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21) Functional and Modular Design

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Obligatory Readings

- Ghezzi Chapter 3, Chapter 4, esp. 4.2
- Pfleeger Chapter 5, esp. 5.7
- David Garlan and Mary Shaw. An Introduction to Software Architecture. In: Advances in Software Engineering and Knowledge Engineering, Volume I, edited by V.Ambriola and G.Tortora, World Scientific Publishing Company, New Jersey, 1993.
  - Also appears as CMU Software Engineering Institute Technical Report CMU/SEI-94-TR-21, ESC-TR-94-21.
  - http://www-2.cs.cmu.edu/afs/cs/project/able/ftp/intro_softarch/intro_softarch.pdf

Literature

- [Parnas] David Parnas. On the Criteria To Be Used in Decomposing Systems into Modules. Communications of the ACM Dec. 1972 (15) 12.
- [Shaw/Garlan] Software Architecture. 1996. Prentice-Hall.

11.1 FUNCTIONAL DESIGN

Function-Oriented Methods

- Examples:
  - **Stepwise function refinement** resulting in function trees
  - Modular decomposition with information hiding (Change-oriented modularization, Parnas)
  - Meyers Design-by-contract: Contracts are specified for functions with pre- and postconditions
    - (see OCL lecture)
  - Dijkstra’s and Bauer’s axiomatic refinement (not discussed here)

Which functionality will the system have?

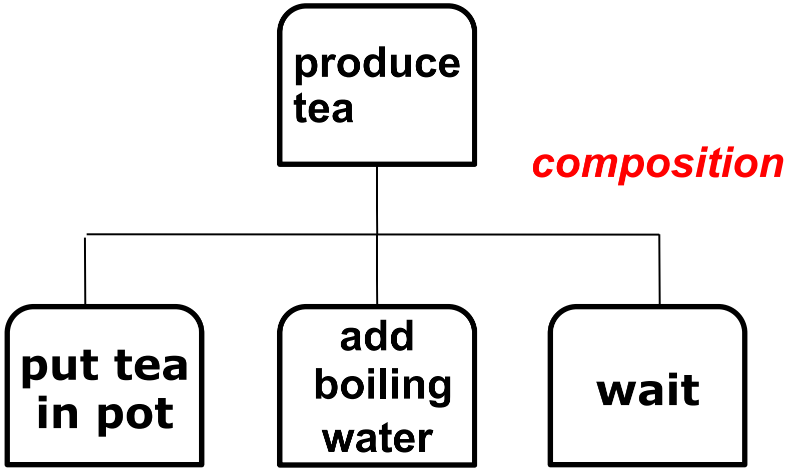
A Start for a Function Tree

- How to design the control software for a tea automaton?

```
Produce Tea
```

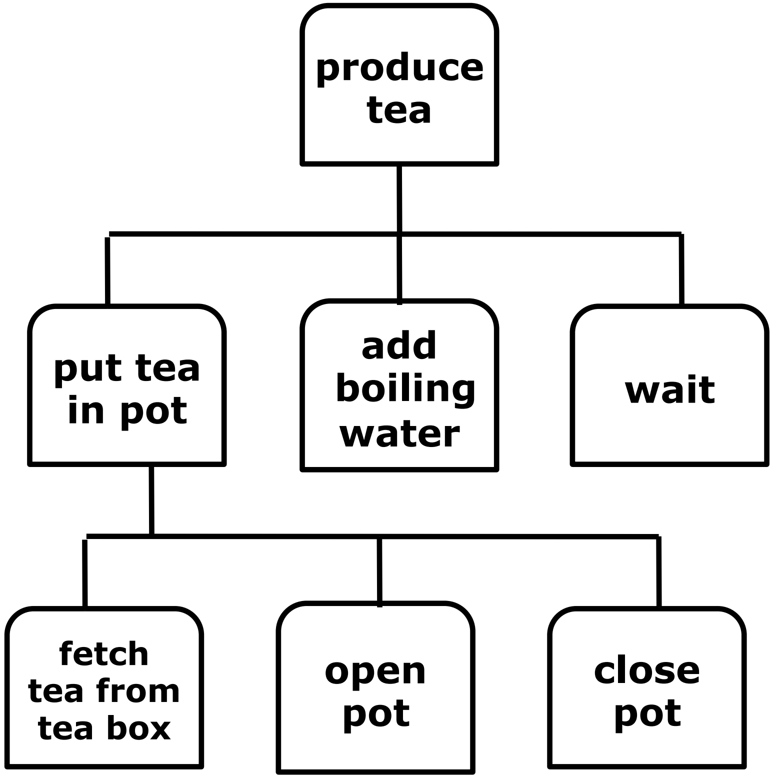
First Refinement of a Function Tree

```
Produce Tea
Put tea in pot
Add boiling water
Wait
```



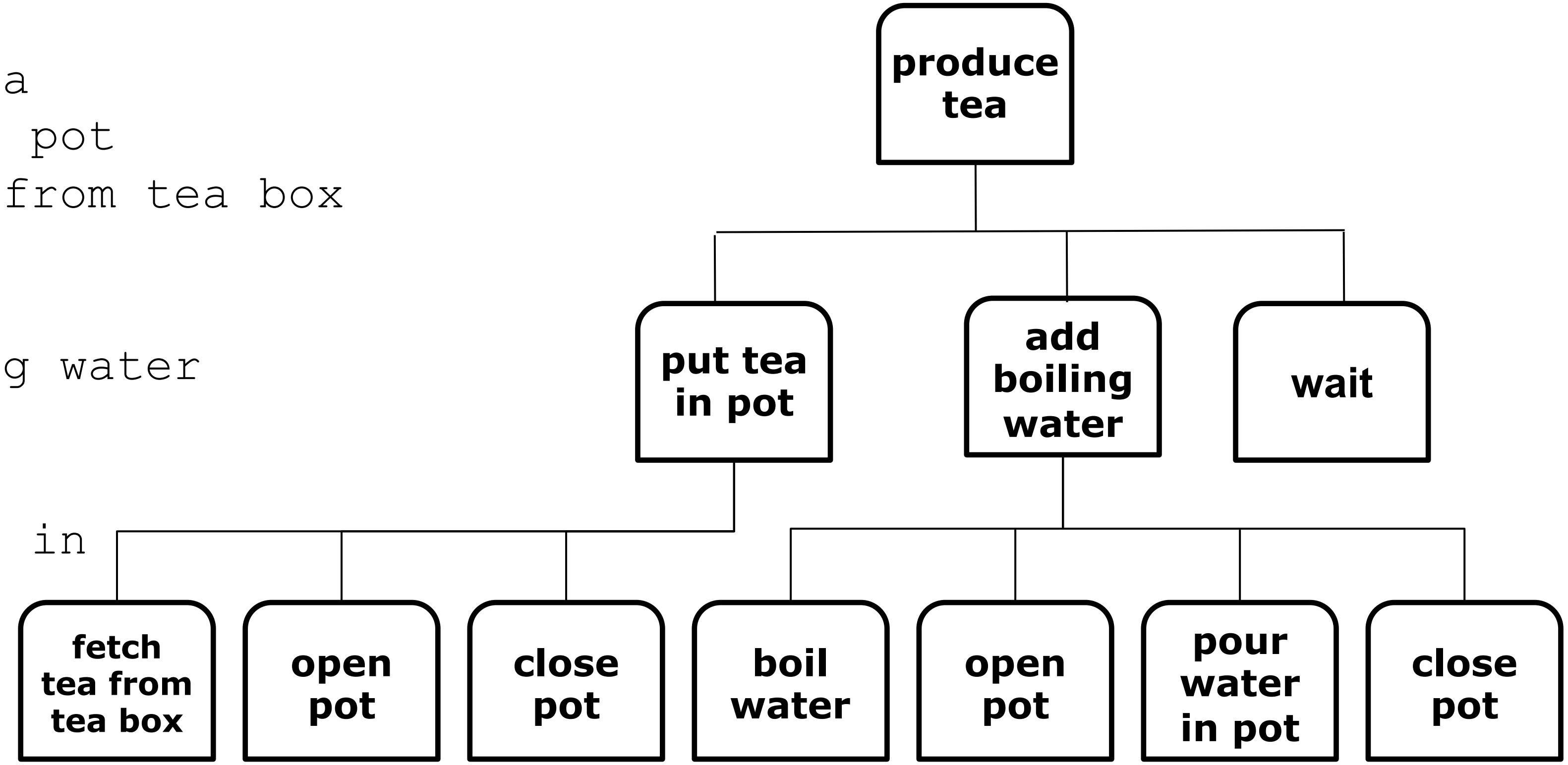
Second Refinement of a Function Tree

Produce Tea
Put tea in pot
Fetch tea from tea box
Open pot
Close pot
Add boiling water
Wait



Third Refinement of a Function Tree

```
Produce Tea
Put tea in pot
Fetch tea from tea box
Open pot
Close pot
Add boiling water
Boil water
Open pot
Pour water in
Close pot
Wait
```



Function Trees

- Function trees can also be derived by a 1:1 mapping from a functional requirements tree (see ZOPP requirements analysis lecture)
- **Stepwise Refinement** works usually top-down
  - But also middle-out and bottom-up possible
- Development of the “subfunction-of” relationship
  - “subfunction-of” is a part-of for functions: the function has which parts (subfunctions)?
  - Usually implemented by call relationship (call graph)
- Functions are **actions**, if they work on *visible* state
  - In functional design, state is disregarded
  - State is important in action-oriented design, actions are usually related to state transitions!

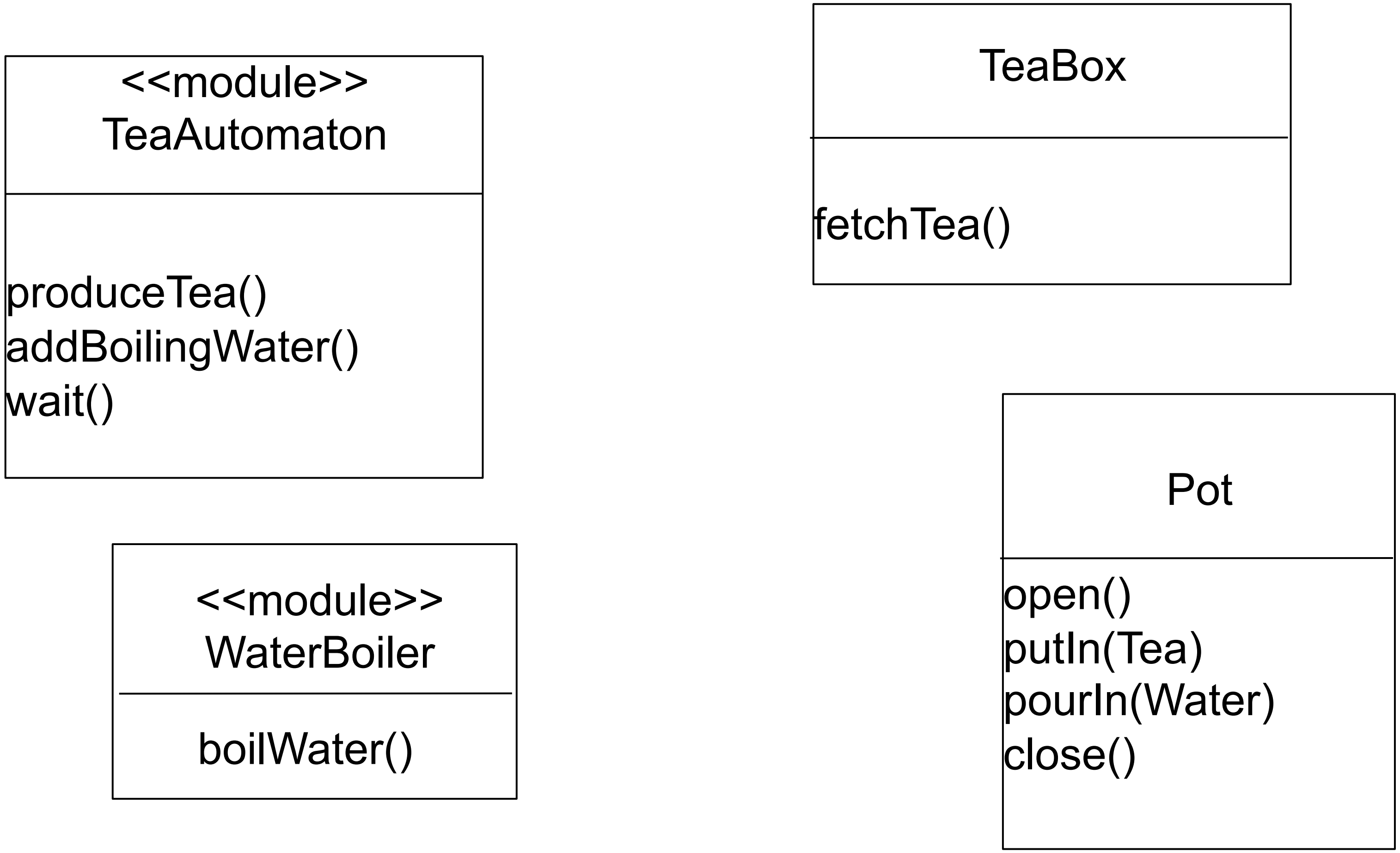
Grouping Functions to Modules

- Group functions according to cohesion: which function belongs to which other function?
- Minimize coupling of modules

```
Module Tea Automaton {
  Produce Tea

  Add boiling water
  Wait
}

Module Water Boiler {
 Boil water
}
```

```
Module Tea Box {
  Fetch tea from tea box
}

Module Pot {
  Open pot
  Put tea in pot
  Pour water in pot
  Close pot
}
```

Grouping Functions to Modules or Classes in UML



<<module>>
TeaAutomaton

produceTea()
addBoilingWater()
wait()

TeaBox

fetchTea()

<<module>>
WaterBoiler

boilWater()

Pot

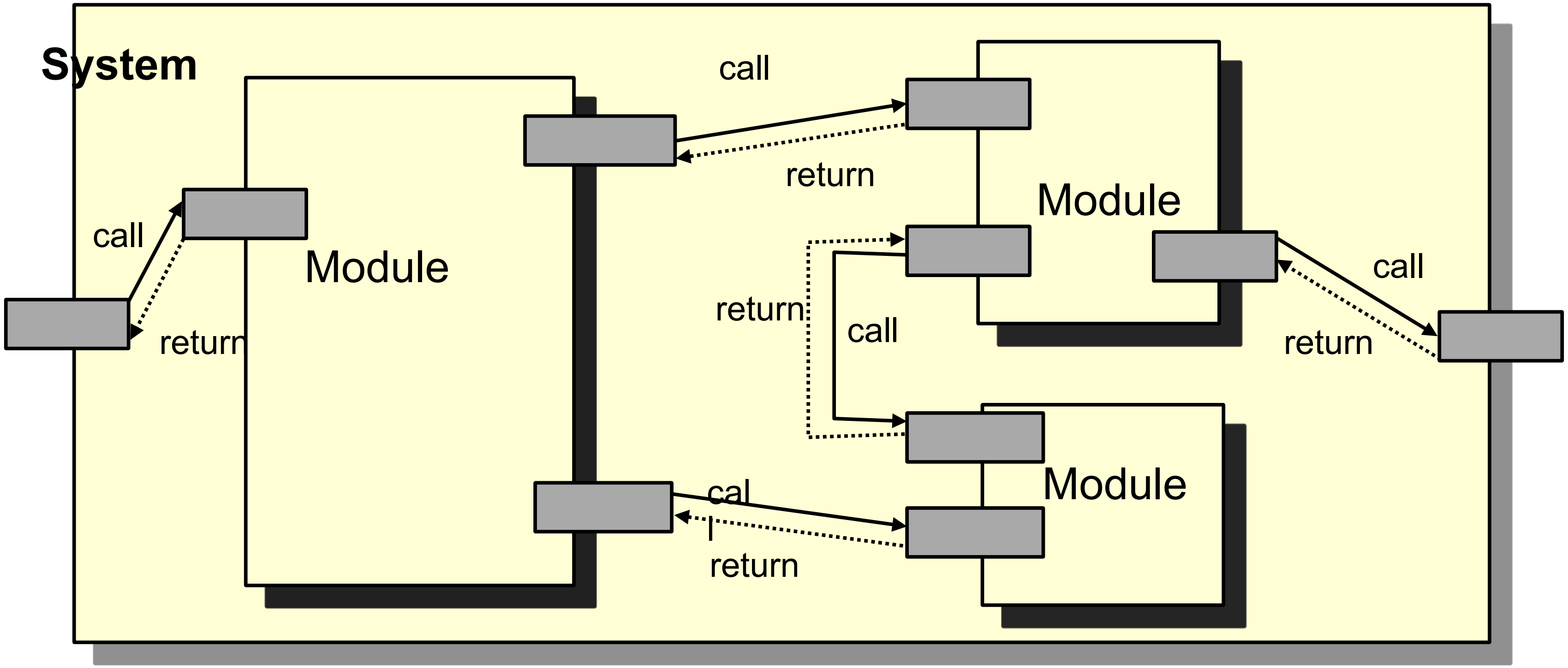
open()
putIn(Tea)
pourIn(Water)
close()

Heuristics

- Don't group too many items onto one abstraction level or into one module (**slim interface** principle)
- Technical classes (classes that do not stem from domain modeling) can be found in similar ways, by grouping cohesive functions together
- Identify **material** classes with CRUD interfaces (see TeaBox and Pot):
    - Create
    - Read
    - Update
    - Delete

Result: Call-Based Architectural Style

- Functional design leads to call-based architectural style



Why is Function-Oriented Design Important?

- Implementation of function trees in a functional language
  - ... or a modular language, e.g., Modula, C, or Ada-83.
- In some areas, object-oriented design and languages have severe disadvantages
- Employment in safety-critical systems:
  - Proofs about the behavior of a system are only possible if the architecture and the call graph are *static.* Then they can be used for proofs
  - Due to polymorphism, object-oriented systems have dynamic architectures (don't program your AKW with Java!)
- In embedded and real-time systems:
  - Object-oriented language implementations usually are slower than those of modular languages
  - ... and eat up more memory
- In high-speed systems:
  - Operating systems, database systems, compilers, ...

(Rep. from ST-1, left out here)

21.2 CHANGE-ORIENTED MODULARIZATION WITH INFORMATION HIDING

What is a Module?

- Software should, according to the divide-and-conquer principle, also physically be divided into basic parts, *modules*
  - A module groups a *set of functions or actions*
  - A module can be developed independently
    - errors can be traced down to modules
    - modules can be tested before assembling
  - A module can be exchanged independently
  - A module can be reused
- The terms *module* and *component* mean pretty much the same
  - Often, a module is a programming-language supported component
  - Here: a module is a simple component
  - In the past, different component models have been developed
  - A component model defines features of components, their compositionality, and how large systems are built with them (architecture)
  - In course “Component-based SE”, we will learn about many different component models

How To Modularize a System?

- Parnas principle of *change-oriented modularization (information hiding)* [Parnas, CACM 1972]:

- 1) Fix all design decisions that are likely to change
- 2) Attach each of those decisions to a new module
  - The design decision becomes the secret of a module (called *module secret)*
- 3) Design module interface that does not change if module secret changes

Information Hiding

- *Information hiding relies on module secrets*
- Possible module secrets:
  - How the algorithm works, in contrast to what it delivers
  - Data formats
  - Representation of data structures, states
  - User interfaces (e.g., AWT)
  - Texts (language e.g., gettext library)
  - Ordering of processing (e.g., design patterns Strategy, Visitor)
  - Location of computation in a distributed system
  - Implementation language of a module
  - Persistence of the data

Module Interfaces

- Should never change!
  - Well, at least be *stable*
- Should consist only of functions
  - State should be invisible behind interfaces
  - Direct access to data is efficient, but cannot easily be exchanged
    - e.g., emply set/get methods for accessing fields of objects
- Should specify what is
  - Provided (exported)
  - Required (imported)

Different Kinds of Modules

- Functional modules (without state)
  - sin, cos, BCD arithmetic, gnu mp,...
- Data encapsulators
  - Hide data and state by functions (symbol table in a compiler)
  - Monitors in the parallel case
- Abstract Data Types
  - Data is manipulated lists, trees, stacks, ..
  - New objects of the data type can be created dynamically
- Singletons
  - Modules with a singular instance of a data structure
- Data-flow processes (stream processors, filters)
  - Eating and feeding pipelines
- Objects
  - Modules that can be instantiated

What Have We Learned?

- When designing with functions, use function trees and subfunction decomposition
- When grouping to modules, fix module secrets
- The more module secrets, the better the exchange and the reuseability
  - Change-oriented design means to encapsulate module secrets
- Functional and modular design are still very important in areas with hard requirements (safety, speed, low memory)

Conclusion of Information-Hiding Based Design

We have seen how important it is to focus on describing *secrets* rather than interfaces or roles of modules.

When we have forgotten that, we have ended up with modules without clear responsibilities and eventually had to revise our design.

[Parnas/Clements, The Modular Structure of Complex Systems, CACM]

(repetition from ST-1)

11.3 FUNCTION-ORIENTED DESIGN WITH USE-CASE DIAGRAMS

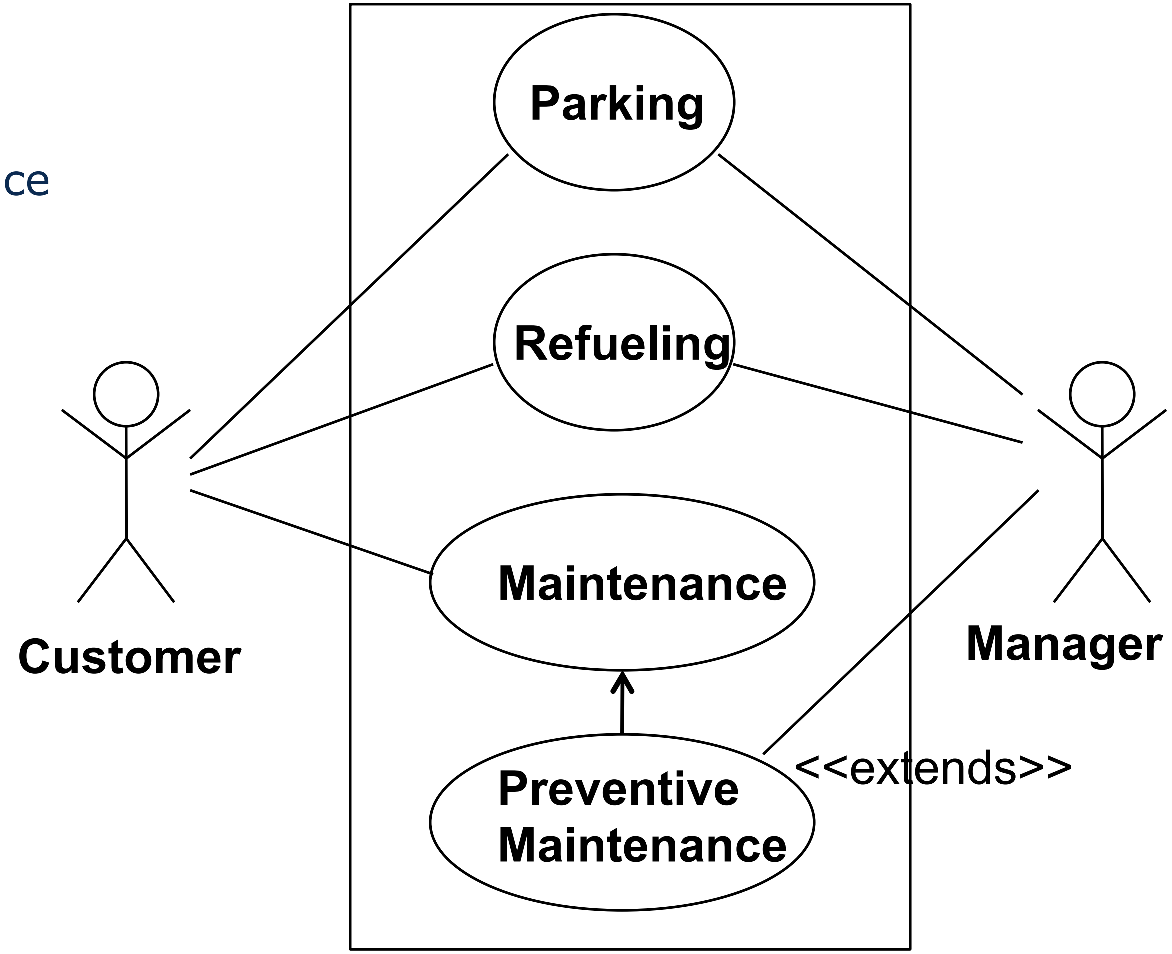
Use Case Diagrams

- Action-oriented design is similar to function-oriented design, but admits that the system has states.
  - It asks for the internals of the system
  - Actions require state on which they are performed (imperative, state-oriented style)
- Divide: finding subactions
- Conquer: grouping to modules and processes

- Example: Use Case Diagram (UCD)
  - A Use Case Diagram consists of several *use cases* of a system
  - A *use case* describes an application, a coarse-grain function or action of a system, in a certain relation with *actors*
  - A use case contains a *scenario sketch*
    - Pseudocode text which describes the functionality
  - Use Case diagrams can be used in Actino-Oriented Design, or in Object-Oriented Design

Example Service Station

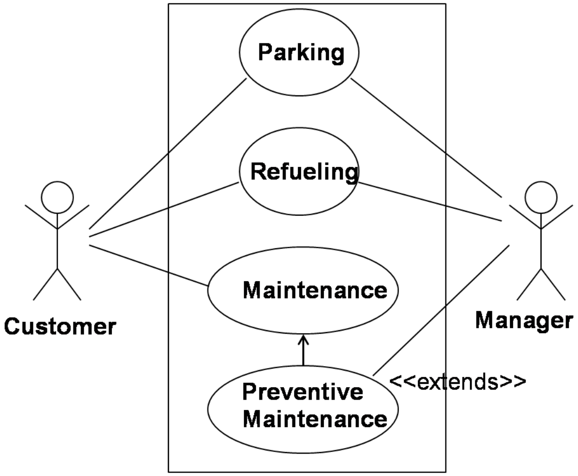
- A Service Station has 4 tasks [Pfleeger]
  - Parking
  - Refueling
  - Maintenance
  - Preventive Maintainance



Questions for Use Cases

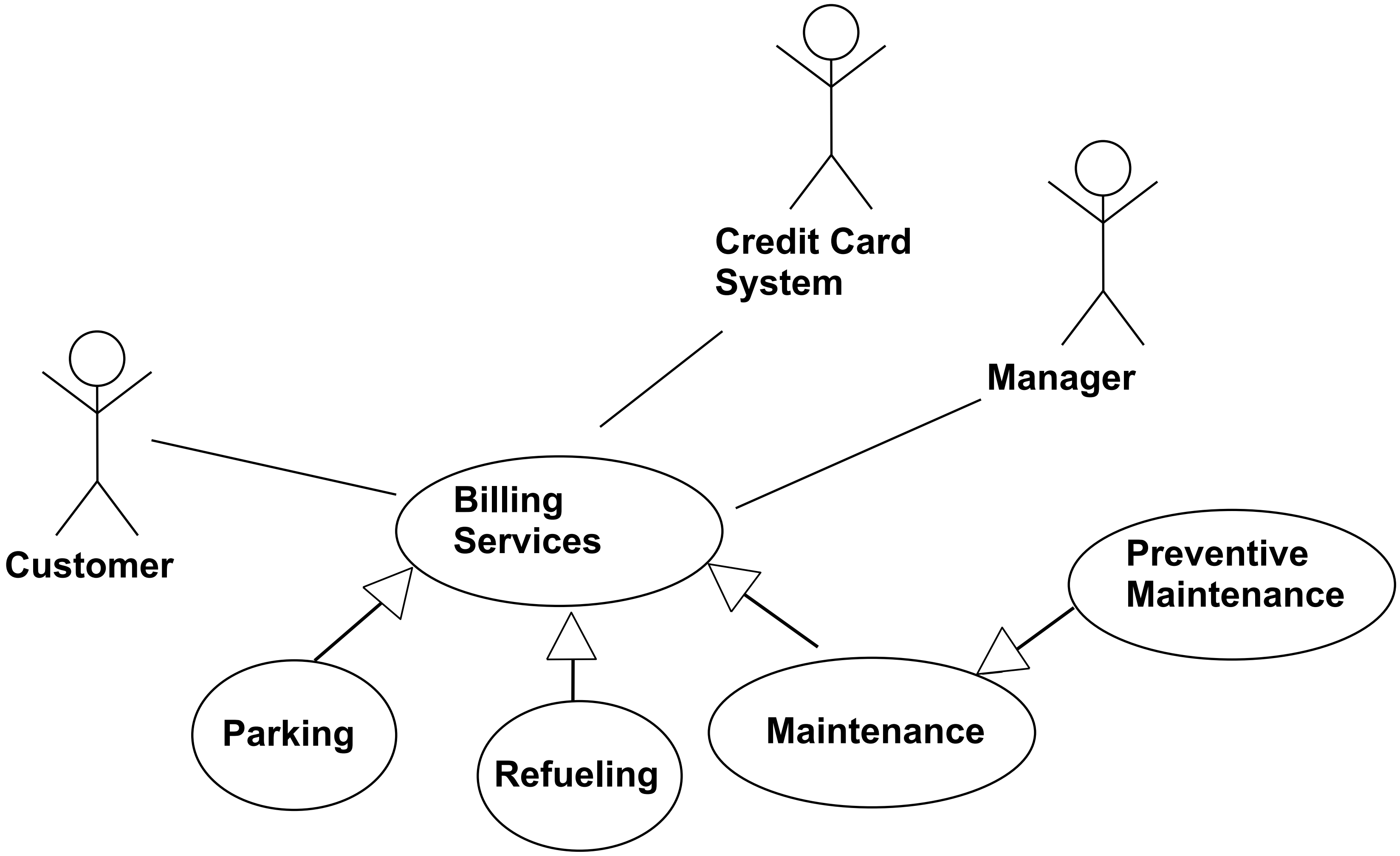
- What is the system/subsystem?
- Who is Actor?
  - A user
    - An active object
    - A person
    - A system
  - Must be external to the described system
- What are the Applications/Uses?
- What are the relations among Use Cases
  - Extends: Extend an existing use case (Inheritance)
  - Uses: Reuse of an existing use case (Sharing)

- Which
  - Users
  - External systems
  - Use
  - Need
- The system for which tasks?
- Are tasks or relations to complex?

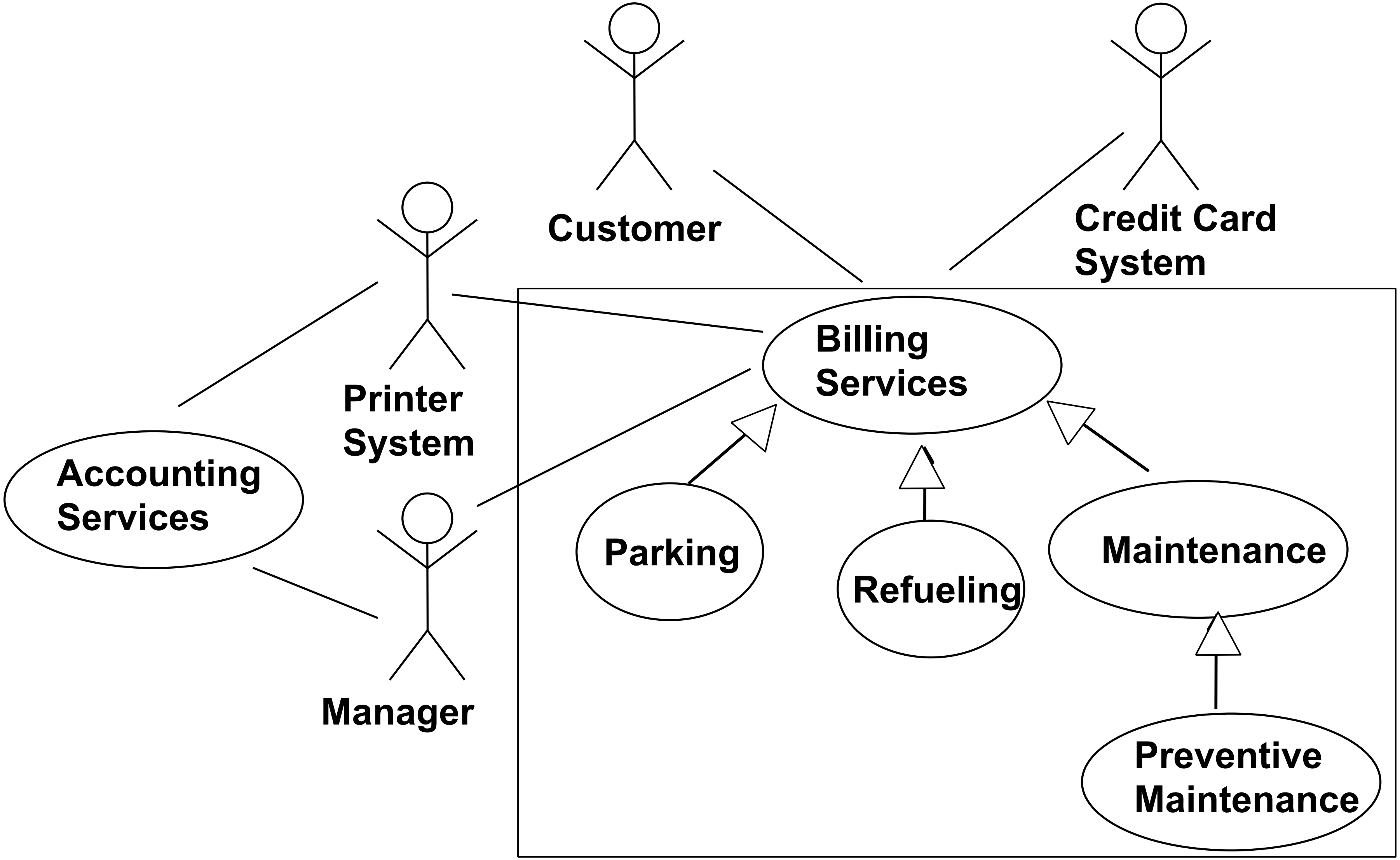


Refinement Service Station

- We introduce an abstraction of the services

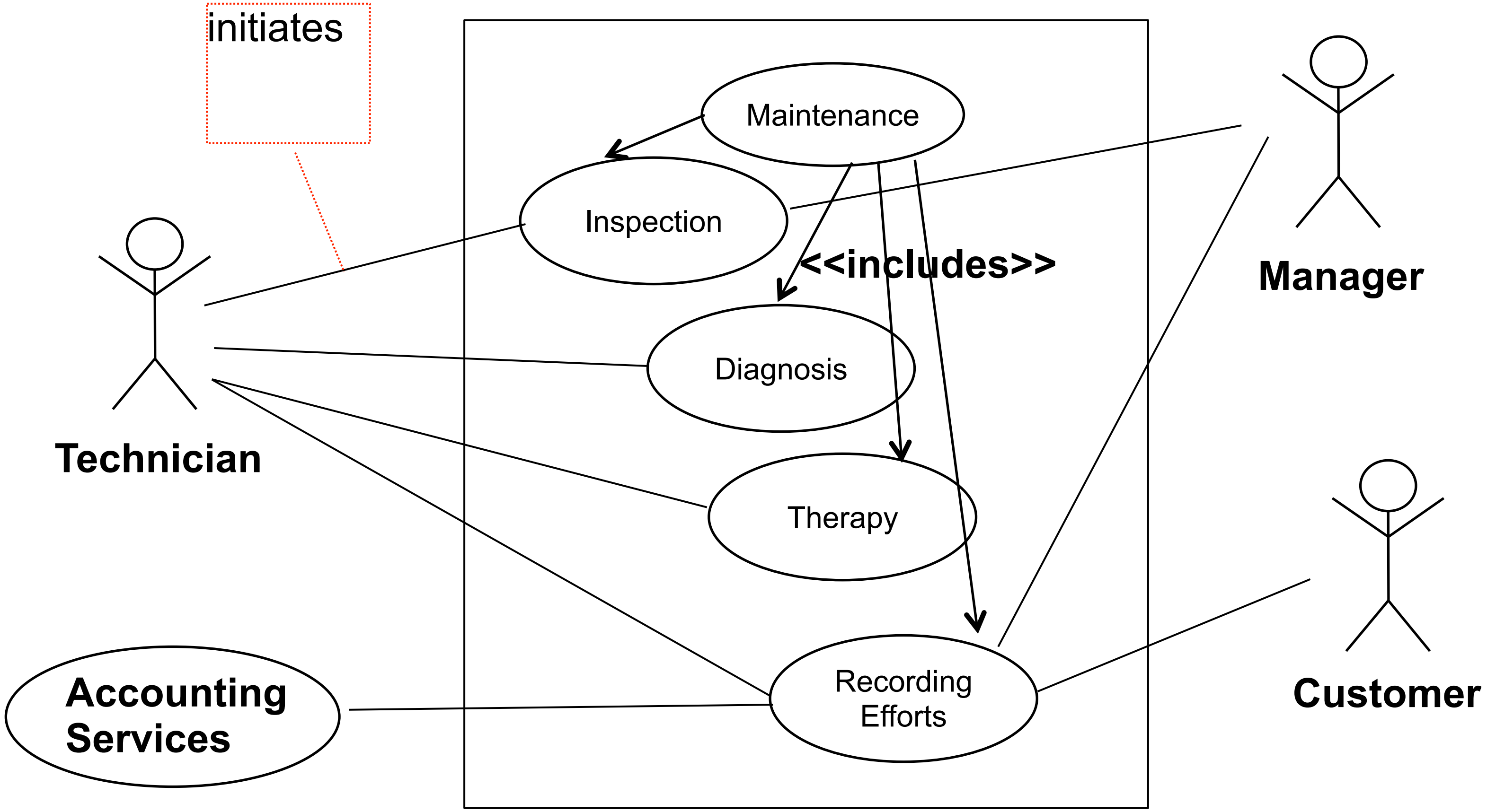


Second Refinement Service Station



Third Refinement Service Station

- The <<includes>> relationship allows for decomposition of a use case. <<includes>> is a form of <<part-of>>



Consistency Checking Check List Use Case Diagrams

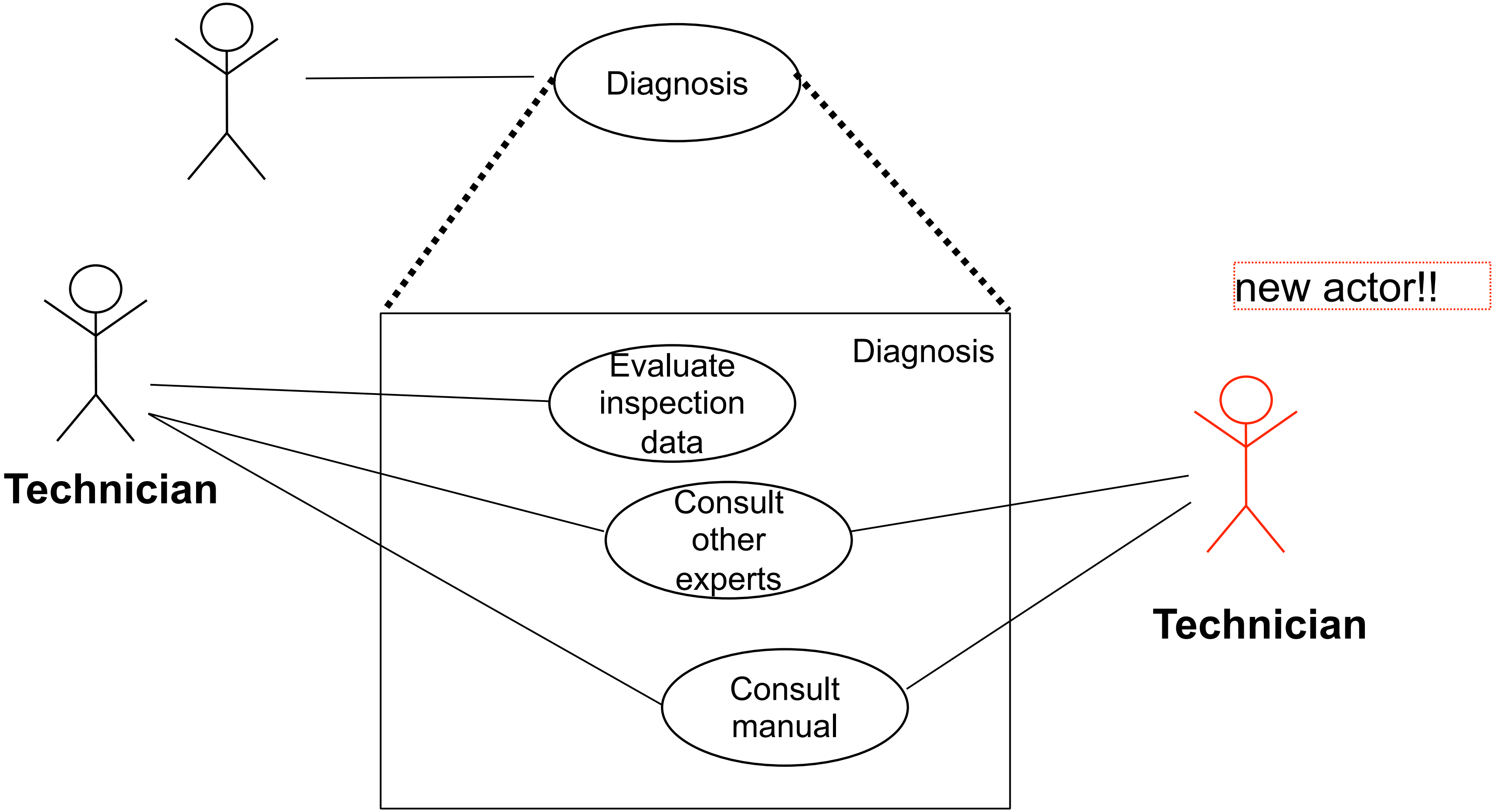
- One diagram
  - Clarity
  - Simplicity
  - Completeness
  - Match the stories of the customer?
  - Missing actors?
- Several diagrams
  - Which actions occur in several diagrams? Are they specified consistently?
  - Should actors from shared actions be replicated to other UCD?

How To Go On from a Use Case Diagram

- There are several ways how to reach a design from a use case diagram
  - *Hierarchical refinement* of the actions into UCD of second level, yielding a reducible specification
    - Disadvantage of UCD: Hierarchical refinement is sometimes difficult, because new actors have to be added
    - Leads to a correction of the top-level UCD
  - *Action tree method*: action-oriented method to refine the use case actions with an action tree
  - *Collaboration diagram method*: object-oriented method to analyse paths in the use case diagram with communication (collaboration) diagrams (see later)

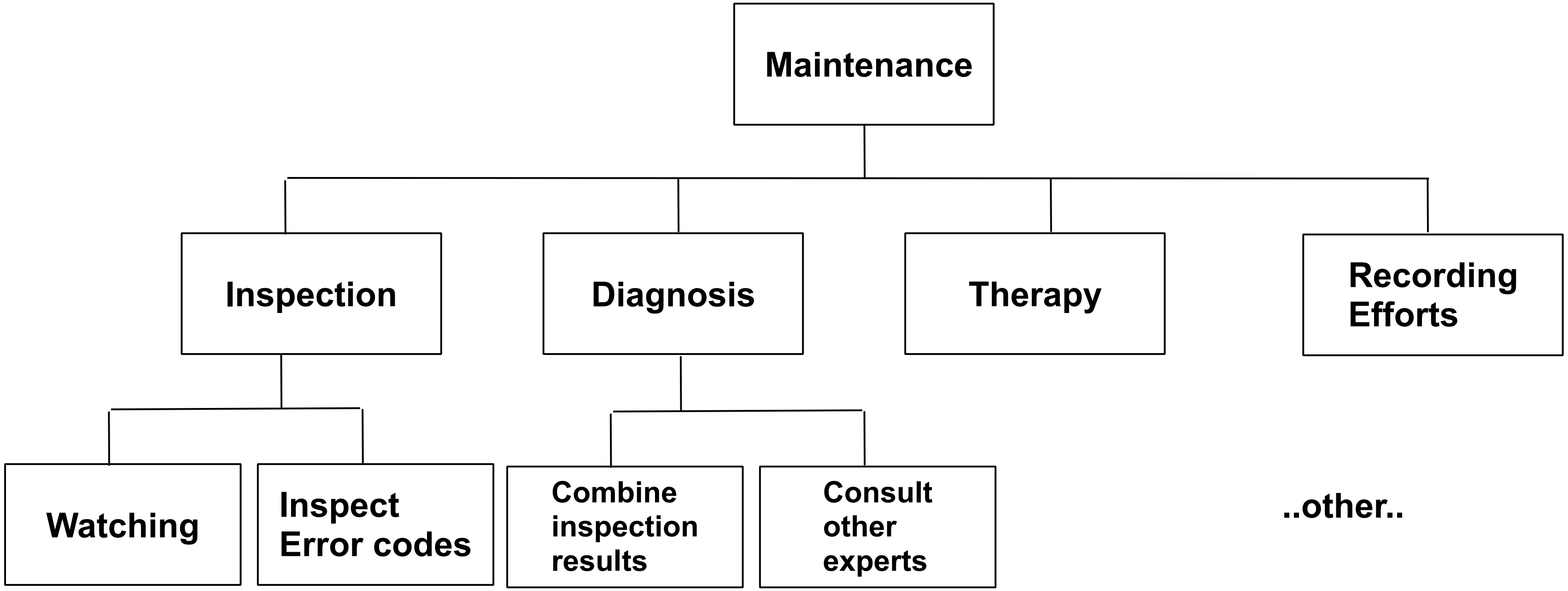
Hierarchical Refinement of a Use Case

- Often, new actors have to be added during refinement



Deriving an Function Tree from a Use Case

- DomainTransformation: From a UCD, set up a function or action tree
  - <<includes>> expresses a part-of hierarchy of function
- Refinement: Refine the functions by decomposition



Benefits of Use Cases

- Use cases are good for
  - Documentation
  - Communication with customers and designers -> Easy
  - Are started for the first layout of the structural model
    - To find classes, their actions, and relations
  - In eXtreme Programming (XP), use cases are called „stories"
    - which are written down on one muddy card
    - collected
    - and implemented one after the other
  - XP does not look at all use cases together, but implements one after the other

The End