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CSC 510
Software Engineering

Refactoring

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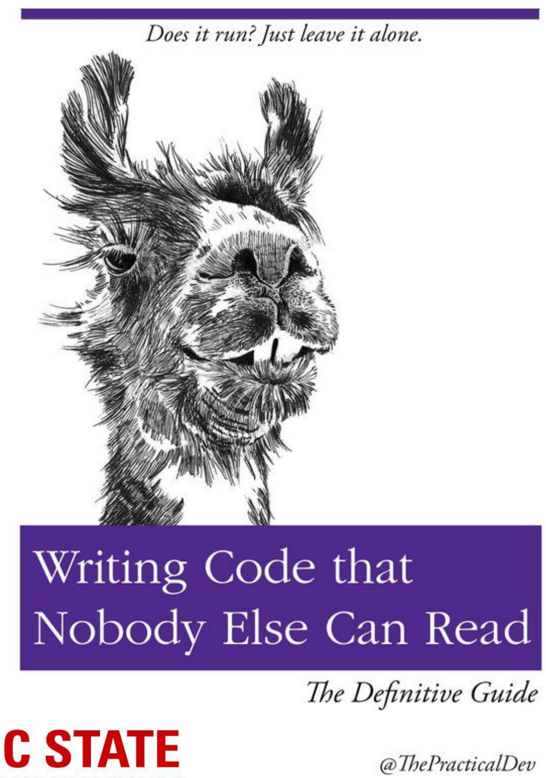
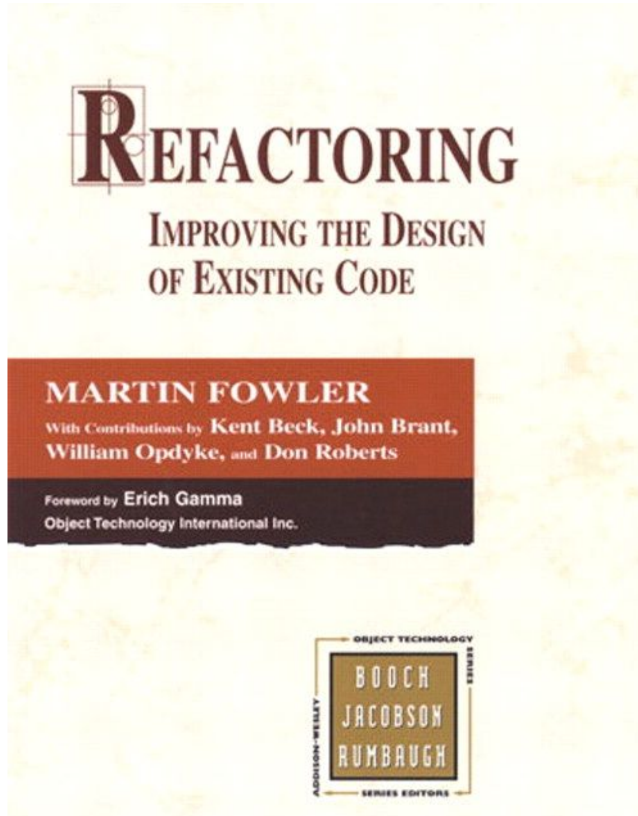
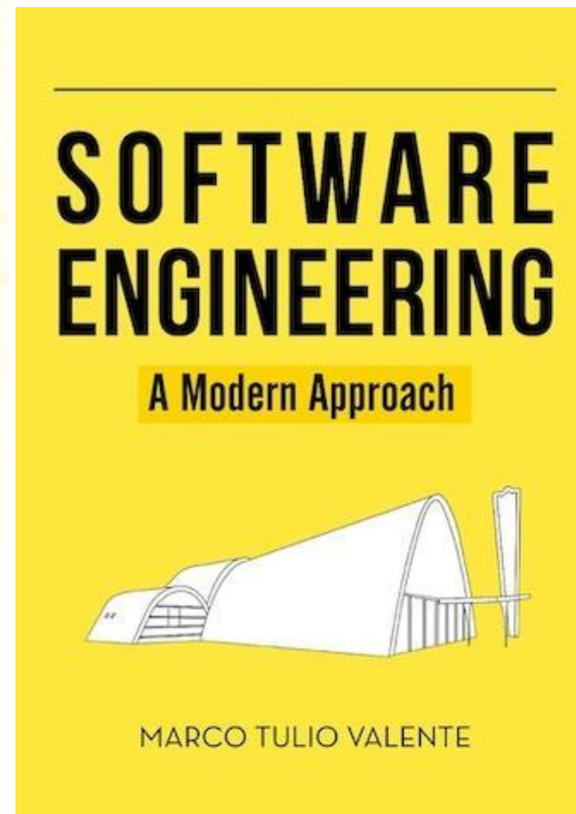
Book Referenced







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Overview

- Introduction to Refactoring
- Origins of Refactoring
- Example of Refactorings
- Refactoring Practice
- Challenges for Refactoring
- Code Smells
- The Importance of Testing

Software Maintenance & Lehman’s Laws

- Software systems require maintenance: corrective, adaptive, and evolutionary.
- Like living organisms, software ages over time.
- Lehman’s Laws (1970s):
- 1. Systems must be continuously adapted.
- 2. Maintenance increases complexity unless action is taken.
- Without intervention, code quality deteriorates naturally.

Example:
A system with years of patches becomes fragile, even if it still 'works.'

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What is refactoring?

"Code refactoring is the process of restructuring existing computer code – changing the factoring – without changing its external behavior.", from the Wikipedia article on Code Refactoring

What is refactoring?

Refactoring = improving maintainability without changing behavior

Key goals:

- Improve modularity, design, readability
- Increase testability and simplify modification

Types of transformations:

- Renaming, splitting methods, moving functions/classes

Behavior must be preserved!
System should work the same after refactoring.

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What isn’t refactoring?

- Adding new functionality to a program
- Fixing bugs
- Is changing a program to use safer libraries a refactoring? Why or why not?

Origins of refactoring

- Unclear where the term first came from
- Also unclear when it first started — to some extent, people have been refactoring for as long as they have been programming
- Two researchers focused on this, made it prominent:
  - Griswold and Notkin (University of Washington)
  - Opdyke and Johnson (University of Illinois at Urbana-Champaign)

Origin 1: Griswold and Notkin

- Motivating problem: how do we modify deployed applications?
  - Initial solution allowed functionality to be added to extend app
  - Results in a different architecture than what would have been created if extensions known in advance (why?)
- Question: can a program be restructured in a way that changes the design but doesn't change the behavior?
- Result was the Restructure tool for refactoring Scheme

Restructure: Some points

- Restructure worked over Program Dependence Graphs (PDGs), which encode control and data flow dependencies
  - Control flow: loops, conditionals, etc
  - Data flow: how data flows through program statements, which data reaches what places
- Guarded transformations: must meet preconditions first
- Refactoring as graph transformation

Origin 2: Opdyke and Johnson

- Motivating problem: how do we evolve real software?
- Opdyke wanted a "macro" focus, Johnson had a "micro" focus
- This resulted in evolution (macro) through a sequence of small (micro) changes
- One big question: how do we reuse abstractions that are tangled with specifics of the application domain?
- Approach: mine actual changes from existing software

Origin 2: Some points

- Decided to focus on C++, not Smalltalk (why?)
- Came up with a collection of transformations, some bigger and some very focused
- Investigated safe application: refactoring should not change meaning of code (deciding which to apply still being investigated)
- Approach based on code equivalence, cannot change meaning — not decidable in general, but often is in real systems
- Equivalence based on invariants of transformation

Differences in approaches

- Griswold: focused on the semantics, what it means for a refactoring to be meaning-preserving
- Opdyke: focused more on OO aspects and real-world systems, e.g., pushing methods up and down the inheritance hierarchy
- Many other tools and systems for this now, with support for lots of languages and some fairly involved refactoring scripts

History of Refactoring

- Popularized by Extreme Programming (XP) in 1999.
- Martin Fowler’s 2000 book created a refactoring vocabulary:
  - Dozens of common refactorings
  - Benefits, examples, and trade-offs
- Kent Beck: 'I’m not a great programmer; I’m just a good programmer with great habits.'

Extract Method

Before Refactoring:

```python
def process_order(order):
    print("Processing order")
    print(f"Customer: {order['customer']}")
    print(f"Items: {order['items']}")
    print(f"Total: ${order['total']}")
```

After Refactoring:

```python
def print_order_details(order):
    print(f"Customer: {order['customer']}")
    print(f"Items: {order['items']}")
    print(f"Total: ${order['total']}")

def process_order(order):
    print("Processing order")
    print_order_details(order)
```

This separates the logic of printing order details into its own method. This improves **readability**, supports **code reuse**, and makes the code easier to **test and maintain**.

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Motivations for Extract Method

Study of GitHub projects showed top motivations:

- Code reuse (43 cases)
- Alternative signature (25)
- Improve understanding (21)
- Remove duplication (15)
- Facilitate features or bug fixes (14)

Quote: 'I always try to reuse code... duplication complicates maintenance.'

“Make one change in one place.”

Inline Method

- Opposite of Extract Method.
- Replace a call to a short method with its body.
- Used when a method is very short and rarely reused.

Use when method adds no meaningful abstraction.

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Inline Method

Before Refactoring:

```python
def calculate_tax(price):
    return price * 0.08

def checkout(price):
    tax = calculate_tax(price)
    return price + tax

```

The method `calculate_tax` was small and only used once. Inlining makes the code more **straightforward** when the method doesn't add meaningful abstraction.

After Refactoring:

```python
def checkout(price):
    tax = price * 0.08  # inlined the method
    return price + tax
```

Move Method

- Move a method to the class it most logically belongs to.

- Improves cohesion and reduces coupling.

- If the method accesses more of another class's data, it probably belongs there.

Move method 'f' from Class A to Class B

Before:
A.f() { ... uses B }

After:
B.f() { ... }

Move Method

Before Refactoring:

```python
class ShoppingCart:
    def __init__(self, items):
        self.items = items

    def calculate_total(self):
        return sum(item.price for item in self.items)
```

After Refactoring:

```python
class ShoppingCart:
    def __init__(self, items):
        self.items = items

    def calculate_total(self):
        return sum(item.get_price() for item in self.items)

class Item:
    def __init__(self, name, price):
        self.name = name
        self.price = price

    def get_price(self):
        return self.price
```

`calculate_total` relied on the data from `Item`, so moving price access logic into the `Item` class improves **cohesion** and makes each class responsible for its own behavior.

Extract Class

- When a class has too many responsibilities, extract related fields and methods.

Example:

- Person class had 4 phone fields.
- Extracted new class Phone; Person now uses Phone objects.

Improves modularity and reuse.

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Extract Class

Before Refactoring:

```python
class Person:
    def __init__(self, name, home_phone, mobile_phone):
        self.name = name
        self.home_phone = home_phone
        self.mobile_phone = mobile_phone
```

After Refactoring:

```python
class Phone:
    def __init__(self, home, mobile):
        self.home = home
        self.mobile = mobile

class Person:
    def __init__(self, name, phone):
        self.name = name
        self.phone = phone
```

The `Person` class had too many responsibilities. Extracting the phone info into a Phone class improves **modularity**, reduces **duplication**, and supports **reuse**.

Rename

- Rename elements (methods, classes, variables) to more meaningful names.

- Helps readability and maintainability.

- Keep deprecated version of old method to allow gradual migration.

"Naming is one of the two hard things in CS."

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Rename

Before Refactoring:

```python
def f():
    return "Hello"
```

After Refactoring:

```python
def greet():
    return "Hello"
```

Renaming `f` to `greet` improves **readability** and helps other developers understand the method’s purpose. Good naming is essential for long-term **maintainability**.

Other Useful Refactorings

- Extract Variable – simplify expressions (e.g., extract delta).
- Remove Flag – use return/break instead of boolean flags.
- Replace Conditional with Polymorphism – move logic to subclasses.
- Remove Dead Code – eliminate unused code to improve clarity and reduce risk.

Simple changes → big readability improvements.

Extract Variable

Before Refactoring:

```
total_price = price * (1 + tax_rate)
```

After Refactoring:

```
tax = price * tax_rate
total_price = price + tax
```

Extracting `tax` improves **clarity** and helps when debugging or modifying tax logic.

Remove flag

Before Refactoring:

```python
found = False
for item in items:
    if item == target:
        found = True
        break
```

After Refactoring:

```python
if target in items:
    print("Found!")
```

Simplifies logic by eliminating unnecessary flags and using built-in Python capabilities.

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Replace Conditional with Polymorphism

Before Refactoring:

```python
def get_discount(customer_type):
    if customer_type == "Student":
        return 0.10
    elif customer_type == "Senior":
        return 0.15
    else:
        return 0.0
```

Instead of using conditionals to determine behavior, polymorphism delegates it to subclasses. This makes the system easier to **extend**, test, and **modify** without modifying existing code.

After Refactoring:

```python
class Customer:
    def get_discount(self):
        return 0.0

class Student(Customer):
    def get_discount(self):
        return 0.10

class Senior(Customer):
    def get_discount(self):
        return 0.15
```

Remove Dead Code

Before Refactoring:

```python
def calculate_area(radius):
    pi = 3.14159
    unused_variable = 42  # <- dead code
    result = pi * radius * radius
    return result

def unused_function():
    print("This function is never called.")  # <- dead code
```

After Refactoring:

```python
def calculate_area(radius):
    pi = 3.14159
    return pi * radius * radius
```

`unused_variable` and `unused_function()` were never used or called.

Removing such code improves **clarity**, reduces **cognitive load**, and minimizes the **risk of confusion or bugs** later.

Keeping dead code can mislead future developers or waste time during maintenance.

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Example refactorings

- Extract Method: https://sourcemaking.com/refactoring/extract-method
- Rename Method: https://sourcemaking.com/refactoring/rename-method
- Move Method: https://sourcemaking.com/refactoring/move-method
- Replace Temp with Query: https://sourcemaking.com/refactoring/replace-temp-with-query
- Replace Type Code with State/Strategy: https://sourcemaking.com/refactoring/replace-type-code-with-state-strategy
- Replace Conditional with Polymorphism: https://sourcemaking.com/refactoring/replace-conditional-with-polymorphism
- Self Encapsulate Field: https://sourcemaking.com/refactoring/self-encapsulate-field

Refactoring Practice: The importance of testing

- Why is having automated tests important?

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The importance of testing

- Remember back to concept of regression testing, what was this?

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The importance of testing

- Remember back to our concept of regression testing, what was this?
    - We need a way to ensure our changes don't break anything…
    - …and we will be making lots of changes!
- Automated testing gives us confidence that we aren't breaking anything when we change the code

Testing: Foundation for Refactoring

- Unit tests are critical for safe refactoring.
- Refactorings don't add features — only modify structure.
- Without tests, changes are risky and often avoided.
- Refactoring should be safe and confidence-driven.
- John Ousterhout: Refactoring without tests leads to design decay.
- 'Make the change easy… then make the easy change.' – Kent Beck

> “Without tests, major structural changes are dangerous.”

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Testing and refactoring

- What do you do if you are working on an existing system that doesn’t have tests?
- When should you add tests? What approaches can you use?

Refactoring Practice

- Opportunistic Refactoring
  - Done during regular development tasks (fixing bugs or adding features).
  - Triggered by code smells: long methods, bad names, duplication, etc.
  - Invest ~20% of task time to improve code while working.
- Strategic Refactoring
  - Planned, larger-scale refactoring efforts.
  - Examples: splitting large packages, reorganizing modules.
  - Scheduled when technical debt has grown over time.
  - Essential when multiple legacy issues accumulate.

The two challenges

- What two challenges do you see with actually doing refactoring?
- (Helpful hint, they were mentioned earlier in the talk…)

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The two challenges

- What two challenges do you see with actually doing refactoring?
- (Helpful hint, they were mentioned earlier in the talk…)
- Challenge 1: How do we know where to refactor (and can we automate this)?
- Challenge 2: How do we know a refactoring is safe (and can we automate this)?

Dealing with challenge 1: code smells

- A funny phrase for structures or patterns in the code that "suggest…the possibility of refactoring"
- Note: these are not bugs!
- They are structural problems in the code that could make it harder to ensure quality, evolve the system over time

— What? How can code "smell"??
— Well, it doesn't have a nose... but it definitely can stink!

How do we detect code smells?

- Manually: this is a matter of gaining experience
- Automatically: many tools now attempt to do this, but this isn’t an easy problem (why?)
- One example: FaultBuster
- Many others, if you go to https://scholar.google.com and search for “code smell detection” you will get lots of links (more than 55,000 as of February 2022)

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Code Smells

- Indicators of low-quality code.
- Difficult to maintain, understand, modify, or test.
- Not every smell demands immediate refactoring.
- Decision to refactor depends on importance and frequency of changes.

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Duplicated Code

- Increases maintenance complexity and risk of inconsistent changes.

Types of clones:

1. Identical (except whitespace/comments)
2. Same logic, different variable names
3. Same logic, minor statement differences
4. Semantically equivalent, different implementations

Solutions: Extract Method, Extract Class, Pull Up Method.

Duplicated Code

Before:

```python
def calculate_invoice_total(invoice):
    total = 0
    for item in invoice['items']:
        total += item['price'] * item['quantity']
    return total

def print_invoice(invoice):
    total = 0
    for item in invoice['items']:
        total += item['price'] * item['quantity']
    print(f"Total: {total}")
```

After:

```python
def calculate_invoice_total(invoice):
    return sum(item['price'] * item['quantity'] for item in invoice['items'])

def print_invoice(invoice):
    print(f"Total: {calculate_invoice_total(invoice)}")
```

Refactor by Extract Method to remove repeated logic.

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Long Method & Large Class

Long Method:

- Hard to read and maintain.
- Solution: Extract Method.

Large Class (God Class/Blob):

- Multiple responsibilities, low cohesion.
- Solution: Extract Class.

Long Method

Before:

```python
def generate_report(data):
    print("Report Header")
    for item in data:
        print(f"{item['name']} - {item['value']}")
    print("End of Report")
    print("Summary:")
    total = sum(i['value'] for i in data)
    print(f"Total: {total}")
```

After:

```python
def print_header():
    print("Report Header")

def print_items(data):
    for item in data:
        print(f"{item['name']} - {item['value']}")

def print_summary(data):
    total = sum(i['value'] for i in data)
    print("Summary:")
    print(f"Total: {total}")

def generate_report(data):
    print_header()
    print_items(data)
    print("End of Report")
    print_summary(data)
```

Refactor by breaking into smaller methods for readability and reuse.

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Large Class (God Class / Blob)

Before:

```python
class Employee:
    def __init__(self, name, salary, hours):
        self.name = name
        self.salary = salary
        self.hours = hours

    def calculate_pay(self):
        return self.salary * self.hours

    def print_badge(self):
        print(f"Employee: {self.name}")
```

After:

```python
class Payroll:
    def __init__(self, salary, hours):
        self.salary = salary
        self.hours = hours

    def calculate_pay(self):
        return self.salary * self.hours

class Employee:
    def __init__(self, name, payroll):
        self.name = name
        self.payroll = payroll

    def print_badge(self):
        print(f"Employee: {self.name}")
```

Refactor by Extract Class
for separation of concerns.

Feature Envy & Long Parameters List

Feature Envy:

- Method heavily uses another class's data/methods.
- Solution: Move Method.

Long Parameters List:

- Method with excessive parameters.
- Solutions: obtain params internally, or group params into objects.

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Feature Envy & Long Parameters List

Before:

```python
def apply_discount(order, price, tax, customer_level):
    if customer_level == "gold":
        return price * 0.9 + tax
    return price + tax
```

After:

```python
#Encapsulate Logic in Order
class Order:
    def __init__(self, price, tax, customer_level):
        self.price = price
        self.tax = tax
        self.customer_level = customer_level

    def apply_discount(self):
        if self.customer_level == "gold":
            return self.price * 0.9 + self.tax
        return self.price + self.tax
```

Feature Envy: move logic to the class whose data is being used.

Long Parameters: use object instead of separate parameters.

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Global Variables & Primitive Obsession

Global Variables:

- Difficult to track changes; cause unintended side-effects.
- Solution: Encapsulate state within classes.

Primitive Obsession:

- Overuse of basic types (int, String).
- Solution: Create dedicated classes (e.g., ZIPCode, Currency).

Global Variables & Primitive Obsession

Before:

```python
discount_rate = 0.1  # global
def apply_discount(price):
    return price - (price * discount_rate)
```

After:

```python
#Encapsulate State & Use Domain Types
class Discount:
    def __init__(self, rate):
        self.rate = rate

    def apply(self, price):
        return price - (price * self.rate)

discount = Discount(0.1)
price_after_discount = discount.apply(100)
```

Avoid global variables; use objects to hold state.

Replace **primitive obsession** (e.g., raw `float`) with domain-specific types.

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Mutable Objects & Data Classes

Mutable Objects:

- Objects whose state changes post-creation.
- Prefer immutable objects to ensure thread-safety.

Data Classes:

- Only attributes, no significant behavior.
- Solution: Move relevant methods into these classes.

Mutable Objects & Data Classes

Before:

```python
class User:
    def __init__(self, name):
        self.name = name

user = User("Alice")
user.name = "Bob"  # Mutable object
```

After:

```python
from dataclasses import dataclass

@dataclass(frozen=True)
class User:
    name: str

user = User("Alice")
# user.name = "Bob"  # Will raise an error
```

Use `@dataclass(frozen=True)` for immutability — safer for concurrency and testing.

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Comments & Technical Debt

Comments:

- Often indicate unclear code.
- Solution: Refactor code for clarity, reduce need for comments.

Technical Debt:

- Technical issues that accumulate maintenance costs.
- Examples: lack of tests, poor architecture, unresolved smells.
- Paying off debt improves long-term maintainability.

Comments & Technical Debt

Before:

```
def calculate():
    # calculate square root
    result = x ** 0.5  # ← unclear variable, bad naming
```

After:

```
def calculate_square_root(number):
    return number ** 0.5
```

Clear code reduces the need for explanatory comments.

Paying off **technical debt** improves maintainability.

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Examples of code smells

- Duplicate code: https://sourcemaking.com/refactoring/smells/duplicate-code
- Long method: https://sourcemaking.com/refactoring/smells/long-method
- Large class: https://sourcemaking.com/refactoring/smells/large-class
- **Divergent change**: https://sourcemaking.com/refactoring/smells/divergent-change
- **Shotgun surgery**: https://sourcemaking.com/refactoring/smells/shotgun-surgery
- Feature envy: https://sourcemaking.com/refactoring/smells/feature-envy

Dealing with challenge 2: program analysis

- Program analysis lets us encode rules about when a refactoring is safe (preconditions, invariants) and check these on the code

- Not easy! And some languages are harder than others

- For interesting examples, see work of Max Schäfer (http://dblp.uni-trier.de/pers/hd/s/Sch=auml=fer:Max) (e.g., “Sound and Extensible Renaming for Java”)

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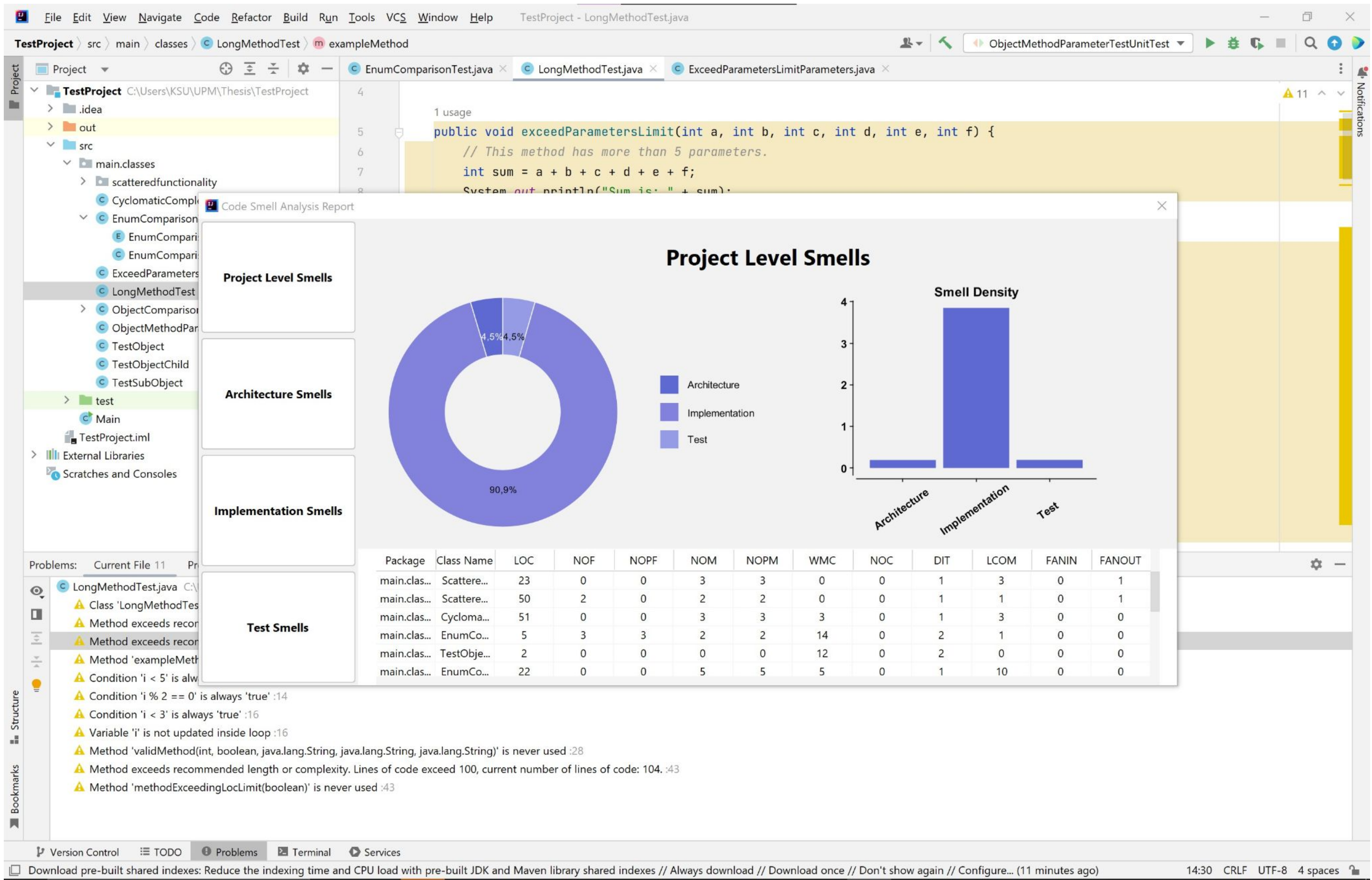
Checking Refactoring Preconditions

- **Tests exist and pass before and after refactoring.** Ensure behavior hasn't changed.
- **Behavior is stable and testable.** Avoid refactoring unknown or unpredictable code.
- **Code compiles or runs cleanly.** Don't refactor broken code unless intentionally fixing it.
- **Dependencies are understood.** Know what classes/functions use the code being changed.
- **No side effects or shared state.** Refactored code shouldn't rely on hidden mutable state.
- **Access and visibility rules are respected.** Ensure moved or renamed methods remain accessible where needed.
- **No name conflicts.** New names should be unique in the current scope.
- **Code is not duplicated after refactoring.** Prevent introducing repetition (e.g., from inlining).
- **Contracts and APIs are preserved.** External behavior, return types, and public interfaces must stay consistent.
- **Changes are isolated.** Refactor in small steps to avoid cascading errors.

IDE warnings prevent subtle errors by checking visibility & behavior.

Automated Refactoring in IDEs



Picture source: https://plugins.jetbrains.com/plugin/24498-autorefactor

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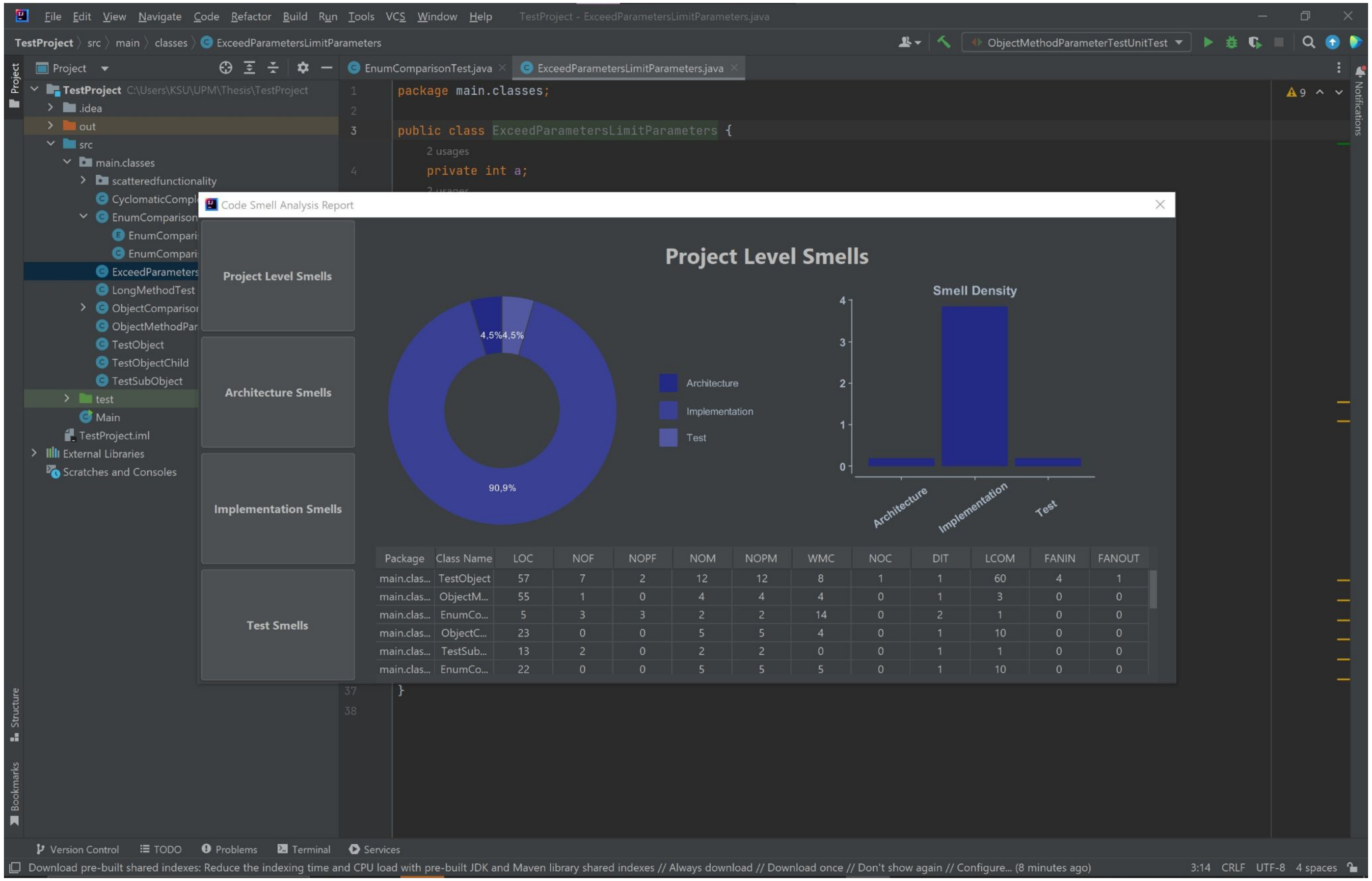
IDE helps automate refactoring, but developers remain in control.

Automated Refactoring in IDEs



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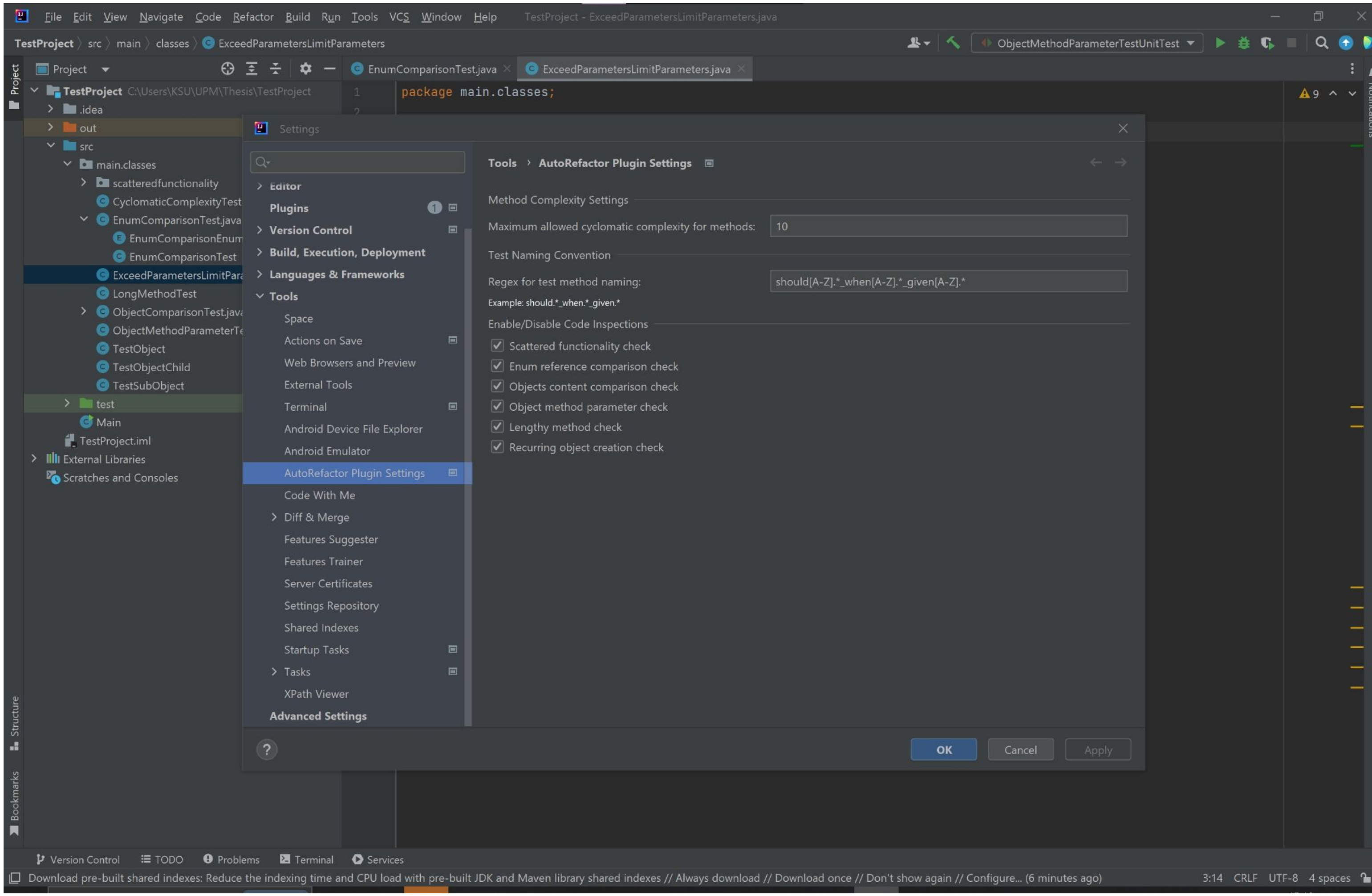

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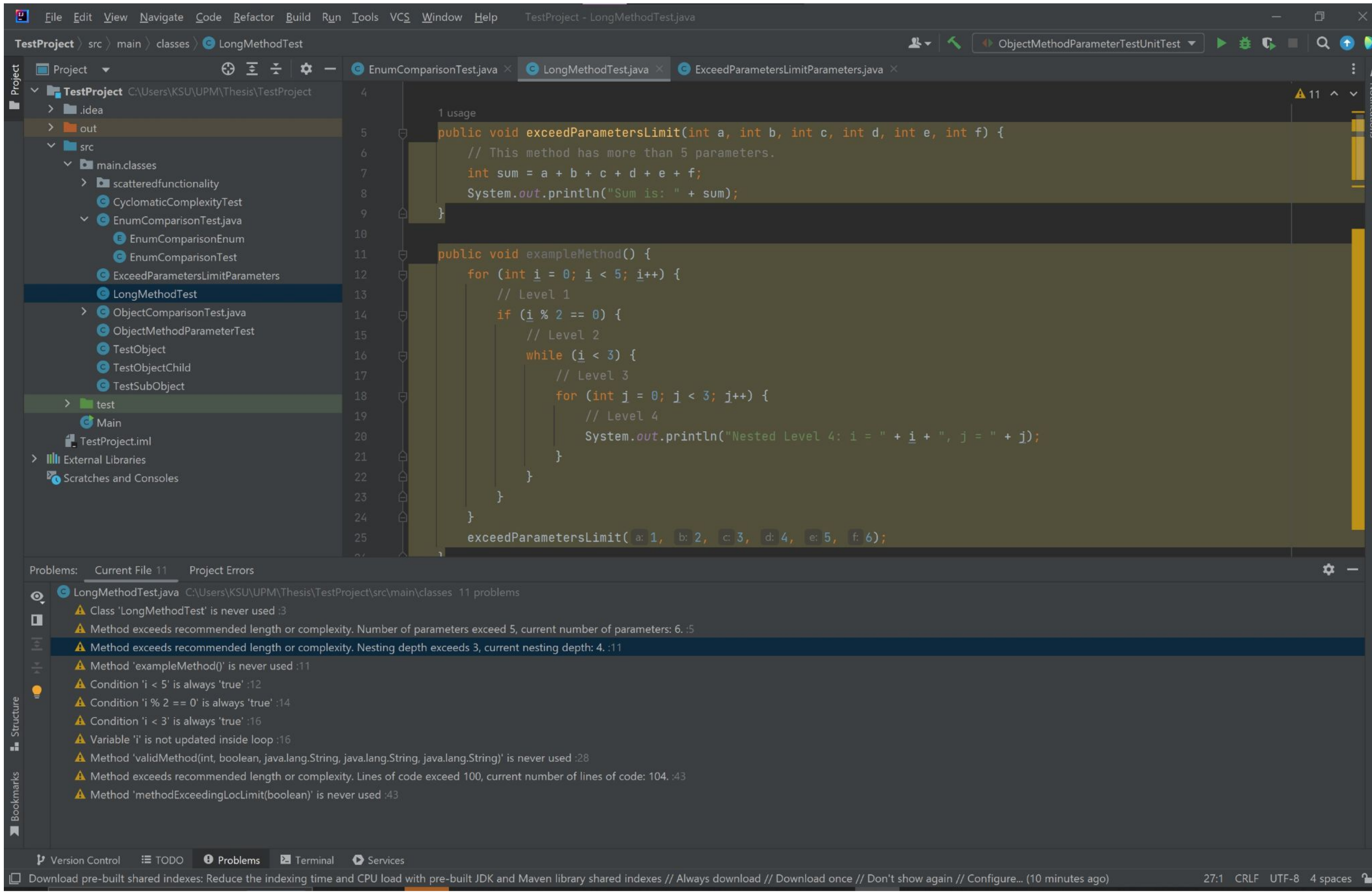

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IDE helps automate refactoring, but developers remain in control.

```
for u in range (0, 1000):
    print ("Thank you!")
```

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