Error Handling

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ADAP C05

Agenda

1. The common bug
2. System model
3. Error detection
4. Error signaling
5. Error handling
6. Component failures

Focus of Lecture

- In this lecture, we focus on a subset of [A+04], specifically
  - Errors caused by software faults that are
    - always development, internal, human-made faults
    - typically non-malicious, non-deliberate
  - Error detection by concurrent detection
  - Error handling using any matching strategy
- In other words, errors caused by the common bug

1. The Common Bug

Catching the Common Bug

- Best done during development (due to cost)
- Still, you can’t avoid errors during runtime

Example of Poor Error Handling Code [1]

```
public int readInt(File f, Buffer b) throws ParseException {
  int result = 0;
  try {
    FileInputStream fis = new FileInputStream(f);
    fis.read(b);
    result = Integer.parse(b.toString());
  } catch (Exception ex) {
    // do nothing
  }

  if (result == 0) {
    // there should never be “0” in file
    System.out.println(“something went wrong!”);
    return -1;
  }

  return result;
}
```

[1] Doesn’t compile; created for demonstration purposes only

Things Wrong with Example

- General programming errors
  - Unclear preconditions; no assertions
  - No need for external buffer variable
  - No clean-up after resource use
- Specific bad practices of error handling
  - Overloading of purpose of return value
  - Mismatch between method signature and behavior
  - System exception swallowed without logging
  - Inconsistent use of error codes and exceptions
  - Unprofessional logging / error message useless

If bugs are inevitable,

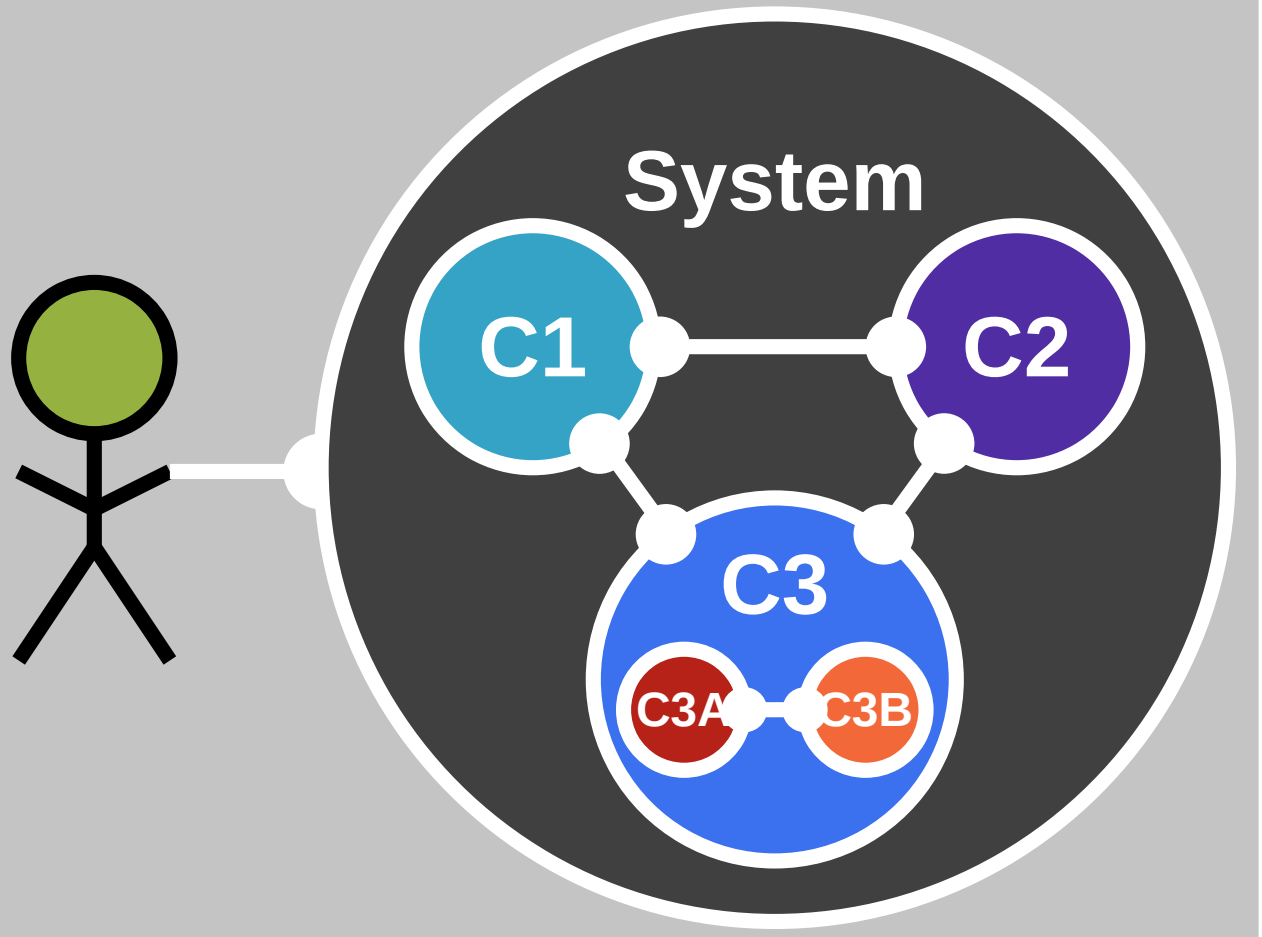
how to handle them?

2. System Model

System Model

Terminology

- System
- Correct service
- Incorrect service
- Component
- Boundary
- Interface
- Structure
- Behavior
- State
- User



Fault

- A fault
  - Is a condition that can cause an error
    - A fault is active, if it causes an error
    - A fault is dormant, if it has not yet caused an error
  - Can be classified by eight independent dimensions
- A software fault (the “common bug”)
  - Is always a development, internal, human-made fault
  - Is typically non-malicious, non-deliberate

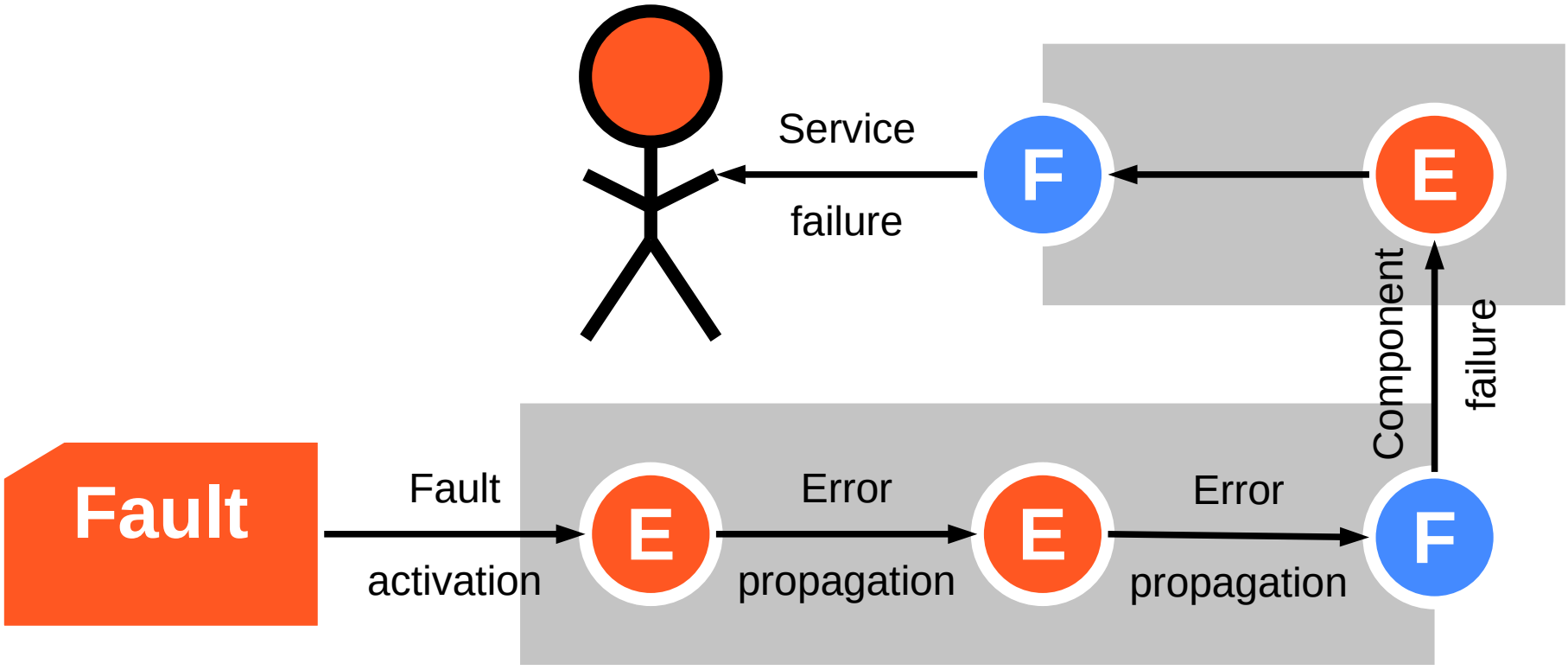
Error

- An error
  - Is a state of the system that may lead to a failure
  - Has been detected, if it has been indicated by error message or signal
    - An error is **latent**, if it has not been detected
  - Can be categorized by the failures it may cause

Failure

- A failure
  - Is an event that transitions the system from correct to incorrect service
  - Has a (failure) mode
    - Can be categorized by four independent dimensions
      - Domain (content, early timing, late timing, halt, and erratic failures)
      - Detectability (signaled and unsignaled failures)
      - Consistency (consistent and inconsistent failures)
      - Consequences (minor to catastrophic failures)
    - Can be ranked by severity (consequences)

Process Leading to Service Failure



Process Leading to Error Handling

1. **Detection**
2. **Signaling**
3. **Handling**

3. Error Detection

Error Detection

- Errors lead to failure to deliver the promised service
  - How to detect? Use design by contract!
- Error detection = recognizing inability to provide service
  - Failing preconditions, class invariants, or post conditions
- Don’t think in error states, think in failure to provide service
  - Remember: No need for defensive programming

Examples of Error Detection

```
public void insert(int i, String c) {
  // assert preconditions
  assertIsValidIndex(i, getNoComponents() + 1);
  assertIsNonNullArgument(c);

  // prepare assertion of postconditions
  int oldNoComponents = getNoComponents();

  doInsert(i, c);

  // assert postconditions
  assert (oldNoComponents + 1) == getNoComponents() : "...";

  assertClassInvariants();
}
```

Error Capture / Representation

- Information to be captured
  - Error ID (instance)
  - Error type
  - Source objects
  - Affected objects
  - Explanatory message
- Representation of information
  - Error codes
  - Error objects
  - Exception objects

Examples of Error Representation

```
protected void assertIsValidIndex(int i) throws IndexOutOfBoundsException {
  if ((i < 0) || (i >= getNoComponents())) {
    throw new IndexOutOfBoundsException("invalid index = " + i);
  }
}
```

```
public class RegExpParseException extends ParseException {
  protected String regExp = "";

  public RegExpParseException(String msg, String exp, int offset) {
    super(msg, offset);
    regExp = exp;
  }

  public String getRegExp() {
    return regExp;
  }

  ...
}
```

Error Logging

- Possibly log the error information using system logger
  - May be helpful in case (poor) client code drops the error
  - Be slow to make assumptions about context
- Using the (system) logger
  - Write error object to appropriate logging level
  - Further functionality depends on the logger

4. Error Signaling

Error Signaling

- A detected error needs to be (logged and) signaled
- Transitions the system from normal to abnormal program state

Normal vs. Abnormal Program State

- Normal program state (NPS)
  - Method performs its duties
  - Control flow returns to caller via return statement
- Abnormal program state (APS)
  - Method failed to provide service
  - Control flow returns to caller
    - Via return error code
    - Via thrown exception

Methods for Error Signaling

- Using normal control flow (via return)
  - Error information can be passed using
    - Return value
    - Method argument
    - Mailbox object
- Using abnormal control flow (via raising an exception)
  - Error information is passed using
    - Exception object as part of raised exception

Exercise for Error Detection and Signaling

- How to implement a basic buffer read method?

Solution Using Error Codes

```
public class File {
  public static final int NO_ERROR = 0;
  public static final int ERROR_END_OF_FILE = 1;
  public static final int ERROR_PARITY = 2;

  public int readBytes(Buffer buf, int no) {
    while (no-- >= 0) {
      int err = readByte(buf);
      if (err != 0) return err;
    }
    return NO_ERROR;
  }

  protected int readByte(Buffer buf) {
    if (handle.isEOF()) return ERROR_END_OF_FILE;
    byte next = handle.getNextByte();
    boolean parity = handle.getParity();
    if (parity != calcParity(next) return ERROR_PARITY;
    buf.add(next);
    return NO_ERROR;
  }
  ...
}
```

Solution Using Exceptions

```
public class File {
  public byte[] readBytes(int no) throws IOException {
    byte[] buffer = new byte[no];
    for(int i = 0; i < no; i++) {
      byte next = readByte();
      buffer[i] = next;
    }
    return buffer;
  }

  protected byte readByte() throws IOException {
    if (handle.isEOF()) throw new EOFException(...);
    byte next = handle.getNextByte();
    boolean parity = handle.getParity();
    if (parity != calcParity(next)) throw new IOException(...);
    return next;
  }

  ...
}
```

Error Code Conventions

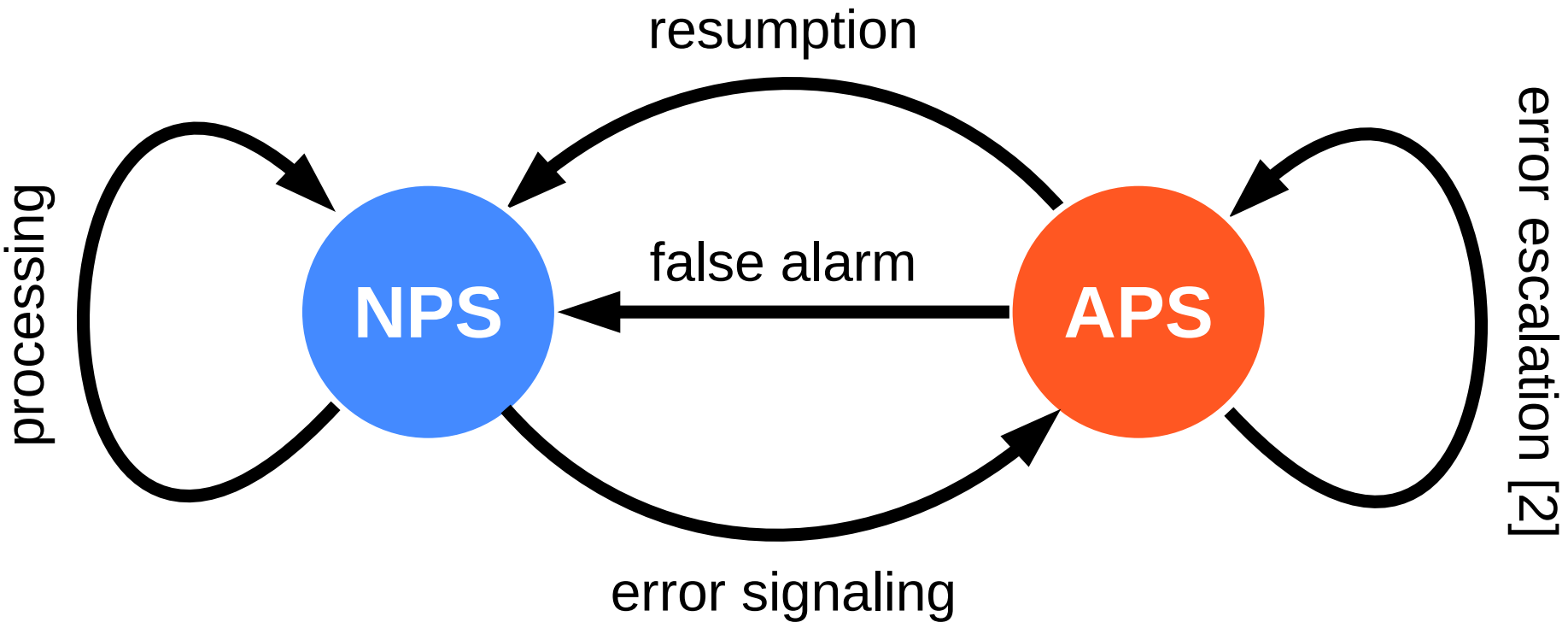
- 0 typically indicates “no error”
- -1 typically indicates a generic error
- 1..onwards indicate specific errors

Error Codes vs. Exceptions

- Error codes are a poor error signaling mechanism
  - Mix normal with abnormal program state code
  - Separate error signal code from error information object
  - **In Java, avoid using error codes if possible**
- Exceptions were designed for error signaling
  - They separate normal from abnormal program state
  - Specifically support passing error information in exception object
  - Corollary: Don’t use exceptions to make a regular return

5. Error Handling

Error Handling State Model [M92] [1]



[1] Adjusted terminology to [A+04]
[2] Called “organized panic” in [M92]

Error Handling

1. False alarm
2. Resumption
3. Escalation

Exercise of Error Handling

- How to handle error signaled by File component?

Solution Using Exception Handling

```
public class Document {
  protected byte[] buffer;
  public void loadFromFile(File file) throws DocumentException {
    ...
    int no = file.getLength();
    buffer = new byte[no];
    int tries = 0;
    for(int i = 0; (i < no) && (tries < 3); i++) {
      try {
        buffer[i] = file.readBytes();
      } catch(EOFException eofex) {
        throw new DocumentException(..., eofex);
      } catch(IOException iex) {
        tries++;
      }
    }
    if (tries == 3) {
      throw new DocumentException(...);
    }
  }
  ...
}
```

Error Escalation (“Organized Panic”)

- Error escalation is
  - The process of cleaning-up and delegating error handling to caller
- Basically, your code has exhausted its options and gives up

Steps in Error Escalation

- Clean-up
  - Always leave the current component in a viable state
    - Make sure you restore class and component invariants
  - Restore and/or release relevant resources
    - Use finally block in exception handling to ensure this
- Escalation
  - Enhance original error information with new insights
    - Do not hide your attempts to handle the error
  - Typically, chain exceptions
    - Attach prior error information (exception) to new one

Checked vs. Unchecked Exceptions [DR]

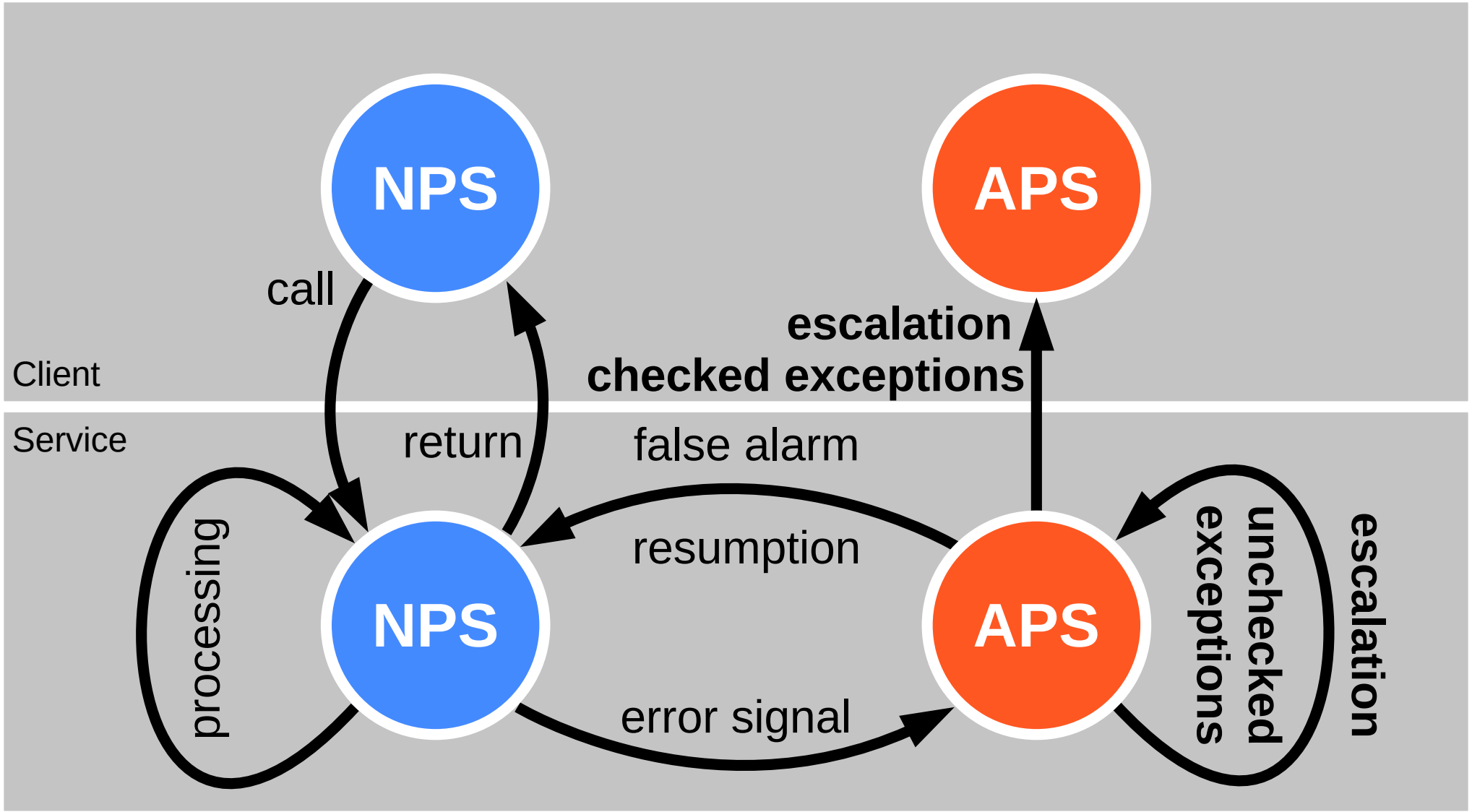
- Checked exceptions
  - Are exceptions that must be declared in a method signature
  - Are intended to force user to take notice of the exception
  - Works well if error handling code is close to where exception was raised
  - Are a pain to handle if code is far removed from origin of exception
  - **Use checked exceptions (or error codes) in component interface**

- Unchecked exceptions
  - Are exceptions that don’t need to be declared
  - Are intended to pass through client code by default
  - May make you miss an error signal that you should have handled
  - Are the only way to not complete clutter your component code
  - **Use unchecked exceptions only within your component**

6. Component Failures

Component Failure

- Error signals
  - Are part of the component interface
  - Should be specific to the component
  - **Use only checked exceptions in interface**
- **Do not let an unchecked exception escape**

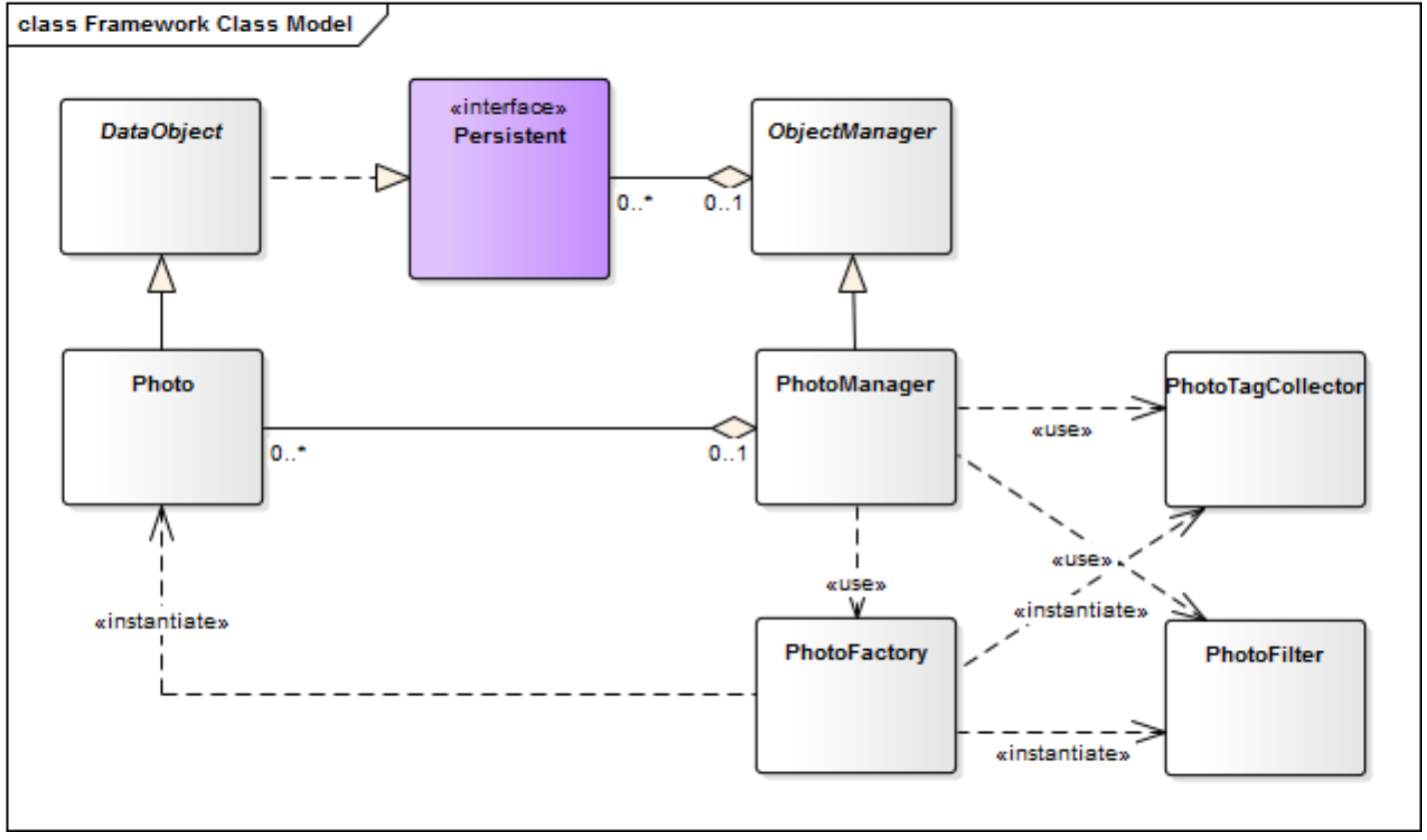

NPS
APS
call
escalation
checked exceptions
Client
Service
return
false alarm
processing
resumption
NPS
APS
unchecked
exceptions
escalation
error signal

Methods for Failure Signaling

- Failure clean-up
  - Like clean-up for error signaling
    - Restore invariants
    - Release resources
- Failure escalation
  - Like error escalation but
    - Catch all unchecked exceptions
    - Escalate using checked exception
  - Provide exception chain with new one

Exercise for Component Failure

- How to handle an ObjectManager failure (to load an object)?



Solution to Component Failure Exercise

- Within component
  - Error detection
    - Catch error signal from storage layer (file or database exceptions)
    - Handle error to the extent possible; eventually, give up
  - Error signaling
    - Capture prior error signal; create new unchecked exception
    - Throw exception about inability to load object
  - Error escalation
    - If method can handle exception, do so
    - If not, let the exception pass through
- At component boundary
  - Capture internal error signal, wrap it in component-specific exception
  - Throw checked exception about component failure to environment

Service Failure (User Interface)

- A service failure
  - Is a component failure with the user as the client
  - User interface is the final system boundary
- Handling a service failure
  - Log the service failure (error)
  - Don’t throw a checked exception
  - Convert the error into human-readable form and display it

Handling Faulty Components

- Well-behaved (but faulty) components
  - Follow error handling strategy as discussed
- Component of unclear quality
  - Wrap component in defensive code
  - Follow error handling strategy as discussed

Final Example of Raising an Exception [S11]

```
Exception up = new Exception("Something is wrong.");
throw up; // ha ha
```

Summary

1. The common bug
2. System model
3. Error detection
4. Error signaling
5. Error handling
6. Component failures

Thank you! Questions?

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