Software Design Patterns

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29 September 2020

Slides + exercises available at github.com/klieret/icsc-paradigms-and-patterns

Thursday 17:00-17:30: Exercise consultation time

Repetition: Object Oriented Programming

- Inheritance: Subclasses inherit all (public and protected) attributes and methods of the base class
- Methods and attributes can be public (anyone has access), private (only the class itself has access) or protected (only the class and its subclasses have access)
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New: class methods: Methods of the class, rather than its instances

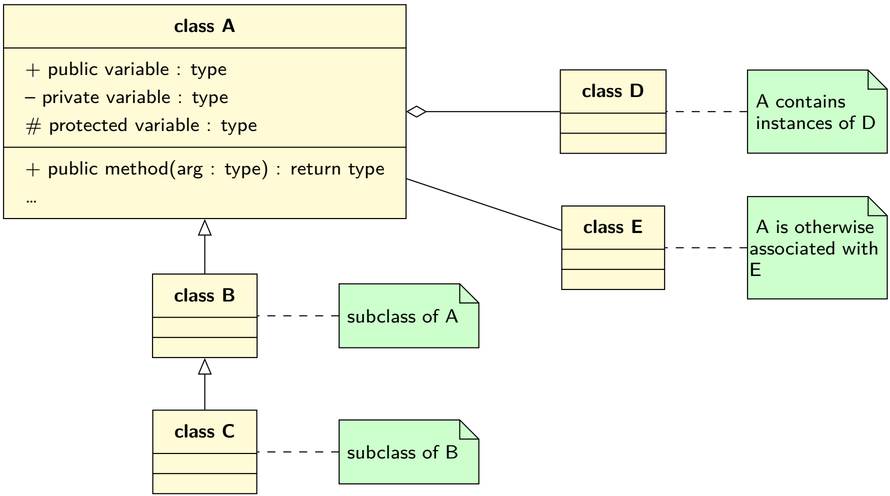
```python
class Class:
    def method(self):
        # needs to be called from INSTANCE and can access instance attributes
    @classmethod
    def classmethod(cls):
        # no access to instance attributes

# This won't work:
Class.method()  # <-- needs an instance, e.g. Class(...).method()

# But this does:
Class.classmethod()
```

Class diagrams I

UML (Unified Markup Language) class diagrams visualize classes and the relationships between them. We will use the following subset of notations:



The SOLID rules of OOP: Single responsibility principle

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Commonly (mis-)quoted as:

A class should only have one responsibility.

More accurate:

A class should only have one reason to change.

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Separate those things that change for different reasons.

So this actually proposes a balance!

- Avoid classes that do too much ("god class")
- But also avoid having changes always affect many classes ("shotgun surgery")

The SOLID rules of OOP: Open Closed Principle

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You should be able to extend the behavior of a system without having to modify that system.

- Writing a library, modifying functionality means that all users have to be informed (not backwards compatible) ⟶ Avoid!
- In your own code: Modifying one functionality (also by overriding methods of the super class, etc.) poses the danger of breaking other parts (though tests can help with that)
- Extending code by providing additional methods, attributes, etc. does not have this danger ⟶ preferred!
- Requires thinking ahead: What parts have to be flexible, what remains constant?
- Again a balance is required:
  - Be too generic (avoid modifications) and your code won't do anything
  - Be too concrete and you will need to modify (and potentially break things) often

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The SOLID rules of OOP: Liskov Substitution Principle

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e.g. I can replace all instances of `Animal` with instances of `Cat`

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This can be expanded to a series of properties that should be fulfilled:

- Signature of methods of the subclass:
  - Required type of arguments should be supertype (*contravariance*)
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Clients should not be forced to depend on methods they do not use

- "Thin" interfaces offering a reasonably small number of methods with *high cohesion* (serve similar purposes; belong logically together) are **preferred** over "fat" interfaces offering a large number of methods with low cohesion
- Sometimes we should therefore split up (segregate) fat interfaces into thinner *role interfaces*
- This leads to a more decoupled system that is easier to maintain
- Example: Even if all data is contained in one (e.g. SQL) database, the ISP asks to write *different* interfaces to do different things, e.g. have a `CustomerDb`, `OrderDb`, `StoreDb`, …

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This is about decoupling different classes and modules:

1. *High-level modules should not depend on low-level modules. Both should depend on abstractions (interfaces).*

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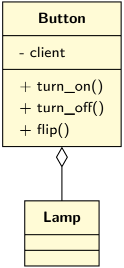
Let's consider a very simple example: A button controlling a lamp. One way to implement this:



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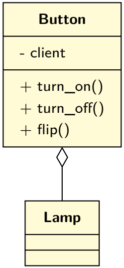

This violates the DIP, because `Button` (high-level) depends on `Lamp` (detail).

What if we have multiple consumers (`Motor`, `Lamp`, ...) and multiple types of buttons (swipe button, switch, push button, ...)? How can we force them to behave consistent? What methods does a consumer have to implement to work together with the button?

$\longrightarrow$ Enter abstractions (interfaces)

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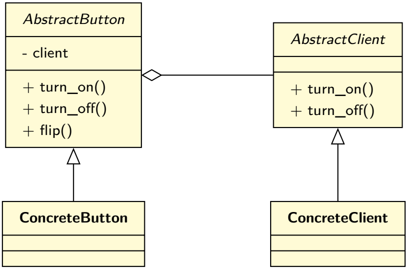

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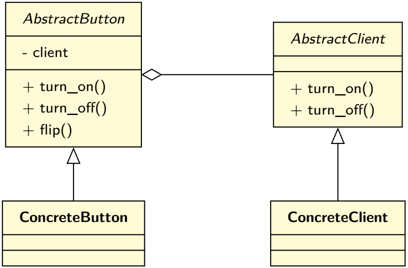

Now it's clear which methods the concrete client has to implement. Both high level and low level modules only depend on abstractions.

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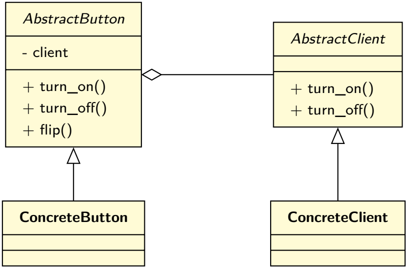

Now it's clear which methods the concrete client has to implement. Both high level and low level modules only depend on abstractions.

This also fulfills the second part of the DIP:

2. *Abstractions should not depend on details. Details* (*i.e. concrete implementations*) *should depend on abstractions.*

Performance considerations

Some patterns will advocate:

- Classes that only act as interfaces and pass on calls to other (worker) classes
- Using separate classes to facilitate communication between classes
- Accessing attributes (only) through methods
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However, when writing performance critical (`C++`, …) code, you should avoid unnecessary "detours":

- Avoid unncessary interfaces
- Consider inlining simple, often-called functions (e.g. getters and setters)
- Inheritance > composition > `if` statements

Modern compilers will try to apply some optimization techniques automatically (automatic inling, return value optimization, …)

General rule: Profile before Optimizing

Patterns

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Commonly categorized as:

- Creational patterns: How are instances of classes instantiated? (What if I have a class that can create instances in different ways?)
- Structural patterns: Concerned with relationships between classes. (How can classes form flexible larger structures?)
- Behavioral patterns: Concerned with algorithms and communication between classes. (How are responsibilities assigned between classes?)
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Bad:

```python
class Uncertainty:
    def __init__(self, absolute_errors=None,  relative_error=None,
        data=None, config=None, ...):
        if config is not None:
            # load from config
        elif absolute_errors is not None:
            # add absolute errors
        elif relative_errors is not None and data is not None:
            # add relative errors
        ...


instance = Uncertainty(config="path/to/my/config")
```

Factory method

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Good:

```python
class Uncertainty:
    def __init__(self, absolute_errors):
        # construct from absolute errors

    @classmethod  # <-- doesn't need instance to be called (cf. first slide)
    def from_config(cls, config):
        # get absolute errors from config file
        return cls(absolute_errors)

    @classmethod
    from relative_errors(cls, data, relative_errors):
        return cls(data * relative_errors)


instance = Uncertainty.from_config("path/to/my/config")
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Alternatively, you can also have subclasses that provide (implementations to) factory methods.

Builder Pattern

If you build a very complex class, try to instantiate (build) it in several steps.

Bad:

```
class Data:
    def __init__(
        data: array,
        data_error: array
        mc_components: List[array],
        mc_errors: List[array],
        mc_float_normalization: List[bool],
        mc_color: List[string],
        ...
    )

    def fit(...)

    def plot(...)
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You will probably consider different fits and plots; violates Single Responsibility Principle ⟶ Rather have `Fit` and `Plot` classes

Builder Pattern

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Better:

```python
class Data:
    def __init__(data: array, data_error: array)
        pass

    def add_mc_component(data, errors, floating=False, color="black", ...):
        pass


data = Data(...)
data.add_mc_component(...)
...
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- What if we have multiple ways to build of the object?
- Do I want to have the `add_mc_component` method after I start using the data?

⟶ Have a separate `Data` and `Builder` hierarchy.

Builder Pattern

If you build a very complex class, try to instantiate (build) it in several steps.

Best:

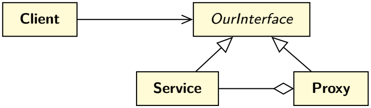
```python
class Data:
    pass

class Builder:
    def __init__(...)

    def add_mc_component(...)

    def create(...) -> Data


builder = Builder(...)
builder.add_mc_component(...)
...
builder.add_mc_component(...)
data = builder.create()
```

And of course I could now create `AbstractData` and `AbstractBuilder` etc.

Proxy, Adapter, Facade

Three patterns that deal with interfaces:

- Proxy: Given a *servant* class (doing the actual work), create a new *proxy* class with the same interface in order to inject code. The client can then use the `Proxy` instead of using the `Service` class directly.



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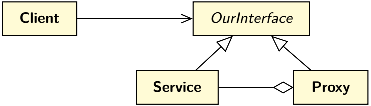

Usage examples:

- Protection proxy: Enforce access rights (always check authorization before method call/attribute access; e.g. in web applications)
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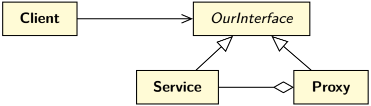

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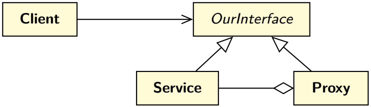

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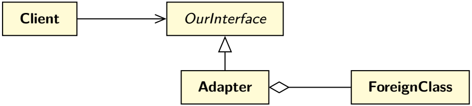

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Adapter

```python
class OurMLModel(ABC):
    """ Our interface """
    @abstractmethod
    def train(...):
        pass


class TheirMLModel(ABC):
    """ Their interface """
    @abstractmethod
    def training(...)  # <-- this method should be called train
        pass


class ModelAdapter(OurMLModel):  # <-- implements our interface
    def __init__(self, model: TheirMLModel):
        self._model = model   # <-- our adapter holds the foreign model

    def train(...):           # <-- and defines a different interface for it
        self._model.training(...)


# Their model with our interface:
model = ModelAdapter(TheirMLModel(...))
```

Template Method

Questionable:

```
class MLModel():
    def load_data(...)
    def prepare_features(...)

    def train(...):
        if self.model == "BDT":
            # train BDT
        elif self.model == "RandomForest":
            # train random forest
        elif ...

    def validate(...)
    ...
```

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- What if multiple methods depend on the model? ⟶ Need to keep track of more `if`s everywhere
- What if we want to add or remove a model? ⟶ Need to make changes in many places ⟶ ~~Open/Closed Principle~~, "divergent change"
- Depend on all implementations ⟶ ~~Dependency Inversion Principle~~

Template Method

- **Use case:** Several different algorithms that only contain minor differences in few places
- **Suggestion:** Put shared code in superclass, have subclasses implement or override specific methods

- **Advantages:** Simple and clean with little overhead
- **Warnings:**
  - If there are many differences between original classes, we need (to override) many methods → increasingly hard to read and maintain
  - If there are multiple "options" for every method and we want to realize them, the number of subclasses grows exponentially → Strategy pattern
  - If overriding default methods, the Liskov Substitution Principle can be easily violated

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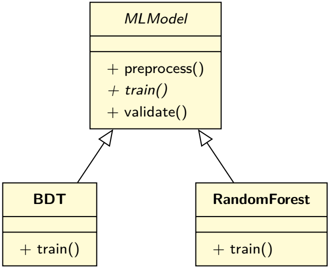

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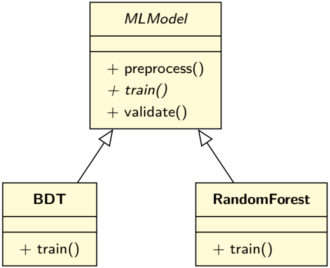

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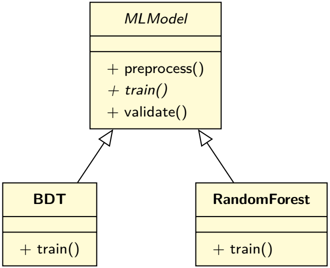

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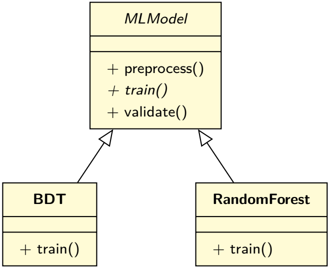

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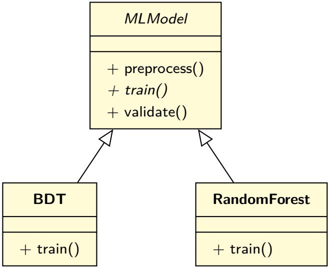

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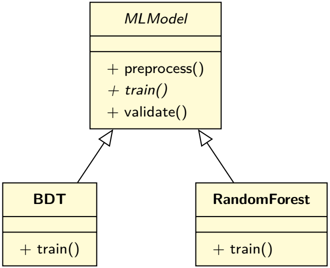

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Template Method

Better:

```python
class MLModel(ABC):  # <-- abstract class
    def load_data(...)
    def prepare_features(...)

    @abstractmethod
    def train(...):
        pass

    def validate(...)
    ...


class BDT(MLModel):  # <-- concrete class
    def train(...):
        # Implementation


class RandomForest(MLModel):
    def train(...):
        # Implementation
```

Strategy

- Usage: Your problem consists of several steps. Each step can be solved with different algorithms (strategies)
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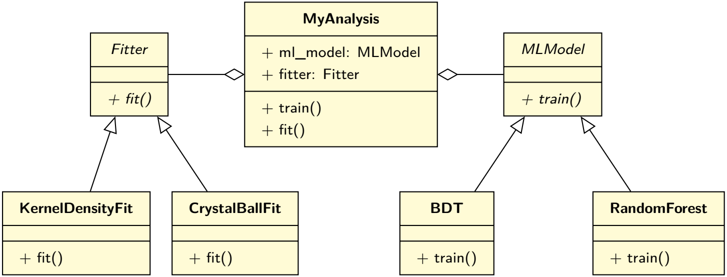

Strategy

```python
class MyAnalysis():
    def __init__(ml_model: MLModel, fitter: Fitter)
        self.ml_model = ml_model
        self.fitter = fitter

    def fit(...):
        self.fitter.fit(...)

    def train(...):
        self.ml_model.train(...)

class MLModel(ABC):
    @abstractmethod
    def train(...)

class RandomForest(MLModel):
    def train(...):
        # Implementation


my_analysis = MyAnalysis(RandomForest(...), KernelDensityEstimator(...))
my_analysis.train(...)
my_analysis.fit(...)
```

Strategy

- Note: The main class holds instances of algorithm classes; the algorithm classes use the the template method pattern
- Advantages:
  - Open/Closed principle: Easily add new strategies
  - Dependencies inverted (`MyAnalysis` does not depend on the individual implementations)
  - Small number of subclasses
  - Separated implementation of algorithms from higher level code
  - For compiled languages: Change algorithms at runtime
- Warnings:
  - Might be overkill for very simple problems
  - For maximum performance, avoid virtual calls
- Alternatives:
  - If your language supports it: Use functions instead of objects (e.g. provide several `fit()` functions and pass them to the class)
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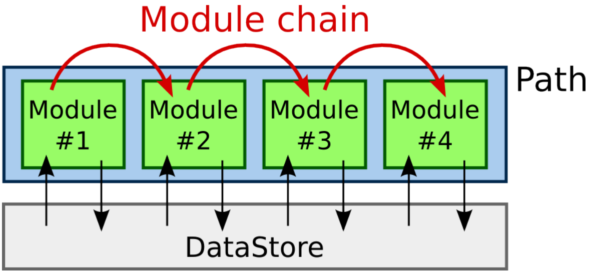
Command

Slightly simplified Belle II steering file:

```python
# Create path to add modules (=Command objects) to
path = create_path()

# Load data (convenience function that adds a "DataLoader" module to the path)
inputMdstList("default", "/path/to/input/file", path=path)

# Get final state particles

# Fill 'pi+:loose' particle list with all particles that have pion ID > 0.01:
fillParticleList("pi+:loose", "piid > 0.01", path=path)
# Fill 'mu+:loose' particle list with all particles that have muon ID > 0.01:
fillParticleList("mu+:loose", "piid > 0.01", path=path)

# Reconstruct decay
# Fill 'K_S0:pipi' particle list with combinations of our pions and muons
reconstructDecay(
    "K_S0:pipi -> pi+:loose pi-:loose", "0.4 < M < 0.6", path=path
)

# Process path = call execute() on all Command objects
process(my_path)
```

Command

Upon processing path:



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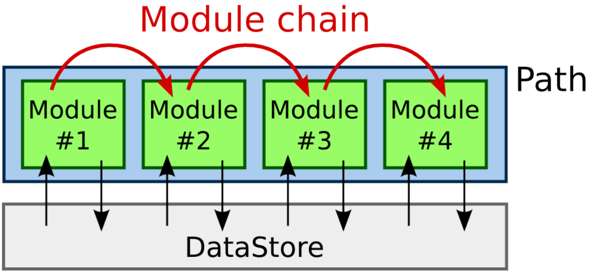

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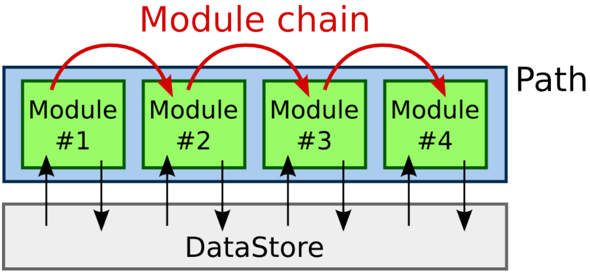

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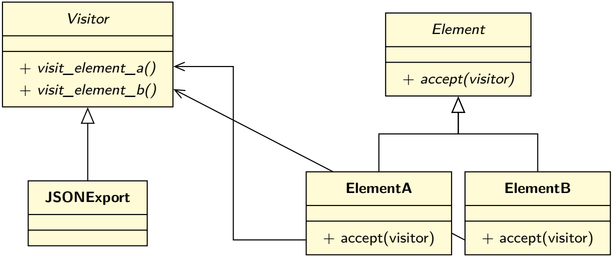
Visitor

- Concrete example: Serialize a collection of instances of different classes (e.g. provide JSON export for a list of different data objects)
- Possible implementation: Provide a `to_json()` method to all classes
- Potential issue: Might soon want to add export for export possibilities: (`XML`, `CSV`, `YAML`, etc.)
  - $\Longrightarrow$ more and more unrelated methods need to be added to the data class
  - $\Longrightarrow$ "polluted" interface (methods are irrelevant for core functionality); people might be wary of frequent changes to a well working class
- Solution: Separate algorithms from the objects they operate on



Visitor

Use case (more formally):

- Given a heterogeneous family of `Element` classes
- Do not expect significant changes to `Element` classes
- Various unrelated operations need to be performed on a collection of `Element` objects
- We expect frequent additions and changes for the operations
- Do not want to frequently change `Element` classes because of that

Advantages of visitor pattern:

- Single responsibility principle: All the operation functionality is in one place
- Open/Closed principle: Easy to add new operations

Disadvantages of the visitor pattern:

- No access to private information of `Element` classes
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Concurrency patterns need their own lecture, so this will only quickly mention basic concepts.

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- Manage/synchronize access to shared resources (e.g. to avoid race conditions when several threads perform read and write operations)
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Concurrency Patterns II

Advanced example: Active object pattern

- Want to decouple method calling from method execution
- Can request a calculation early and check later whether the result is available

The pattern consists of multiple components:

- The client calls a method of a proxy, which (immediately) returns a future object (can be used to check if results are available and get them)
- At the same time the proxy turns the method call into a request object and adds it to a request queue
- A scheduler takes requests from the request queue and executes it (on some thread)
- Once the request is executed, the result is added to the future object
- Only when the client accesses the future (wants to get the result value), the client thread waits (if the result is already available by that time, no waiting/blocking occurs)

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- Only when the client accesses the future (wants to get the result value), the client thread waits (if the result is already available by that time, no waiting/blocking occurs)

Concurrency Patterns II

Advanced example: Active object pattern

- Want to decouple method calling from method execution
- Can request a calculation early and check later whether the result is available

The pattern consists of multiple components:

- The client calls a method of a proxy, which (immediately) returns a future object (can be used to check if results are available and get them)
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Anti-patterns

- God object, The blob: One massive class containing all functionality
- Object orgy: Not using data encapsulation (not distinguishing between public and private members); some objects modify the internals of others more than their own (⟶ it is not clear "who is doing what to whom")
- Not using polymorphism: Having many parallel sections of identical `if` statements rather than using classes and subclasses
- Misusing (multiple) inheritance: Some inherited methods do not make sense for subclass; violations of the Liskov substitution principle
- Overgeneralization/inner platform effect: A system so general and customizable that it reproduces your development platform

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Common criticism

"Repetitive use of the same patterns and lots of boilerplate indicates lack or abstraction or lacking features of your programming language."

- Example: If functions are first-level objects (can be passed around like normal datatypes), I do not need to define a strategy class hierarchy.
  However, this could still be considered the same "pattern" (only with a simpler implementation)
- The "Patterns" give you vocabulary to describe your problem in an abstract way, even if the implementation details very a lot between languages
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Outlook

Exercise consultation time Thursday 17:00 – 17:30!

Discussion on mattermost:
mattermost.web.cern.ch/csc/channels/software-design

Get the exercises at github.com/klieret/icsc-paradigms-and-patterns