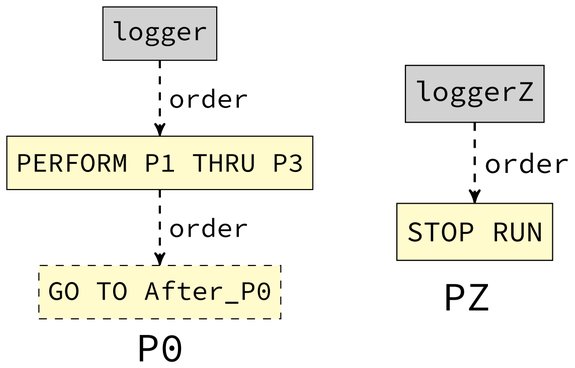
PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

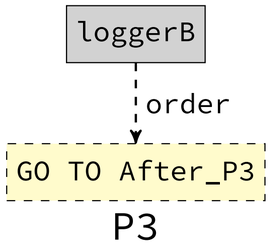
P1.
    CALL "loggerA".
    GO TO P3.
```

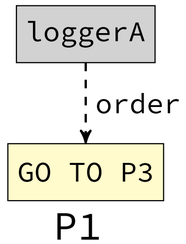


Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.
PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"
P1.
    CALL "loggerA".
    GO TO P3.
```





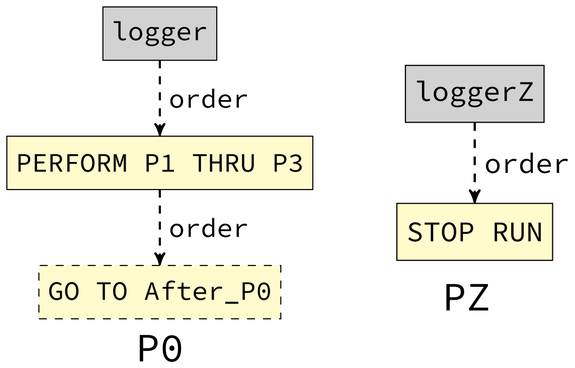


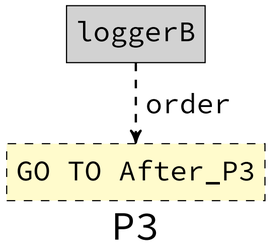
Jump Table

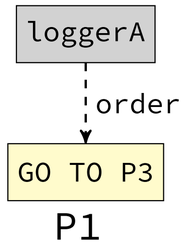
After_P0	PZ
After_P3	P0

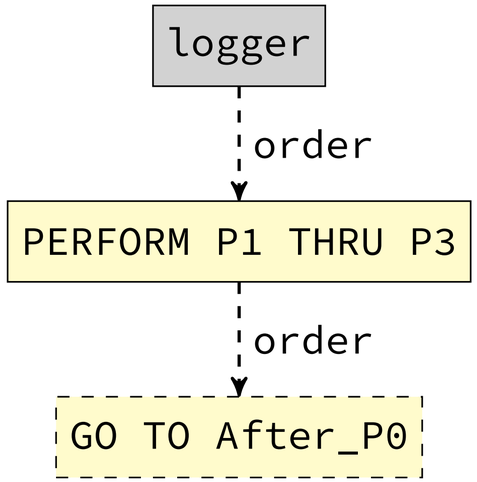
Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.
PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"
P1.
    CALL "loggerA".
    GO TO P3.
```







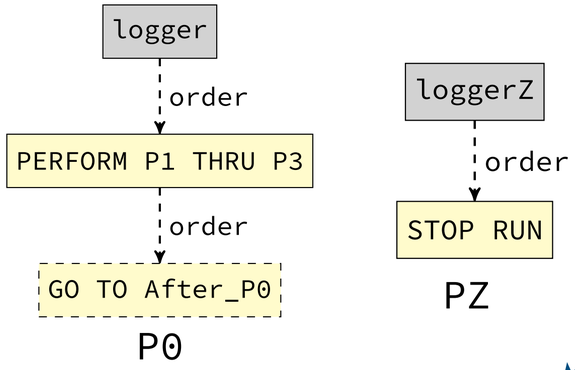


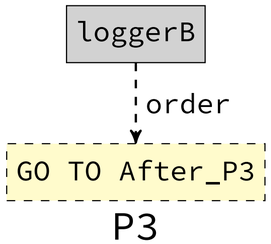
Jump Table

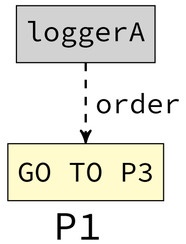
After_P0	PZ
After_P3	P0

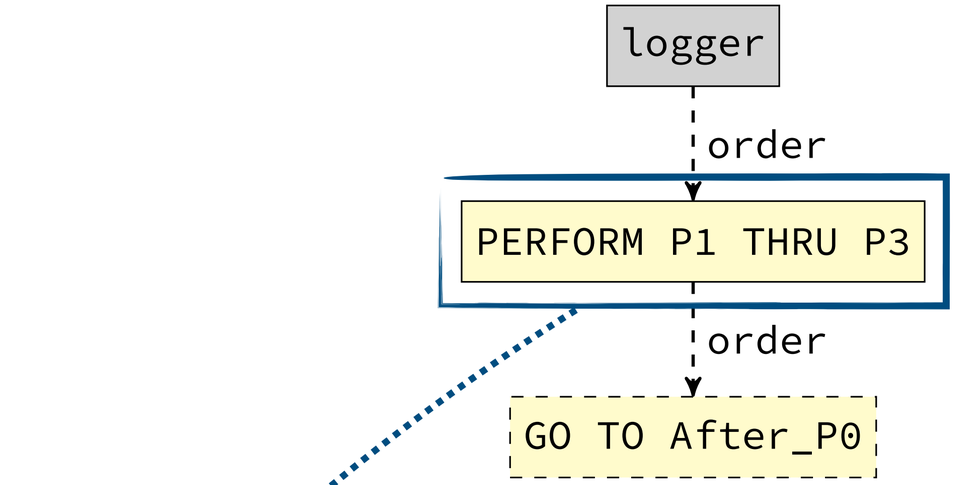
Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.
PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"
P1.
    CALL "loggerA".
    GO TO P3.
```









PERFORM

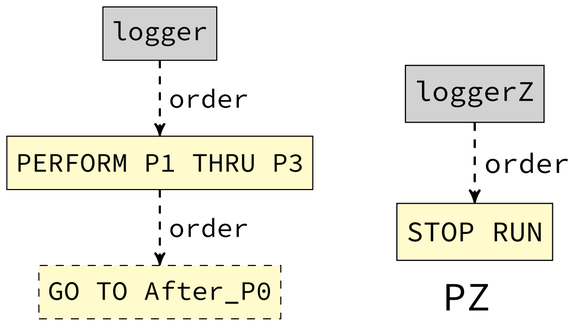
- Inline first paragraph
- Adjust last paragraph in jump table

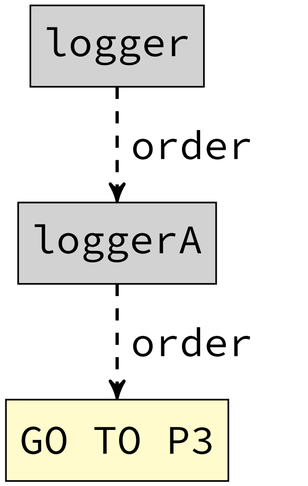
Jump Table

After_P0	PZ
After_P3	P0

Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.
PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"
P1.
    CALL "loggerA".
    GO TO P3.
```





GO TO After_P0

PERFORM

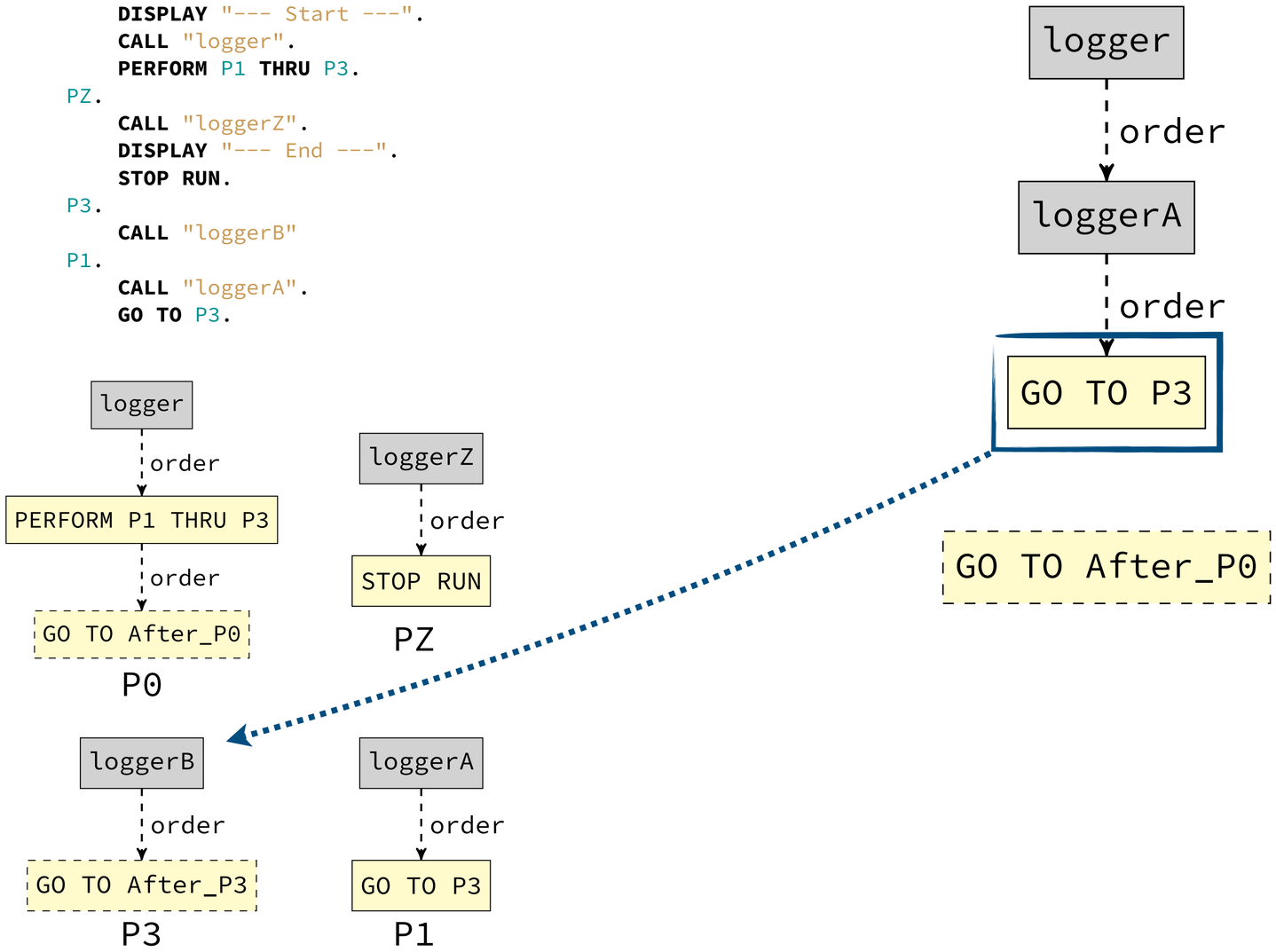
- Inline first paragraph
- Adjust last paragraph in jump table

Jump Table

After_P0	PZ
After_P3	GO TO After_P0

Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.
PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"
P1.
    CALL "loggerA".
    GO TO P3.
```



GO TO
Inline target paragraph

Jump Table

After_P0	PZ
After_P3	GO TO After_P0

Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
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    CALL "loggerZ".
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P3.
    CALL "loggerB"
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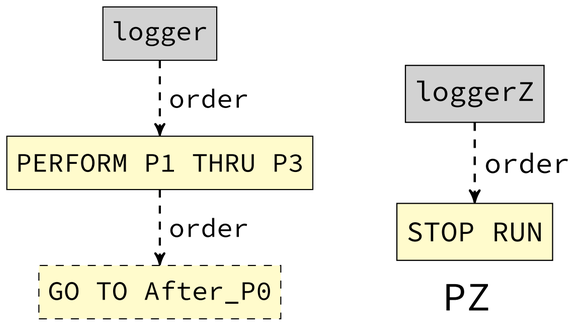
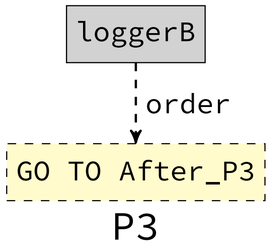
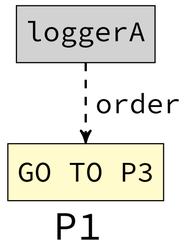
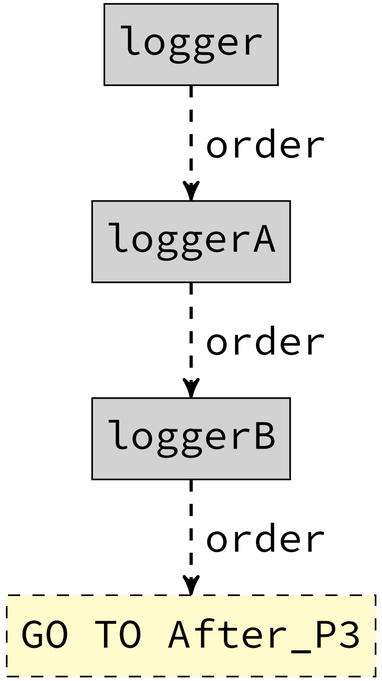
    CALL "loggerA".
    GO TO P3.
```









GO TO
Inline target paragraph

Jump Table

After_P0	PZ
After_P3	GO TO After_P0

Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
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    CALL "loggerZ".
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P3.
    CALL "loggerB"
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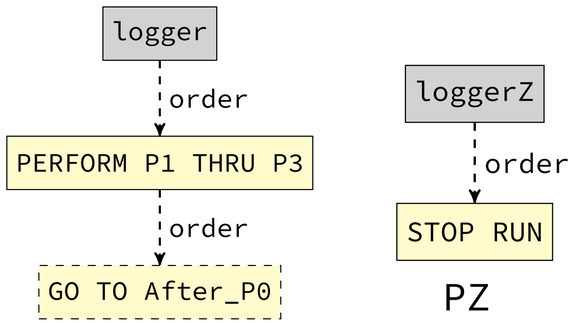
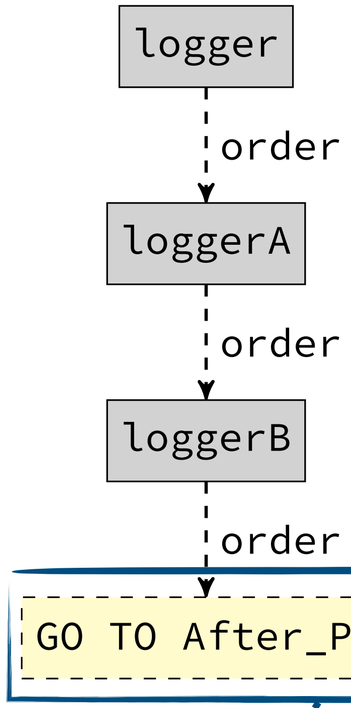
    GO TO P3.
```





Implicit jump after paragraph
Consult jump table

End of PERFORM
Reset jump table entry

Jump Table

After_P0	PZ
After_P3	GO TO After_P0

Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
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    CALL "loggerZ".
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    CALL "loggerB"
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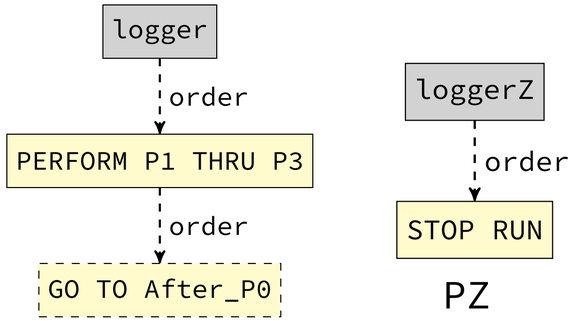

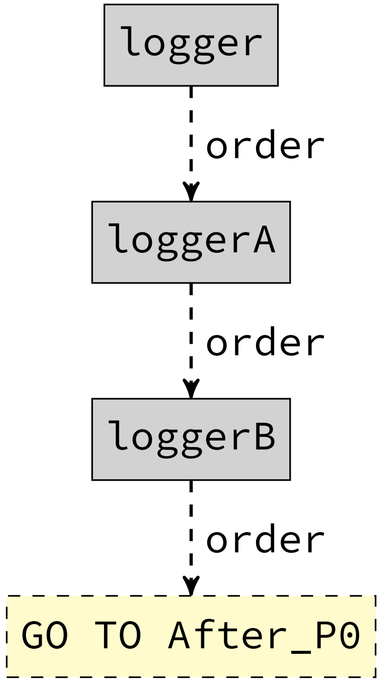

Implicit jump after paragraph
Consult jump table

End of PERFORM
Reset jump table entry

Jump Table

After_P0	PZ
After_P3	P0

Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
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    CALL "loggerZ".
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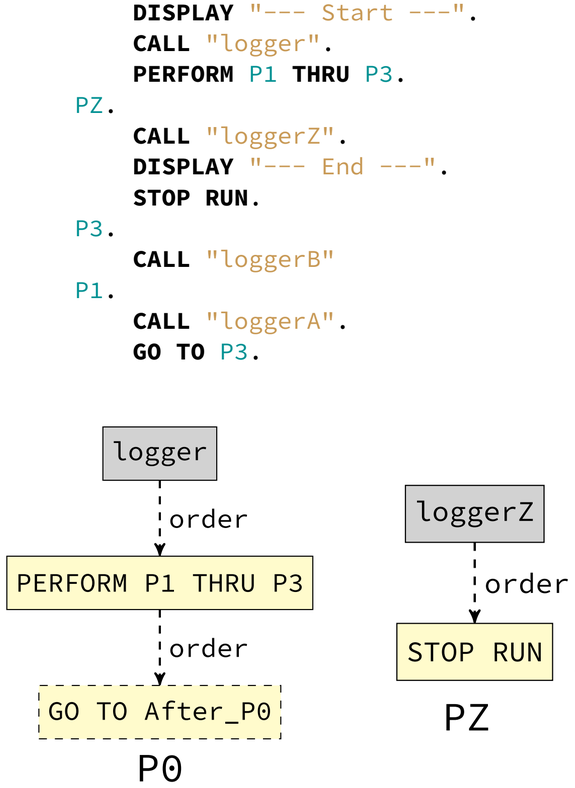

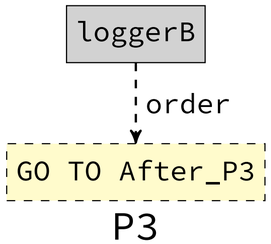

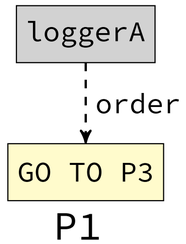

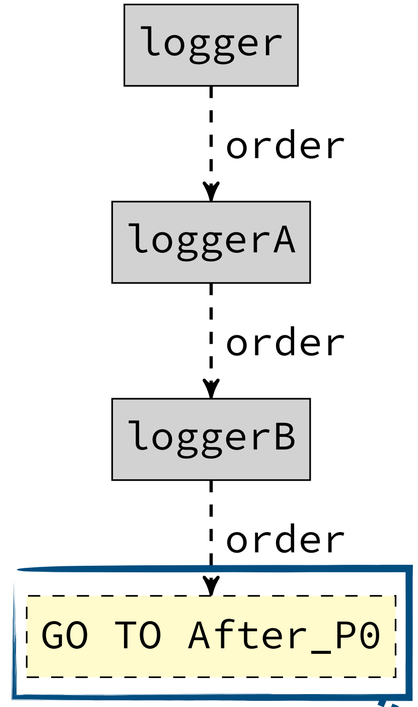

Implicit jump after paragraph
Consult jump table

Jump Table

After_P0	PZ
After_P3	P0

Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
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    CALL "loggerZ".
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    STOP RUN.
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    CALL "loggerB"
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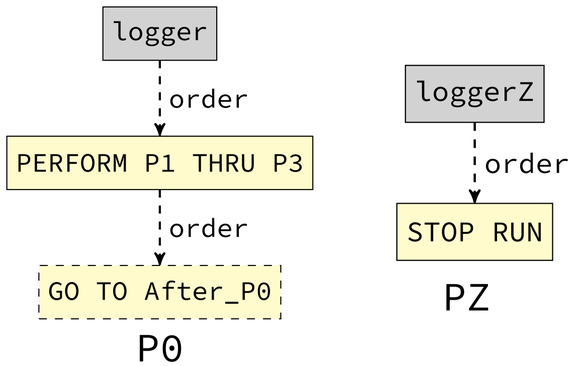
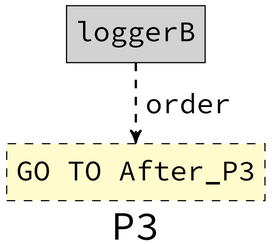
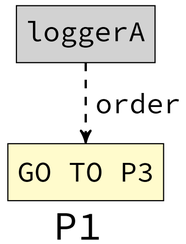
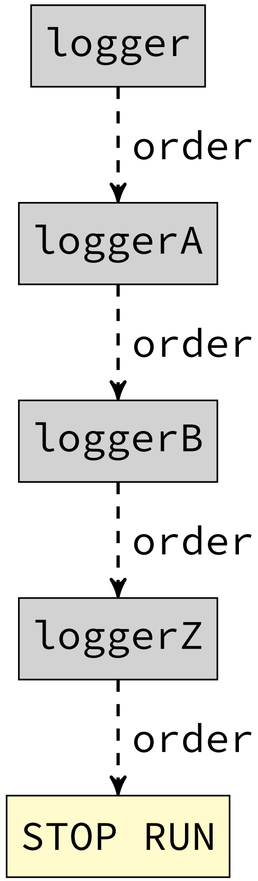








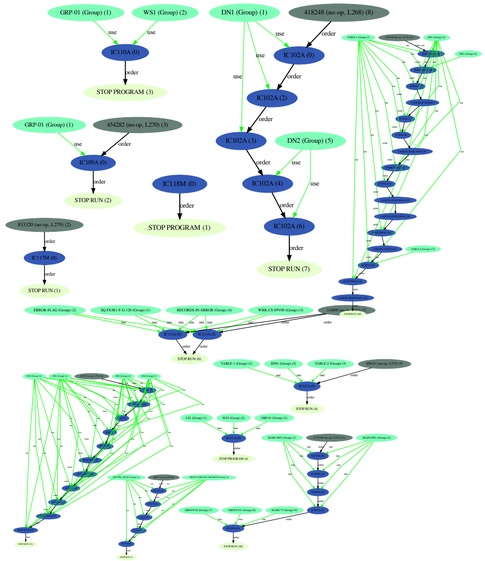
Implicit jump after paragraph
Consult jump table

Jump Table

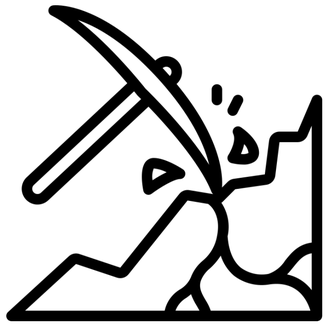
After_P0	PZ
After_P3	P0

Next Steps: Mining, Visualisation

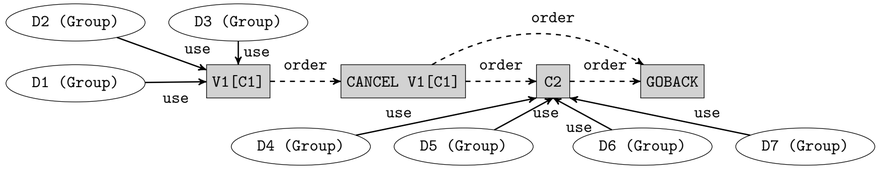
Groums

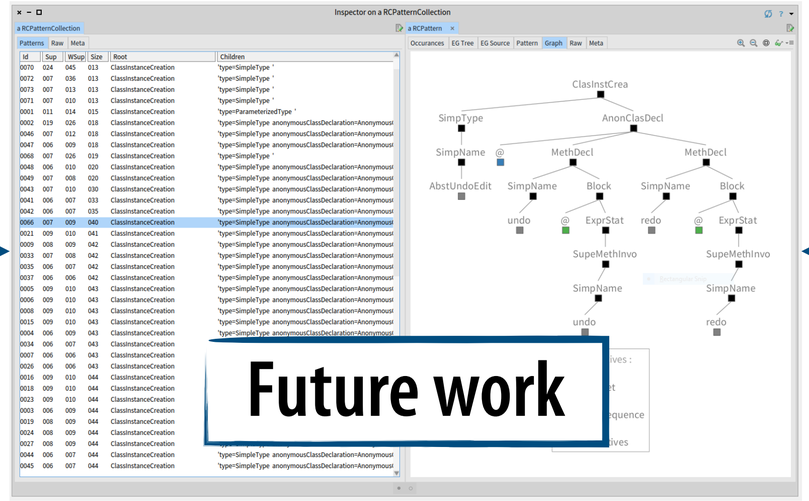


Frequent Subgraph Mining



Library Usage Patterns



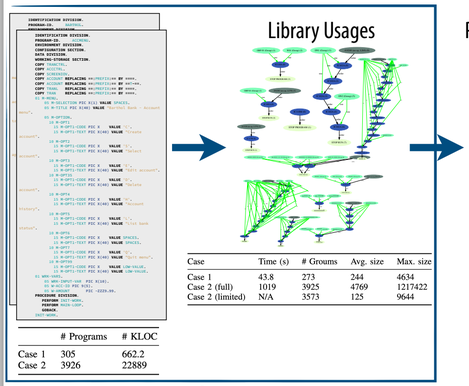


Future work

Visualisation Tool

Conclusion

COBOL Library Usage Pattern Mining



Library Usages

Pattern Mining

Library Usage Patterns

Case	Time (s)	# Grooms	Avg. size	Max. size
Case 1	43.8	273	244	4634
Case 2 (full)	1019	3925	4769	1217422
Case 2 (limited)	N/A	3573	125	9644

	# Programs	# KLOC
Case 1	305	662.2
Case 2	3926	22889

Today

Corpus	GrouMiner*		BigGroum		
	Time (min)	# P	Time (min)	# Part.	# P
Corpus 1	0.95	3	10.4	3	4
Corpus 2	121.8	7	618.2	1	0

Goal: Understand library usages
to estimate modernisation effort

Grooms for COBOL

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.

PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"

P1.
    CALL "loggerA".
    GO TO P3.
```

Single paragraph (often) too small

⇓

Inter-paragraph Grooms

⇓

Inter-paragraph control flow

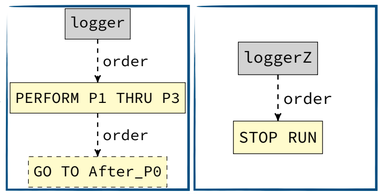
⇓

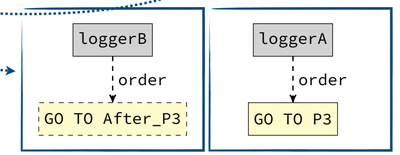
Graph inlining

Other challenges
- Definition of library calls
- Absence of “def” edges
- Iteration through jumps
- Exit calls
- ...

Phase 1: Intermediate Groum Construction

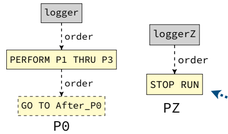
```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.
PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"
P1.
    CALL "loggerA".
    GO TO P3.
```

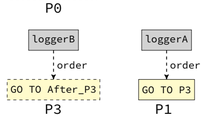


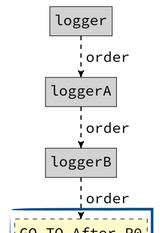


Phase 2: Groum Inlining

```
IDENTIFICATION   DIVISION.
PROGRAM-ID.      exc.
PROCEDURE DIVISION.
P0.
    DISPLAY "--- Start ---".
    CALL "logger".
    PERFORM P1 THRU P3.
PZ.
    CALL "loggerZ".
    DISPLAY "--- End ---".
    STOP RUN.
P3.
    CALL "loggerB"
P1.
    CALL "loggerA".
    GO TO P3.
```







Implicit jump after paragraph
Consult jump table

End of PERFORM
Reset jump table entry

Jump Table

After_P0	PZ
After_P3	P0