Debugging

CSE 403 Software Engineering

Autumn 2023

Amazing demos, everyone!

Take-aways ranged from:

- Really helpful to **learn about more UI tooling, host tooling, test tooling AND authentication tooling** options
- Appreciate that most everyone is going through similar learnings on the value of **breaking down tasks**, being **agile with planning and designing** (revisions happen!), learning and **adapting to each others' strengths** in the group

to

- **Helped us identify some bugs**
- **Story telling** of a demo is powerful

Today's outline

- Debugging basics
- Delta debugging technique
  - In-class exercise on 11/15 will complement this material

Background Reading (link on the Calendar):
Simplifying and Isolating Failure-Inducing Input, Zeller and Hildebandt, 2002

Let's level set

A bug is an **error or flaw** in a program or system that produces incorrect or **unexpected results**

Debugging is the process to **identify** and **resolve** bugs

The typical debugging process

- **Identify** – it's a bug, not a feature
- **Understand** – what are the inputs and conditions causing the error
- **Reproduce** – create a (minimal) test to illustrate the issue
- **Investigate** – locate the problematic code
- **Fix** the code
- **Validate** and capture in a **regression test**

What's a good bug (issue) report look like?

A bug report should be as specific as possible so that the engineer knows how to recreate the failure

- Provide information to reproduce the bug, including context
- What might be "context"?
- Also! Provide criticality of the bug (to influence priority in getting it fixed)

A test case should be as simple as possible

- Why?

Delta Debugging

A debugging technique to create a minimal test case that exposes the bug

This is a crashing test case

```
<td align=left valign=top>
<SELECT NAME="op sys" MULTIPLE SIZE=7>
<OPTION VALUE="All">All
<OPTION VALUE="Windows 3.1">Windows 3.1
<OPTION VALUE="Windows 95">Windows 95
<OPTION VALUE="Windows 98">Windows 98
<OPTION VALUE="Windows ME">Windows ME
<OPTION VALUE="Windows 2000">Windows 2000
<OPTION VALUE="Windows NT">Windows NT
<OPTION VALUE="Mac System 7">Mac System 7
<OPTION VALUE="Mac System 7.5">Mac System 7.5
<OPTION VALUE="Mac System 7.6.1">Mac System 7.6.1
<OPTION VALUE="Mac System 8.0">Mac System 8.0
<OPTION VALUE="Mac System 8.5">Mac System 8.5
<OPTION VALUE="Mac System 8.6">Mac System 8.6
<OPTION VALUE="Mac System 9.x">Mac System 9.x
<OPTION VALUE="MacOS X">MacOS X
<OPTION VALUE="Linux">Linux
<OPTION VALUE="BSDI">BSDI
<OPTION VALUE="FreeBSD">FreeBSD
<OPTION VALUE="NetBSD">NetBSD
<OPTION VALUE="OpenBSD">OpenBSD
<OPTION VALUE="AIX">AIX
<OPTION VALUE="BeOS">BeOS
<OPTION VALUE="HP-UX">HP-UX
<OPTION VALUE="IRIX">IRIX
<OPTION VALUE="Neutrino">Neutrino
<OPTION VALUE="OpenVMS">OpenVMS
<OPTION VALUE="OS/2">OS/2
<OPTION VALUE="OSF/1">OSF/1
<OPTION VALUE="Solaris">Solaris
<OPTION VALUE="SunOS">SunOS
<OPTION VALUE="other">other</SELECT></td>
<td align=left valign=top>
<SELECT NAME="priority" MULTIPLE SIZE=7>
<OPTION VALUE="--">--<OPTION VALUE="P1">P1<OPTION VALUE="P2">P2<OPTION
VALUE="P3">P3<OPTION VALUE="P4">P4<OPTION
VALUE="P5">P5</SELECT>
</td>
<td align=left valign=top>
<SELECT NAME="bug severity" MULTIPLE SIZE=7>
<OPTION VALUE="blocker">blocker<OPTION VALUE="critical">critical<OPTION
VALUE="major">major<OPTION
VALUE="normal">normal<OPTION VALUE="minor">minor<OPTION
VALUE="trivial">trivial<OPTION VALUE="enhancement">enhancement</SELECT>
</tr>
</table>
```

- Case crashed Mozilla
- Consider 370 of these being filed!
- What context is sufficient to expose the bug?

This is a crashing test case

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<td align=left valign=top>
<SELECT NAME="op sys" MULTIPLE SIZE=7>
<OPTION VALUE="All">All
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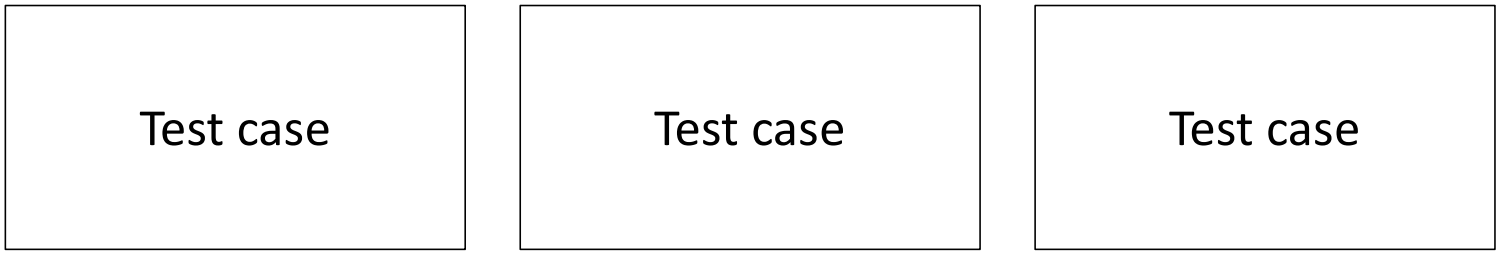
VALUE="trivial">trivial<OPTION VALUE="enhancement">enhancement</SELECT>
</tr>
</table>
```

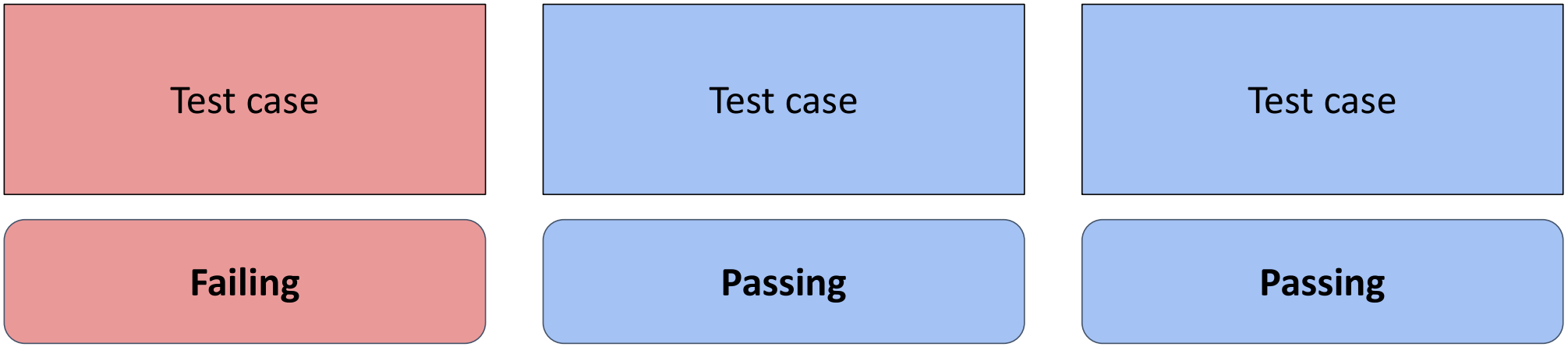
- Crashed Mozilla
- What content is sufficient to expose the bug?
- A minimal test case is: **<SELECT>**
- Can we automate the process of minimizing test cases?

Minimizing test cases

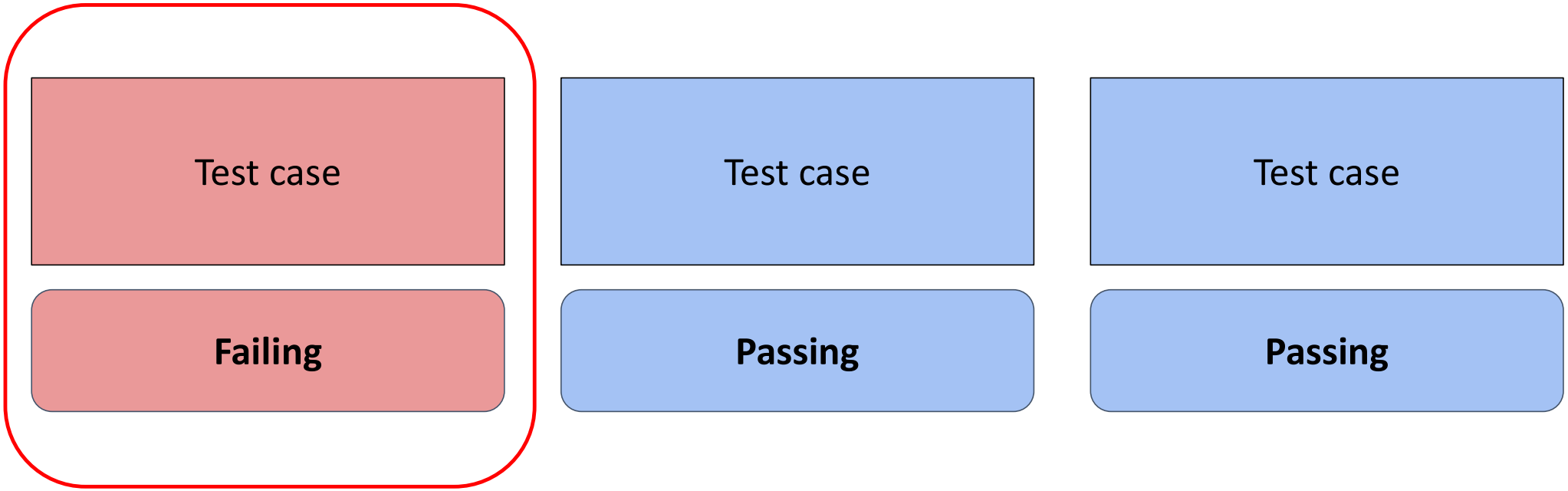


Think of each test case as an input file with n lines

Minimizing test cases

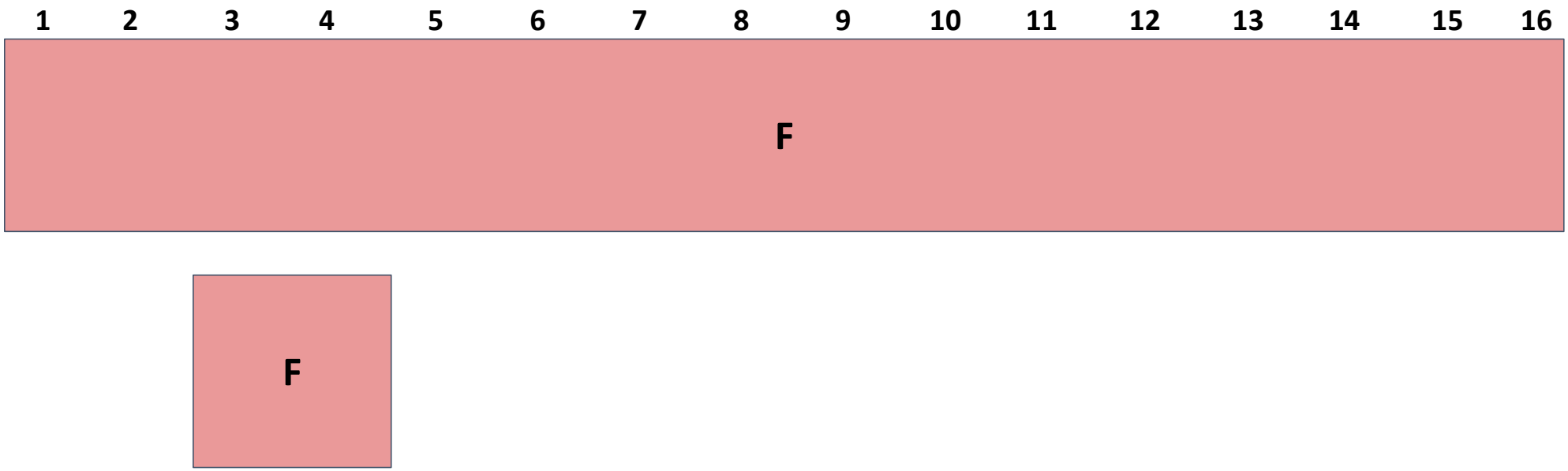


Minimizing test cases



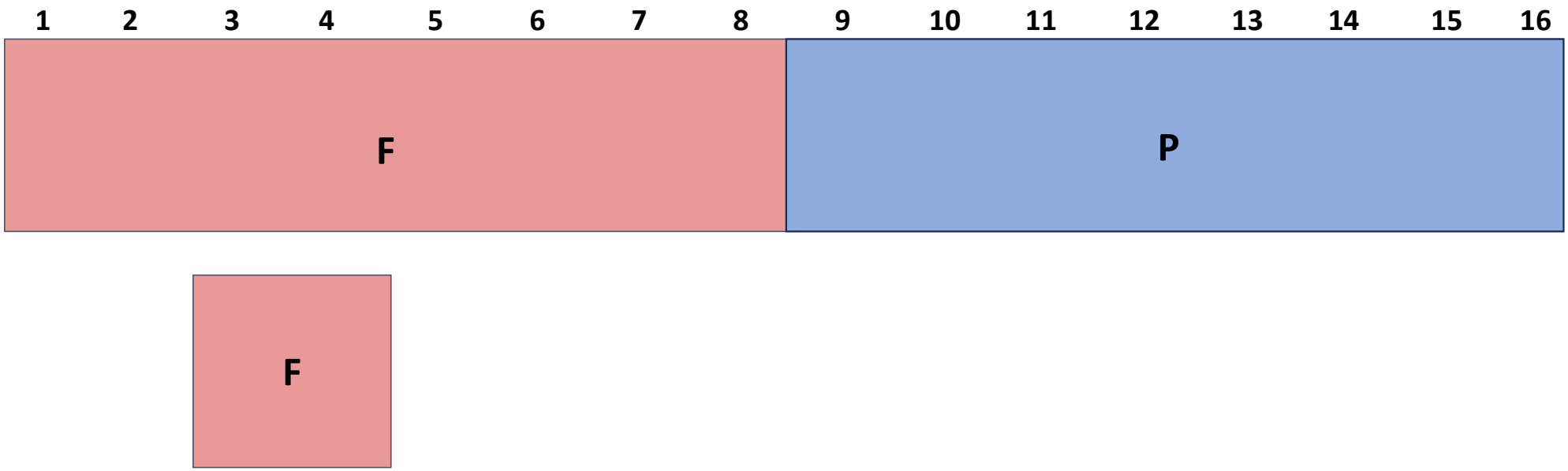
Goal: minimize the failing test case

The happy path: binary search

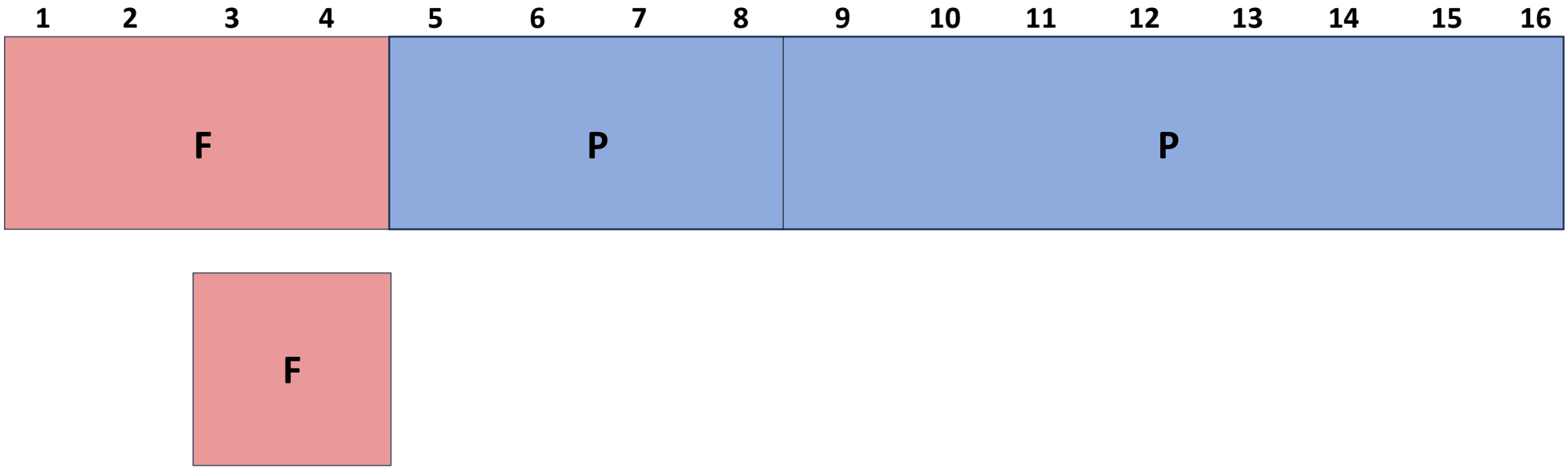


Failing test with 16 lines
The minimal failing test has 2 lines: 3 and 4

The happy path: binary search



The happy path: binary search



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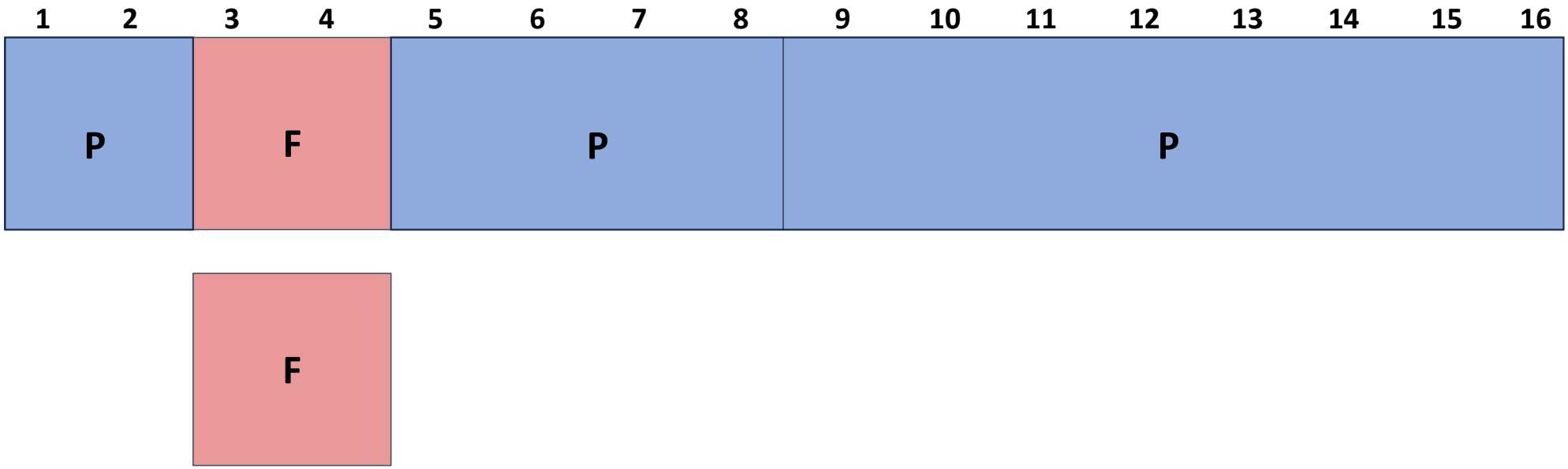
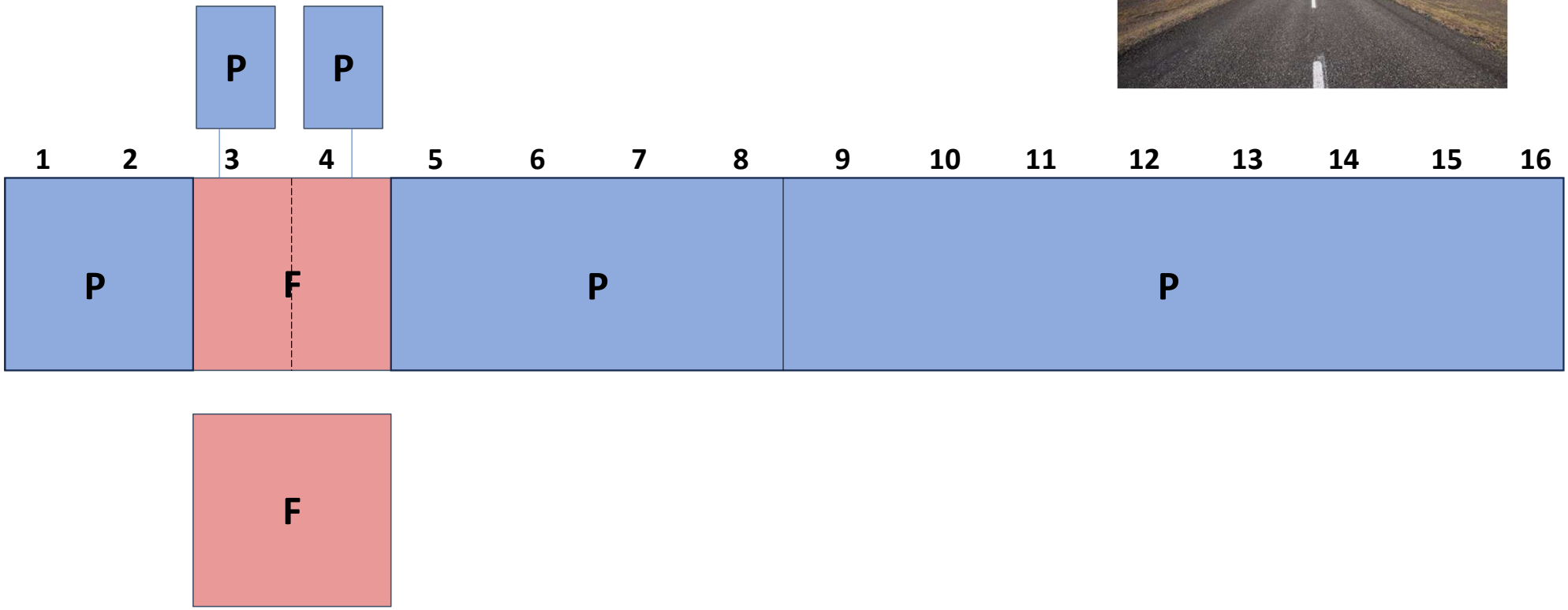
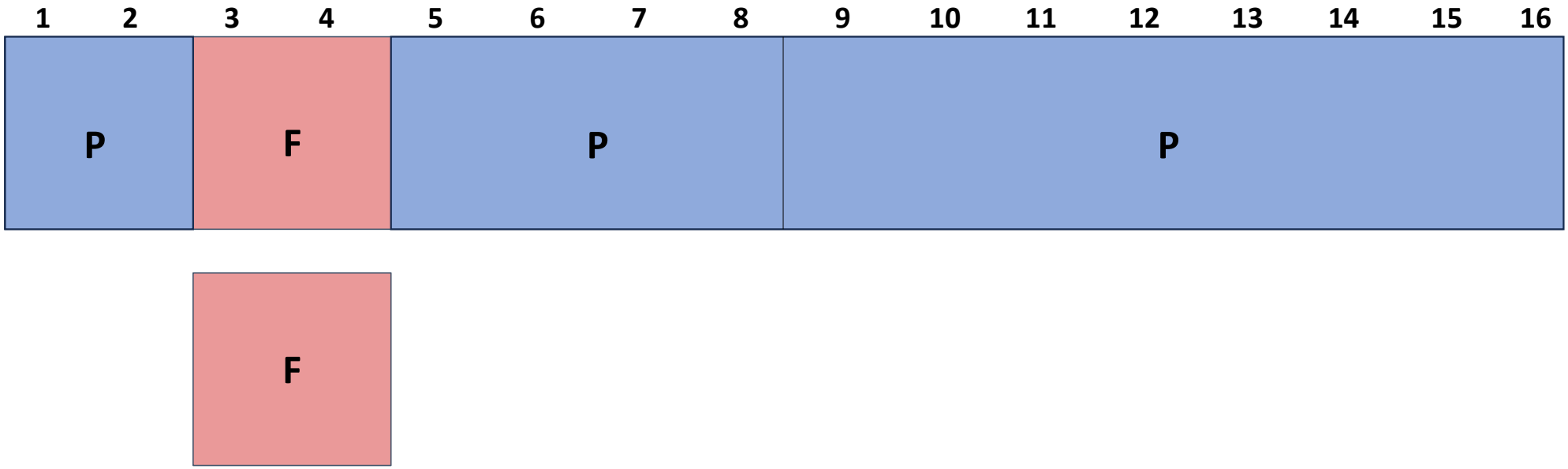


The happy path: binary search

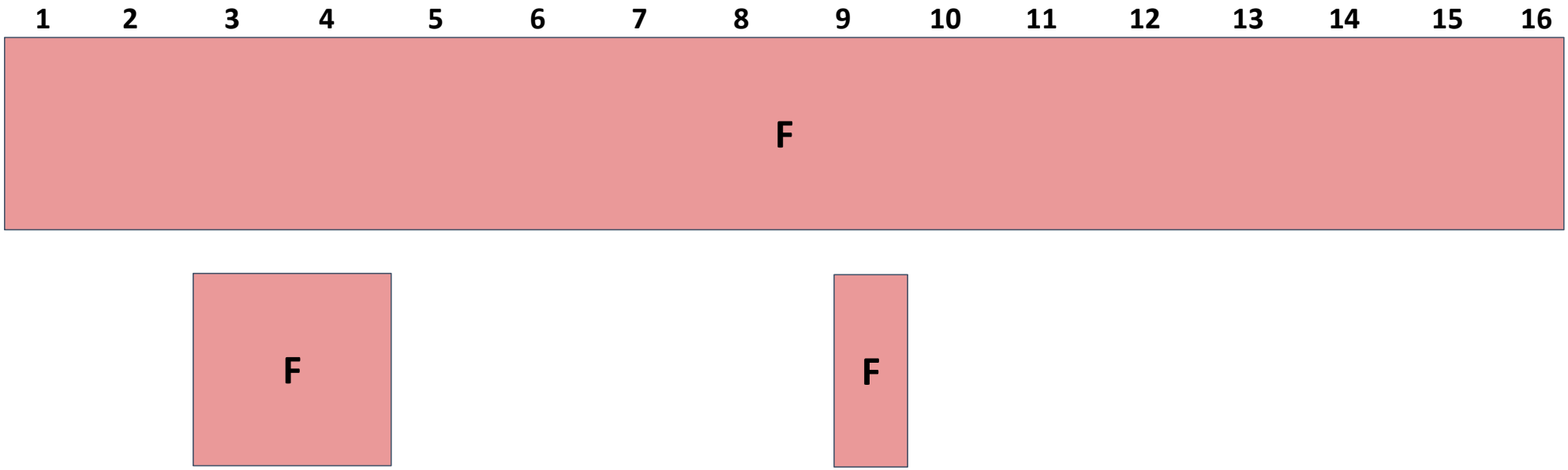


The happy path: binary search



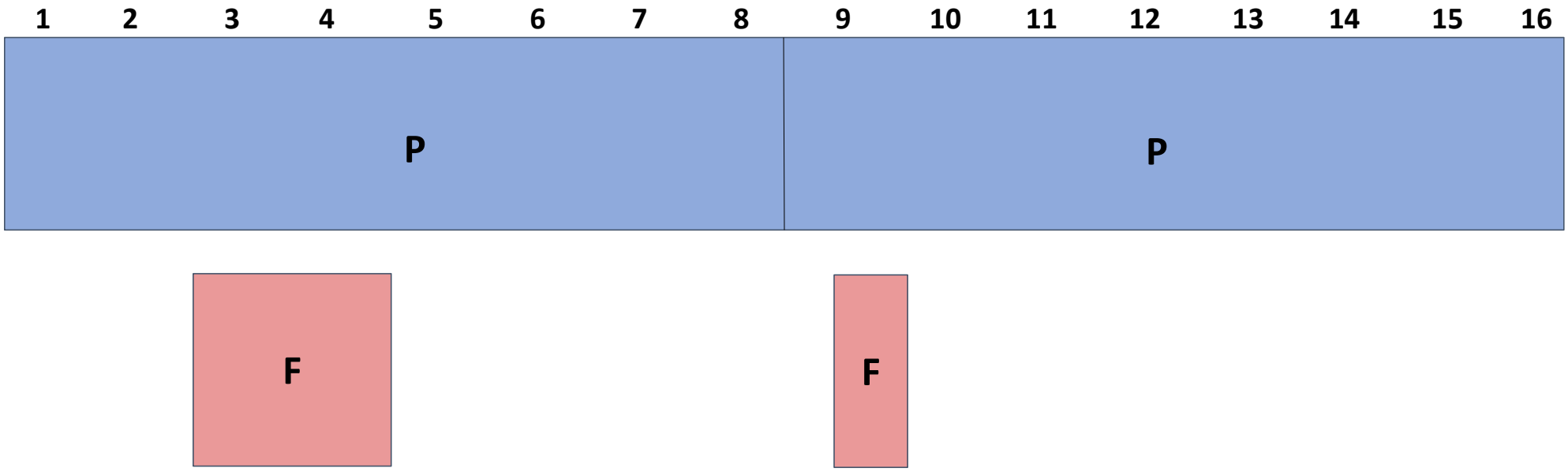
Successfully minimized the failing test to 2 lines

The not so happy path…



Suppose the failure pattern is more complex
All three lines must exist in a failing test case: 3, 4, and 9

The not so happy path…



Binary search does not give optimal results

Delta Debugging = binary search + X

See paper – link on Calendar:
Simplifying and Isolating Failure-Inducing Input
Zeller and Hildebandt, 2002

The Delta Debugging algorithm

Four basic phases:

1. Test each subset
2. Test each complement
3. Increase granularity (increase # subsets)
4. Reduce

Complement example:
List: 1, 2, 3, 4
Complement of 1:
2, 3, 4

Minimizing Delta Debugging Algorithm

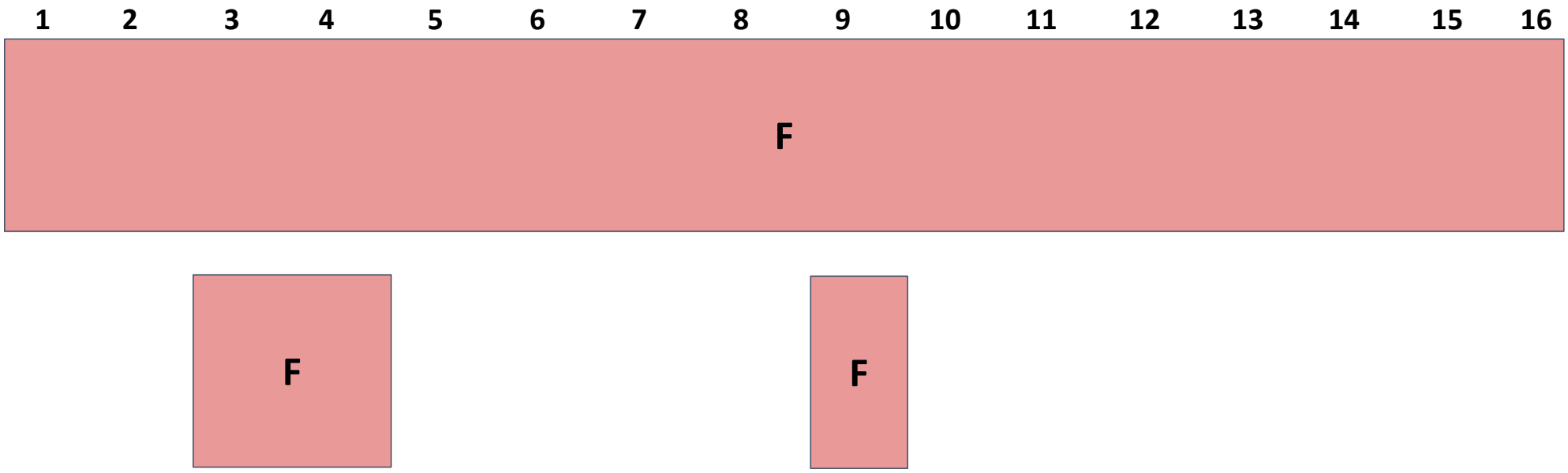
Let *test* and $c_{\text{✘}}$ be given such that $test(\emptyset) = \text{✔} \wedge test(c_{\text{✘}}) = \text{✘}$ hold.
The goal is to find $c'_{\text{✘}} = ddmin(c_{\text{✘}})$ such that $c'_{\text{✘}} \subseteq c_{\text{✘}}$, $test(c'_{\text{✘}}) = \text{✘}$, and $c'_{\text{✘}}$ is 1-minimal.
The *minimizing Delta Debugging algorithm* $ddmin(c)$ is

$$ddmin(c_{\text{✘}}) = ddmin_2(c_{\text{✘}}, 2) \quad \text{where}$$

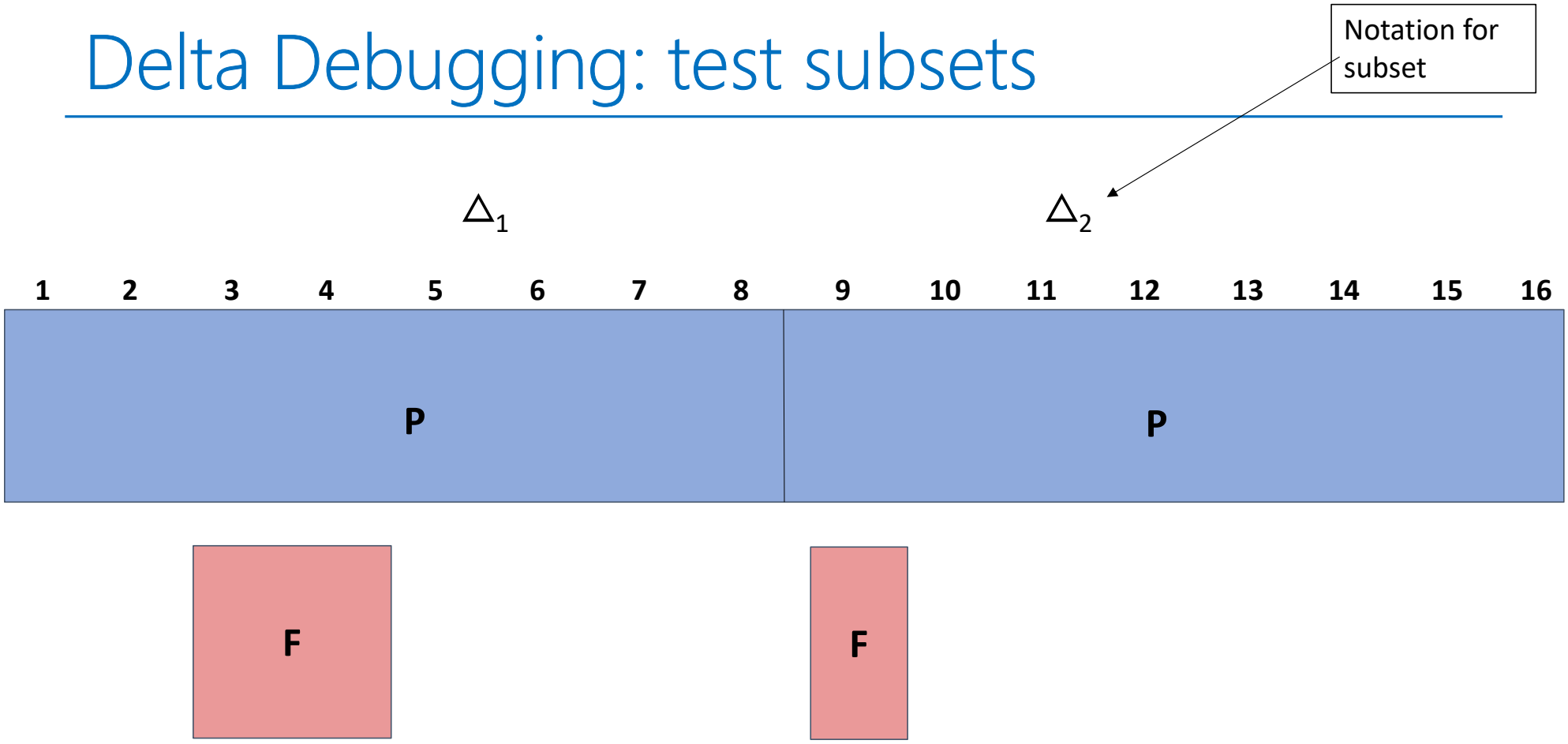
$$ddmin_2(c'_{\text{✘}}, n) = \begin{cases} ddmin_2(\Delta_i, 2) & \text{if } \exists i \in \{1, \ldots, n\} \cdot test(\Delta_i) = \text{✘} \text{ (“reduce to subset”)} \\ ddmin_2\left(\nabla_i, \max(n-1, 2)\right) & \text{else if } \exists i \in \{1, \ldots, n\} \cdot test(\nabla_i) = \text{✘} \text{ (“reduce to complement”)} \\ ddmin_2\left(c'_{\text{✘}}, \min(|c'_{\text{✘}}|, 2n)\right) & \text{else if } n < |c'_{\text{✘}}| \text{ (“increase granularity”)} \\ c'_{\text{✘}} & \text{otherwise (“done”).} \end{cases}$$

where $\nabla_i = c'_{\text{✘}} - \Delta_i$, $c'_{\text{✘}} = \Delta_1 \cup \Delta_2 \cup \cdots \cup \Delta_n$, all Δ_i are pairwise disjoint, and $\forall \Delta_i \cdot |\Delta_i| \approx |c'_{\text{✘}}|/n$ holds.
The recursion invariant (and thus precondition) for $ddmin_2$ is $test(c'_{\text{✘}}) = \text{✘} \wedge n \leq |c'_{\text{✘}}|$.

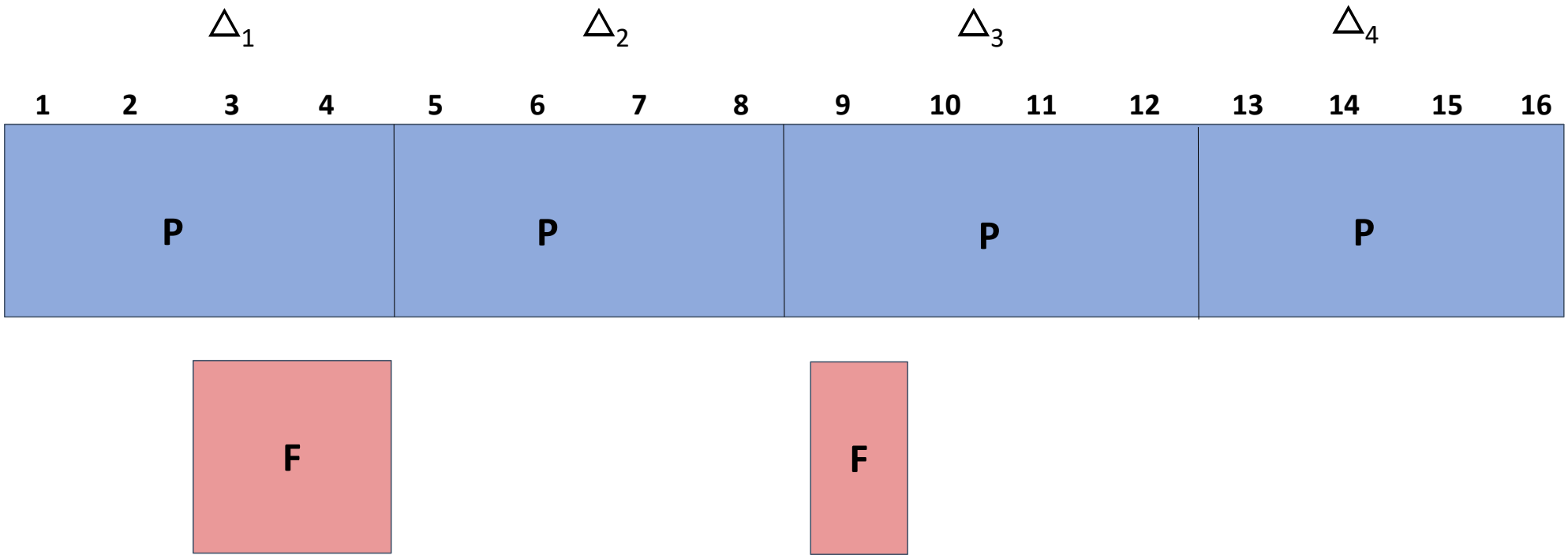
Delta Debugging: it's mostly binary search



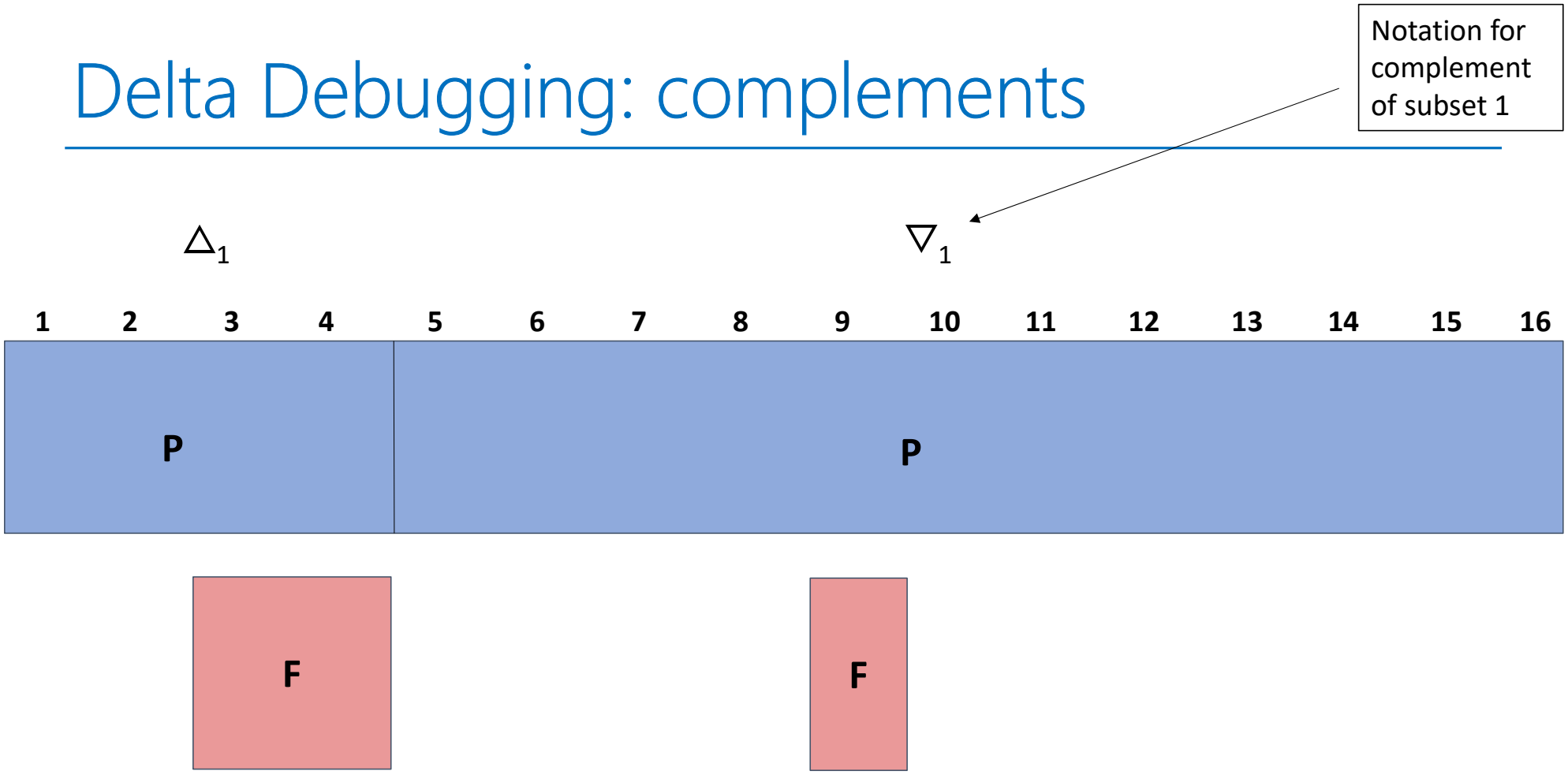
Delta Debugging: test subsets



Delta Debugging: increase granularity

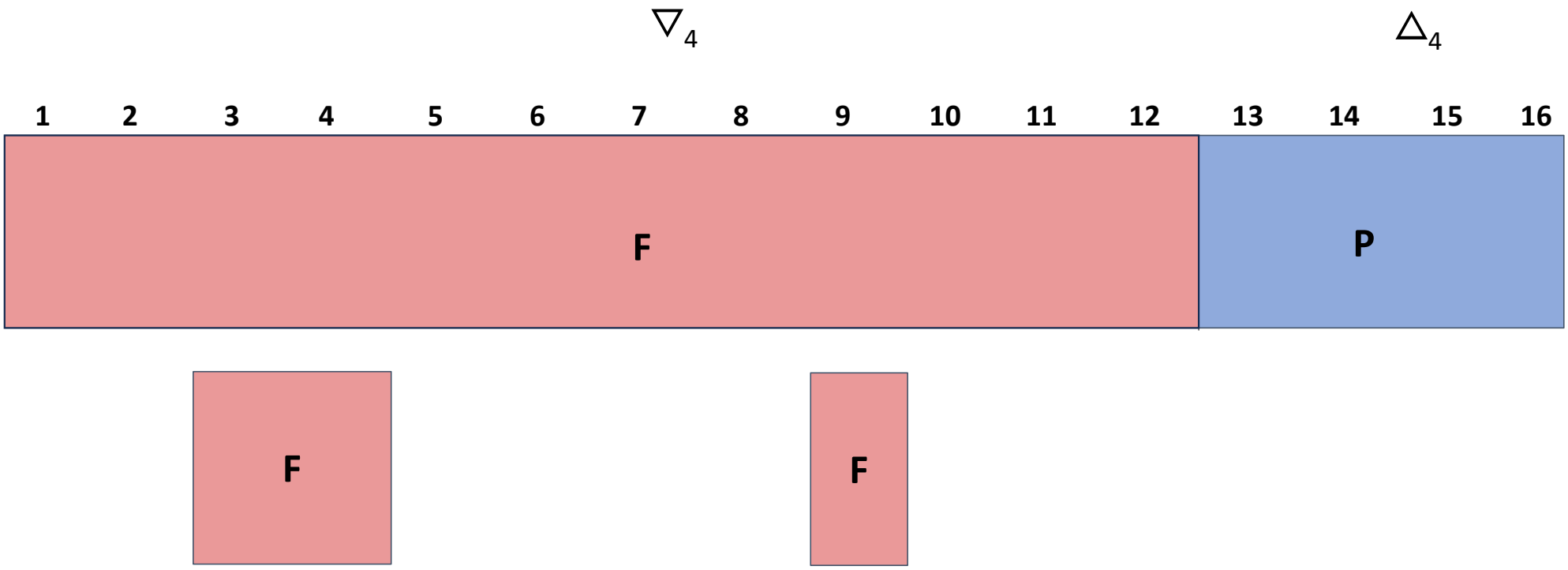


Delta Debugging: complements

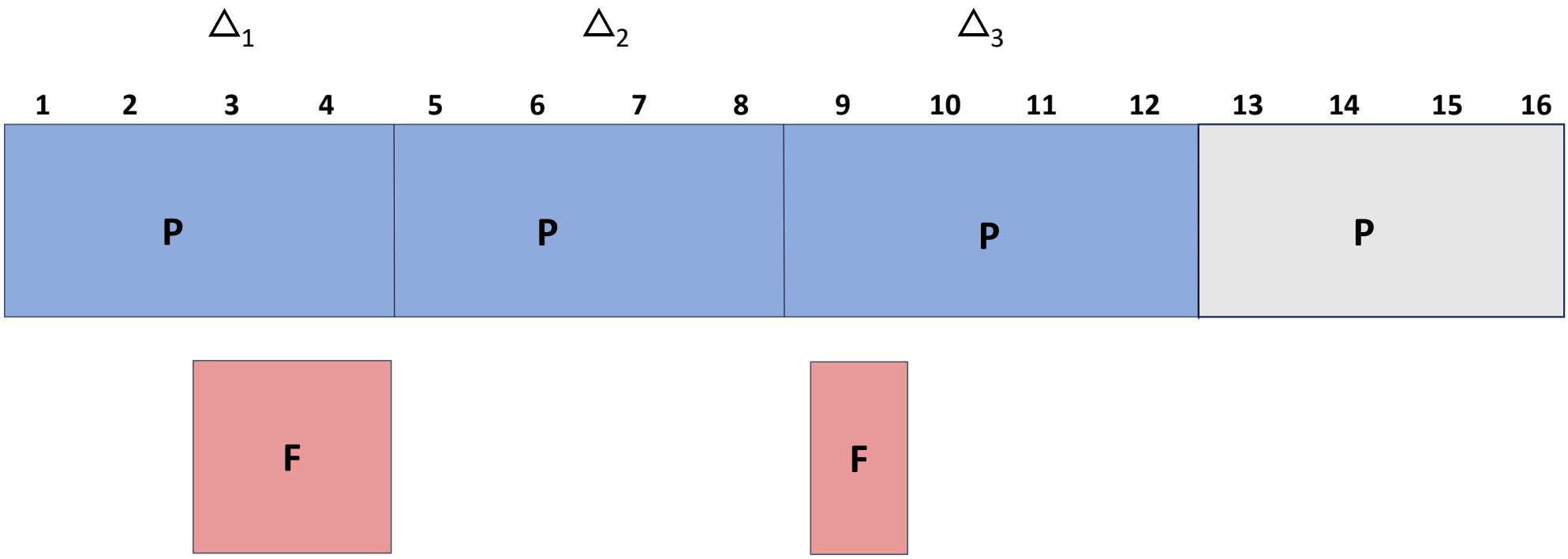


The order in which deltas and complements are evaluated may differ between implementations of the algorithm

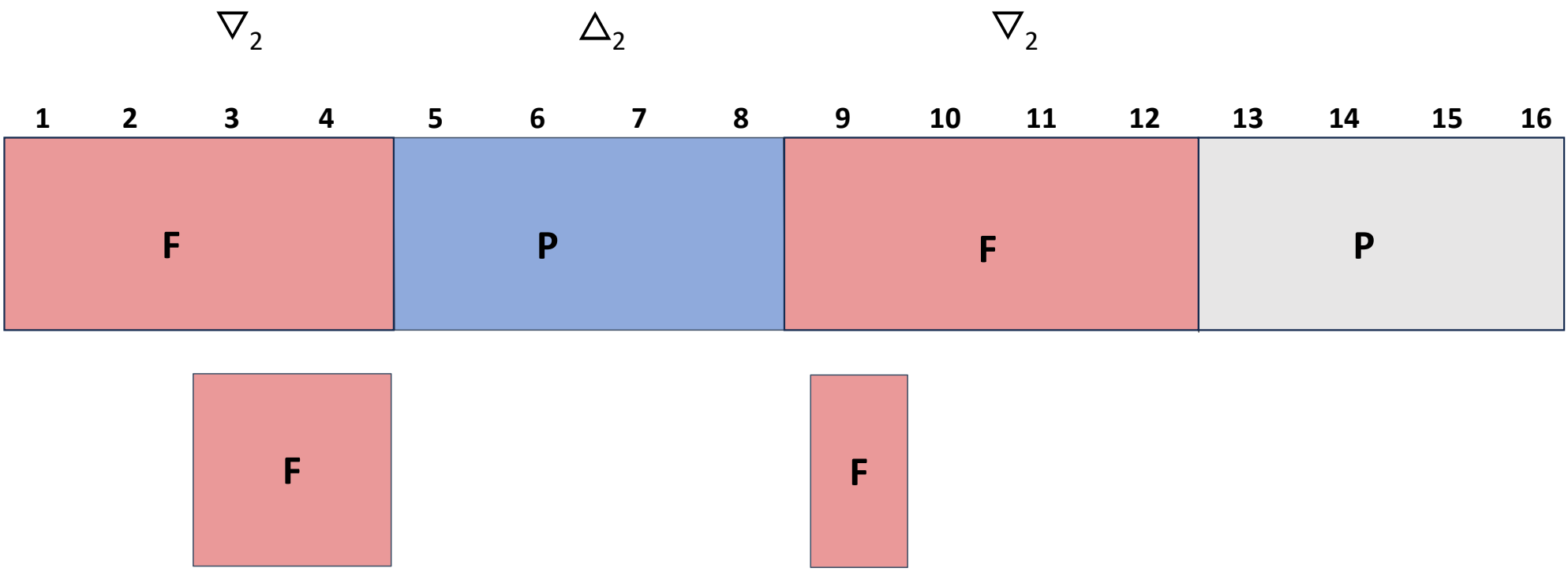
Delta Debugging: complements



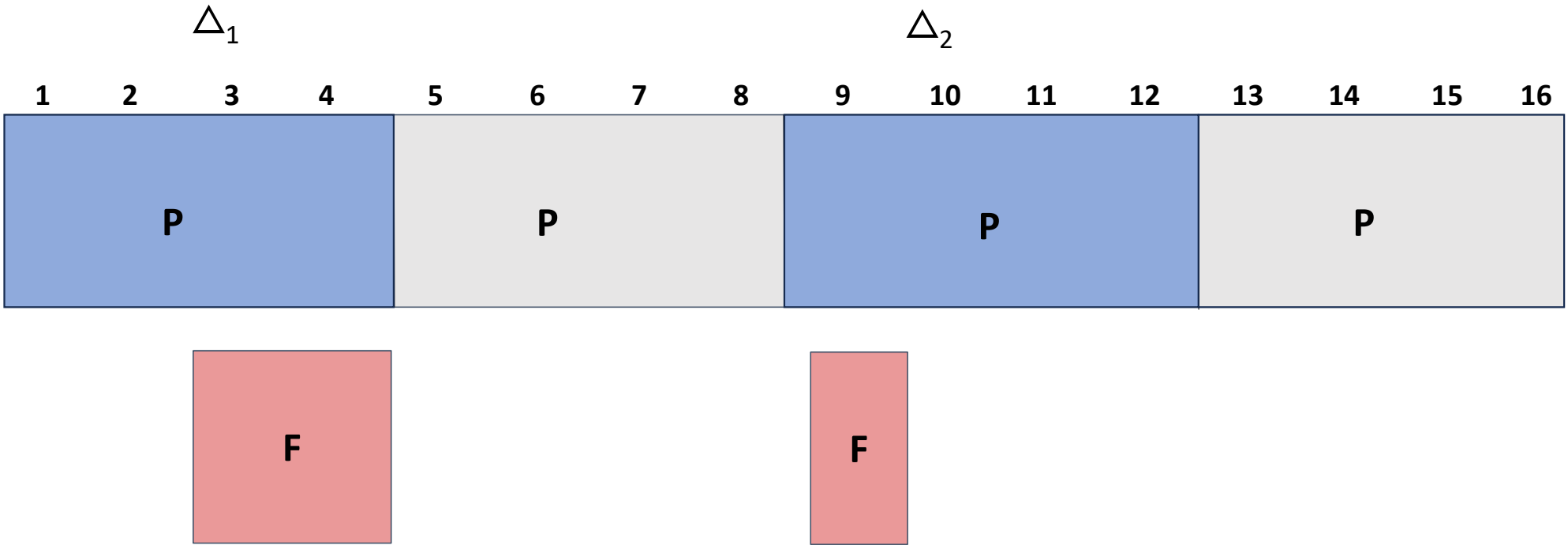
Delta Debugging: reduce



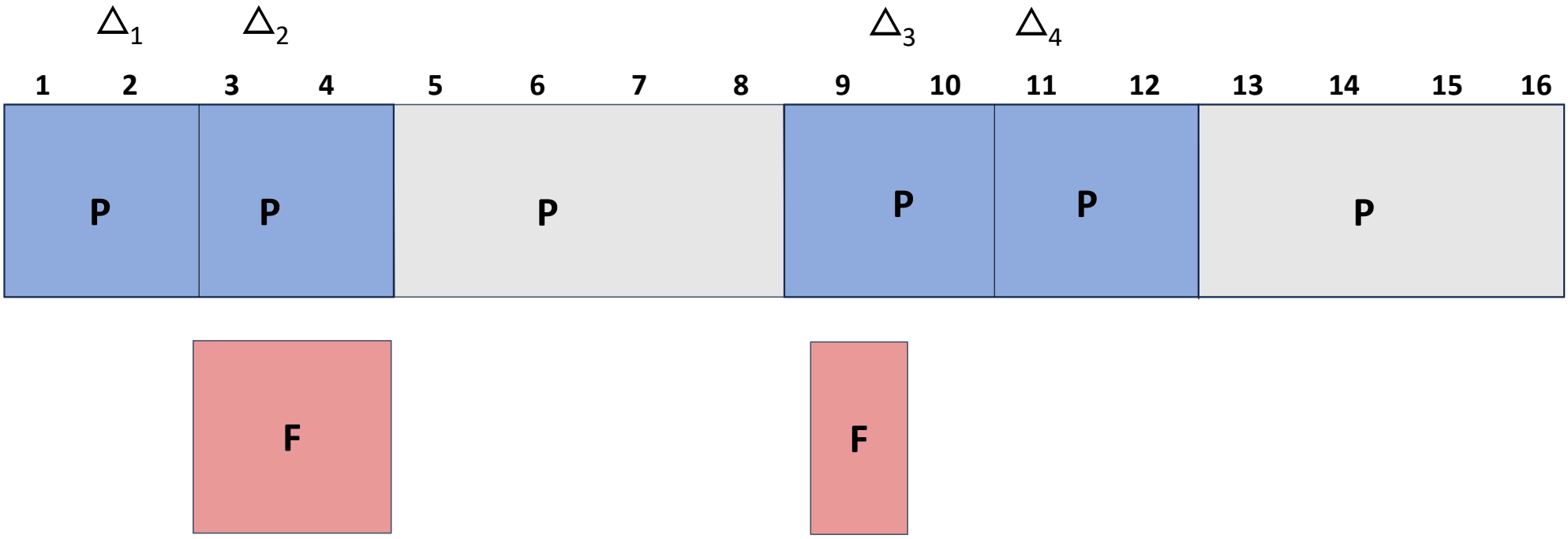
Delta Debugging: complements



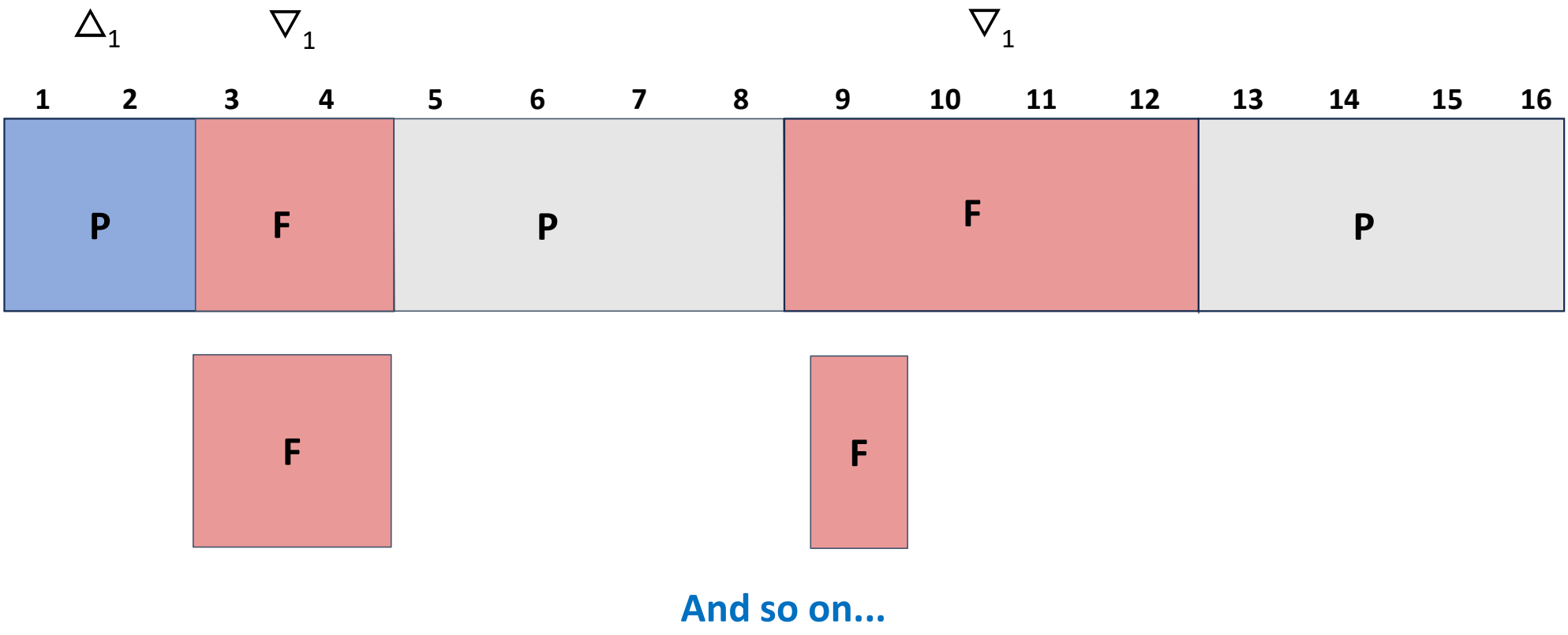
Delta Debugging: reduce



Delta Debugging: increase granularity

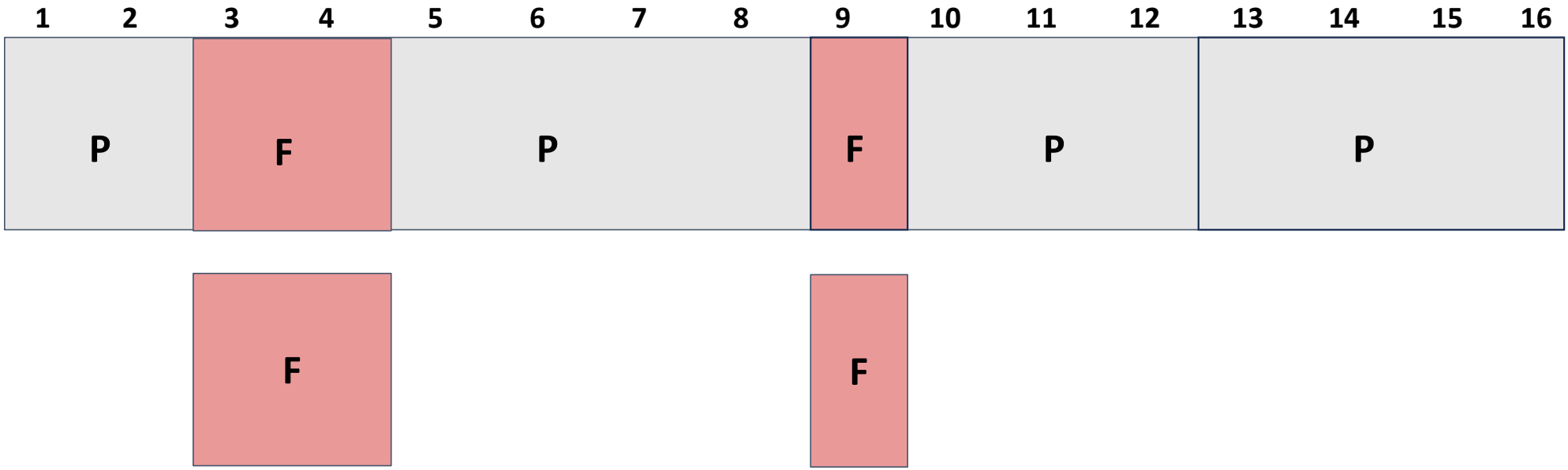


Delta Debugging: complements



And so on...

Delta Debugging: finds a 1-minimal solution



Failing test cases must be deterministic and monotone

Delta debugging: live example

Delta Debugging: live example

Program and initial test case

- Program **P crashes** whenever the input contains **1 2 8**
- Initial crashing test case is: **1 2 3 4 5 6 7 8**

Syntax:

- % ./delta -test=./**test.sh** -cp_minimal=./min.txt < **failing.txt**
- test.sh returns 0 if input causes failure, 1 if input passes

Delta debugging approach:

- Test each subset
- Test each complement
- Increase granularity
- Reduce

Example taken from the reading

Delta debugging: one more example

Let's try one more

Program and initial test case

- Program *P* takes as **input a list of integers *l***.
- ***P* crashes** whenever ***l* contains 4,2**.
- **Initial** crashing **test case** is: **2,4,2,4**

Complete the following table

Iteration	n	input	$\triangle_1, \ldots, \triangle_n$ $\nabla_1, \ldots, \nabla_n$
1	2	2424	…
2	…	…	…

Let's try one more

Program and initial test case

- Program ***P*** takes as **input a list of integers *l***.
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Complete the following table

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1	2	2424	24, (24)
2	4	2424	2, 4, (2), (4), **424**, (224), (244), (242)
3	3	424	(4), (2), (4), (24), 44, **42**
4	2	42	(4),(2)

Delta debugging: in-class exercise Wednesday

Peer review assignment posted

Reading #3 posted - no summary paragraph required