Principles of Compiler Construction

了解

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Lecture 10. Run-Time Environment

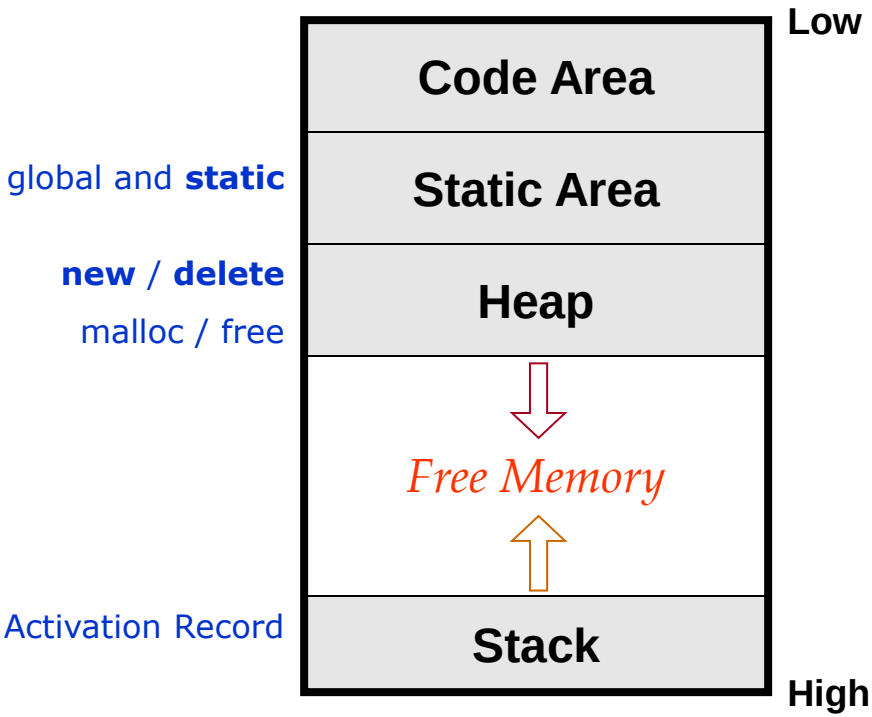
1. Storage Management
2. Stack and Activation Record
3. In-Process Communication
4. Heap Management
5. Garbage Collection

Overview

For example, the subprogram abstraction needs the support by a run-time stack

1. Storage Management

- Typical storage layout and allocation



2. Stack and Activation Record

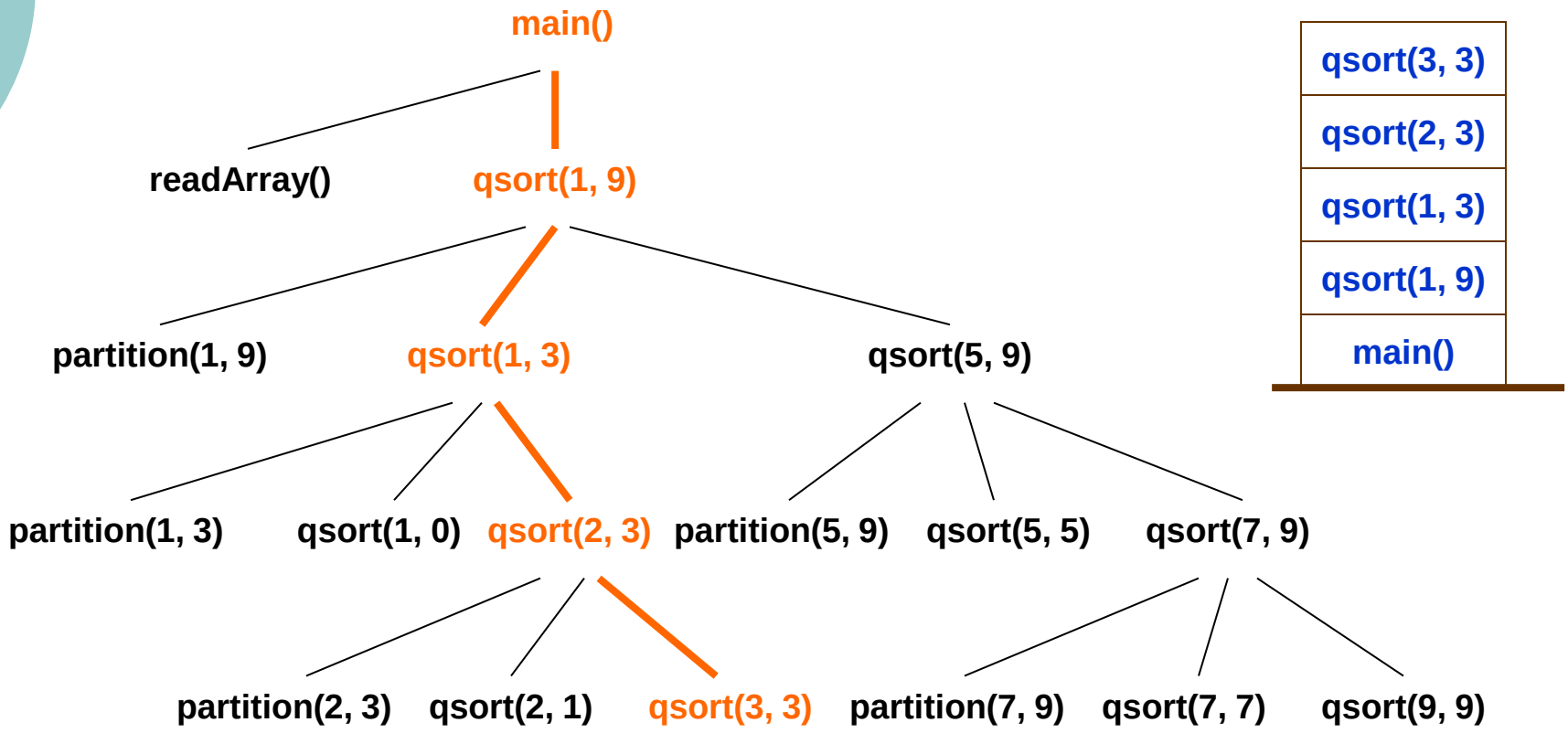
- Support the subprogram abstraction
  - Also called **Control Stack**.
- General design rules
  - **Activation on Demand**

```
(1) program sort(input,output);
(2)     var   a : array[0..10] of integer;
(3)           x : integer;
(4)     procedure readarray;
(5)           var i : integer;
(6)           begin ... a ... end { readarray };
(7)     procedure exchange(i,j : integer);
(8)           begin
(9)                 x := a[i]; a[i] := a[j]; a[j] := x
(10)          end { exchange };
(11)    procedure quicksort(m,n : integer);
(12)          var k,v : integer;
(13)          function partition(y,z:integer) : integer;
(14)                var i,j : integer;
(15)                begin···a ···
(16)                      ···v ···
(17)                      ···exchange(i,j); ···
(18)                end { partition };
(19)          begin···end { quicksort };
(20)    begin···end { sort }.
```

PKU-1990
pp. 294

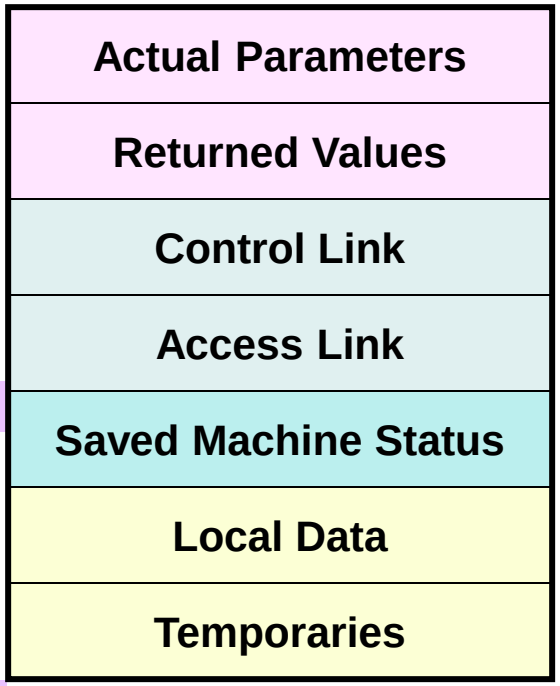
Activation Tree

- Activation tree and run-time stack



Activation Record (or Frame)

- Typical organization of activation records



set by Caller, register preferred

set by Callee, register preferred

pointer to Caller's AR

pointer to the outer AR

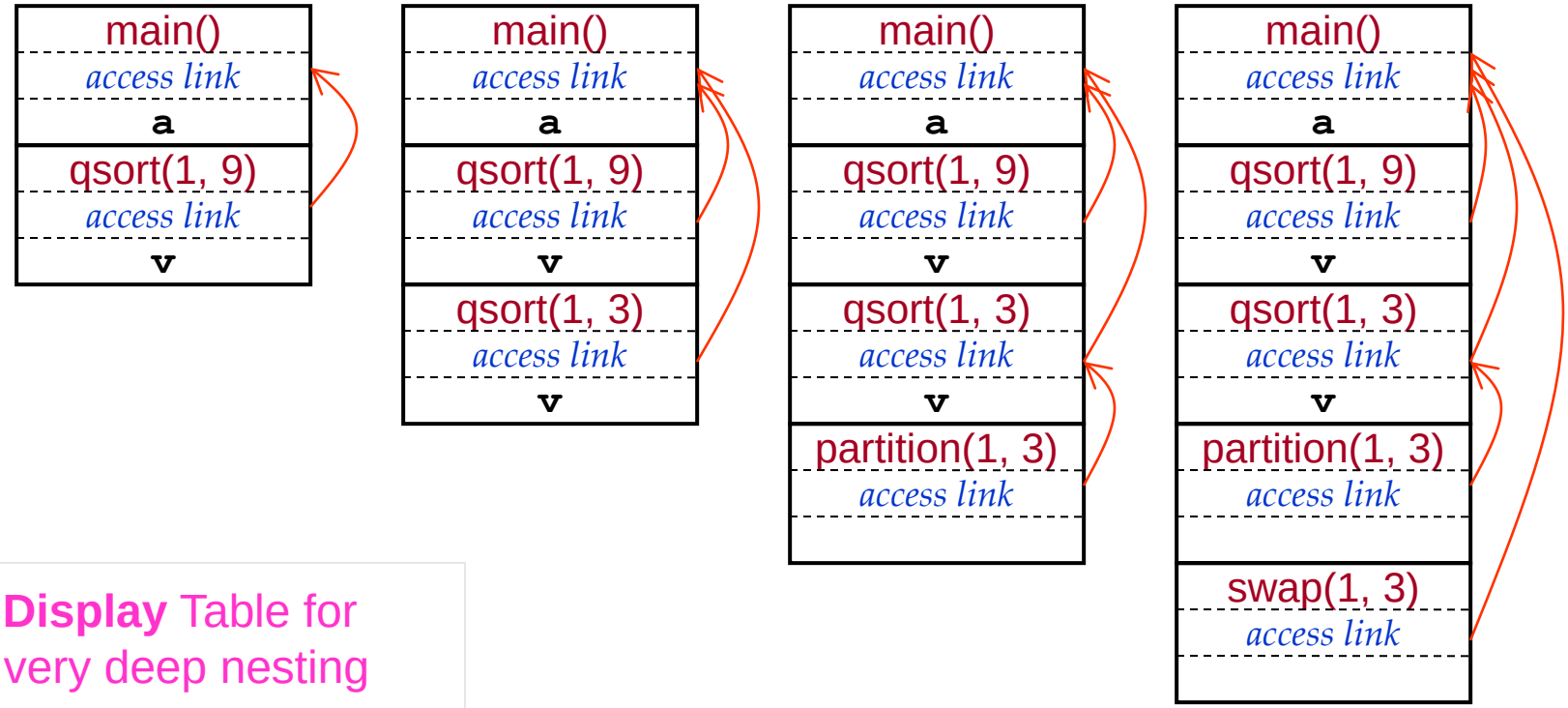
return address & registers

user defined

compiler generated

Access Link

- Access link in the quick sort example



Display Table for very deep nesting

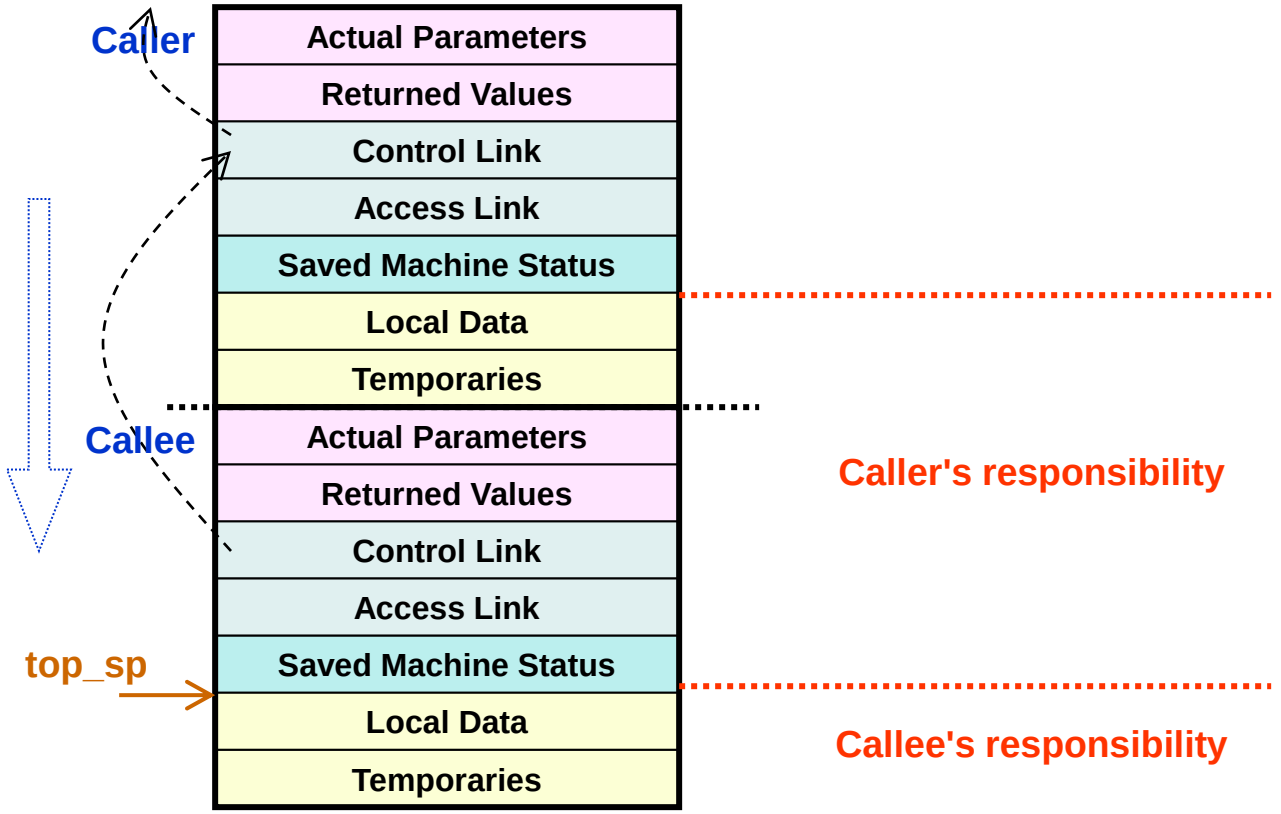
3. In-Process Communication

- Implementation of procedure calls
  - **Calling sequence**
    - Allocate an activation record
    - Enter information into fields
    - ...
  - **Return sequence**
    - Restore the state of the machine
    - Continue the execution of Caller
    - ...

In-Process Communication
vs.
Inter-Process Communication (**IPC**)

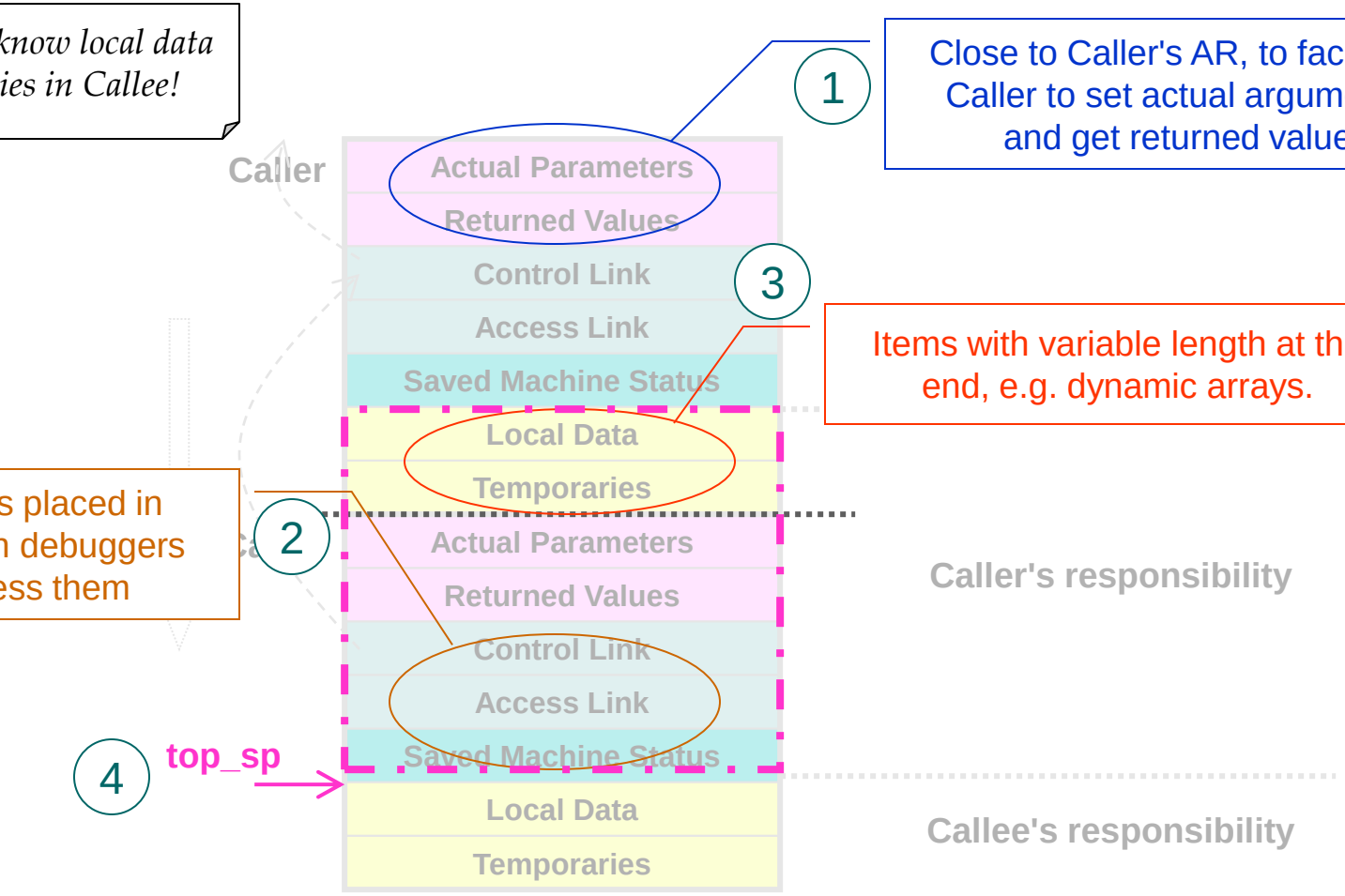
Caller vs. Callee

- Implementation of procedure calls



Activation Record Design

Caller does not know local data and temporaries in Callee!



Calling Sequence

- A typical calling sequence
  1. Caller evaluates the actual arguments.
  2. Caller stores a return address and old **top_sp** to Callee's activation record.
  3. Caller pushes an activation record to the stack (increments **top_sp**).
  4. Callee saves the register values and other status information.
  5. Callee initializes local data and begin the execution.

Return Sequence

- A typical return sequence
  1. Callee sets the return value.
  2. Callee pops the activation record (decrements **top_sp**).
  3. Callee restores the registers.
  4. Callee goes to the return address in the status field.
  5. Caller gets the return value (even **top_sp** has been decremented).

4. Heap Management

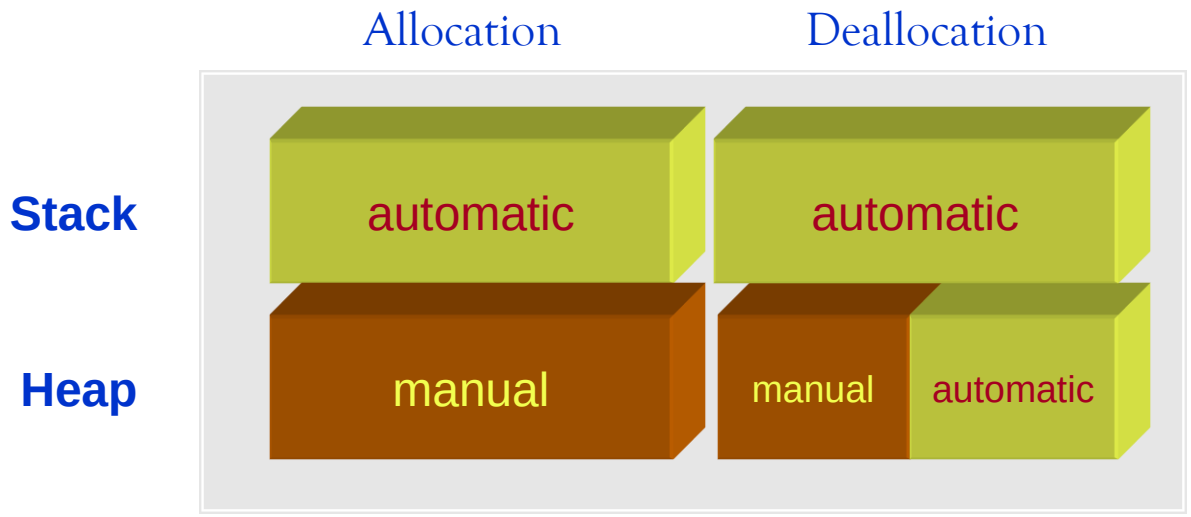
- The critical problem of heap management is **fragmentation**
  - Both **time** efficiency and **space** efficiency are considered.
  - How to minimize fragmentation?

Multithreading

- Multithreading programs share a common heap
  - Of course each program must have its own control stack.
- Communication between procedures in different threads are easier than IPC
  - The shared heap can be utilized in communication.

5. Garbage Collection

- Automatic Memory Management?



Terminology

- Garbage
  - Objects that can not be referenced.
- Memory leaks
  - Maybe the most troublesome bugs.
  - Does Java have memory leaks?
- Profiler (Rational Purify)
  - **JVMPI**: JVM Profiler Interface since JDK 1.2 (Java 2).
  - **JVM TI**: JVM Tool Interface since JDK 5.0
- Garbage collection
  - Pros and cons?
  - High-Level Abstraction in Languages.

Great expectation to **JVMGCI**

Performance Metrics

- Overall Execution Time
- Space Usage
  - Avoid fragmentation
- Pause Time
  - Critical to real-time applications
- Program Locality
  - The program spend most of time executing a relative small code fraction and touching only a small data fraction. (90% time on 10%code)
  - Locality facilitate the utilization of memory hierarchy (register, cache, memory, disk, etc.).
  - Garbage collection can improve both temporal locality and spatial locality.

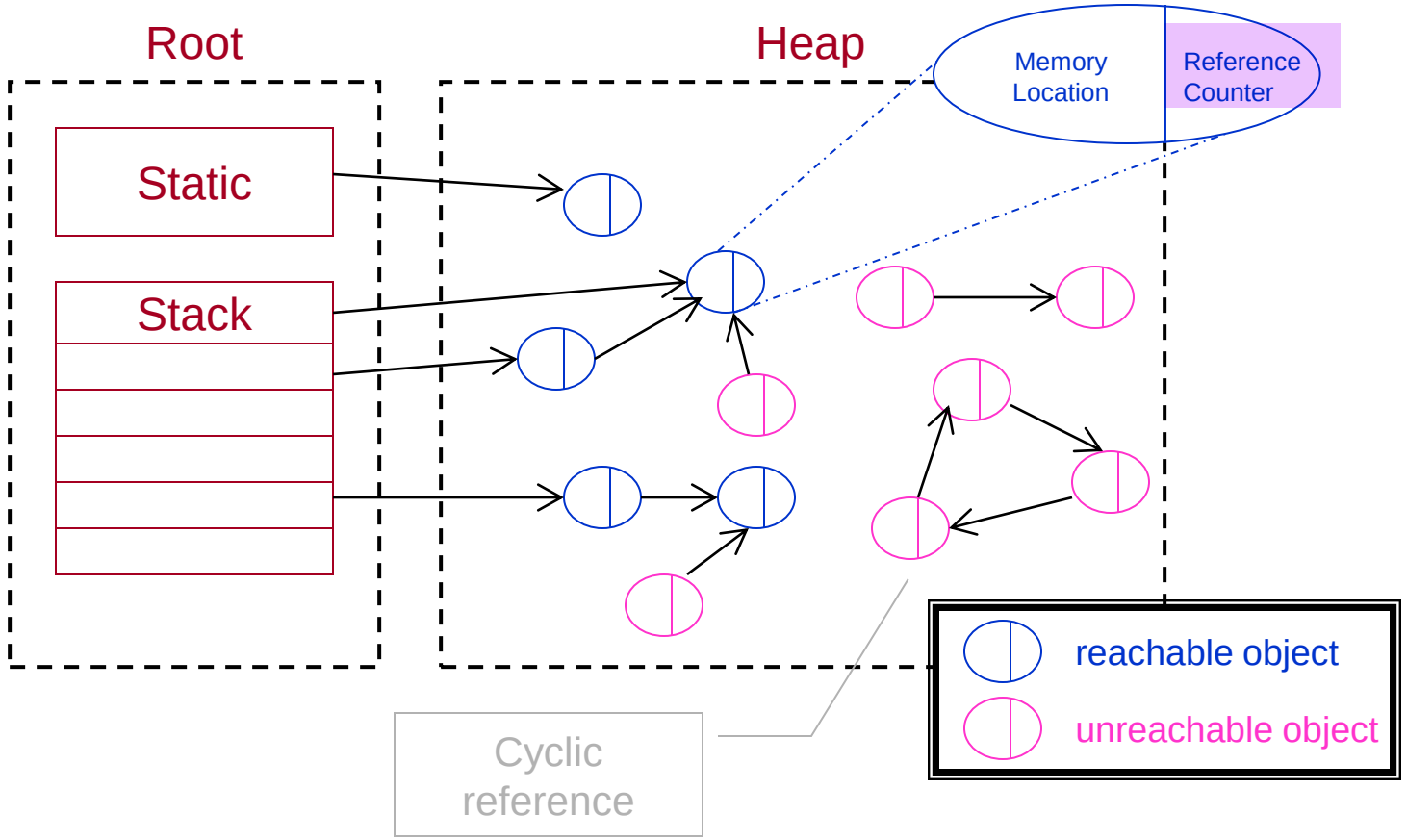
Garbage Collection Algorithms

- Reference counting (immediately)
- Trace-based algorithms (periodically)
  - Basic Mark-and-Sweep
  - Baker's Mark-and-Sweep
  - Basic Mark-and-Compact
  - Cheney's Copying Collector
- Short-pause algorithms
  - Incremental garbage collection
  - Incremental reachability analysis
  - Partial collection
  - Generational garbage collection

Reference Counting

新被指对象 原被指对象

- counter++ vs. counter--



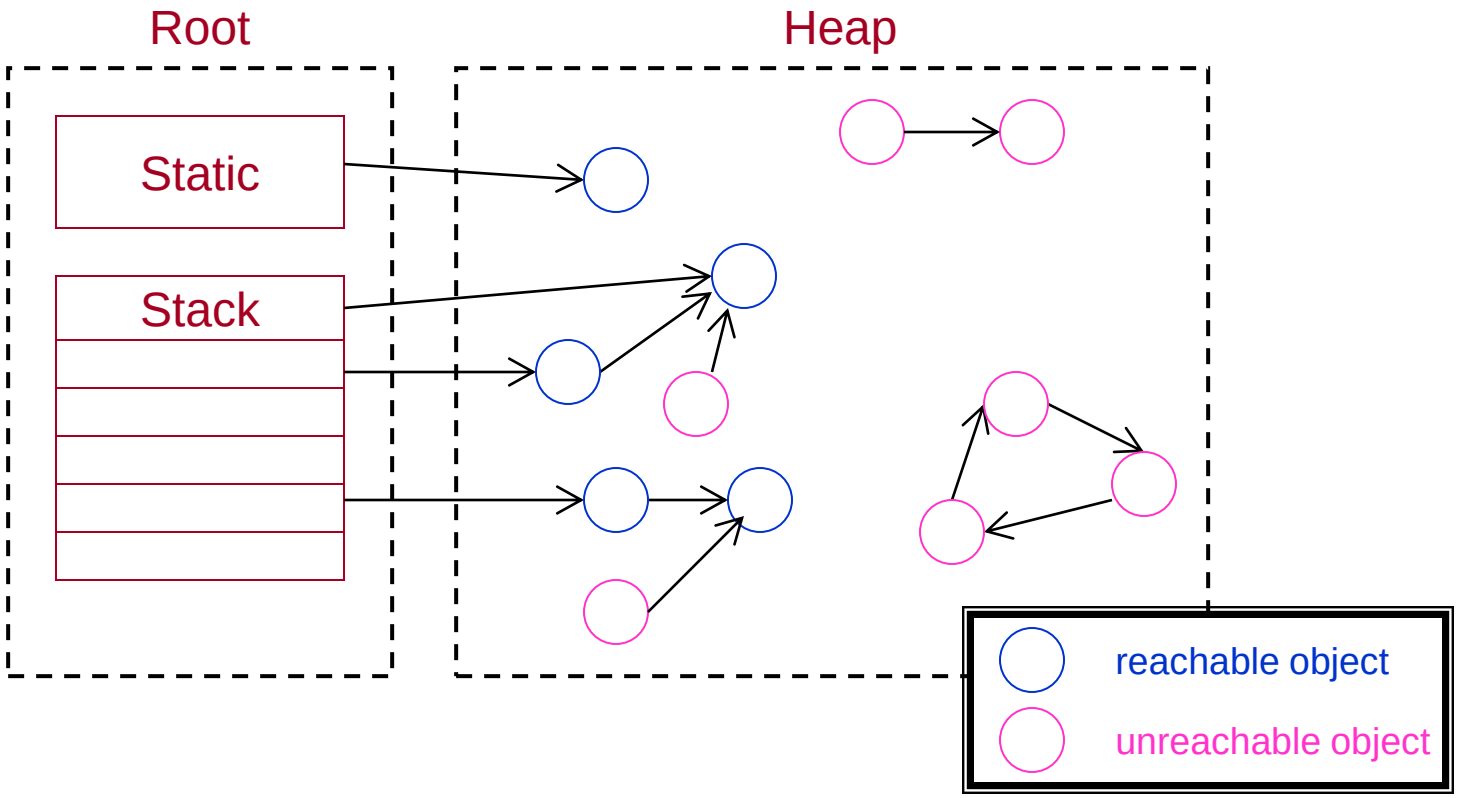
Reference Counting (cont')

- Pros
  - Simple
  - Incremental collection
  - Immediate collection
- Cons
  - Can not collect unreachable cyclic data structures.
  - Additional operations lead to expensive overhead. `++ & --`
    - Depends on computation, not only on number of objects.

Mark-and-Sweep

记录能不能访问

- 2 steps: trace (mark), then sweep.

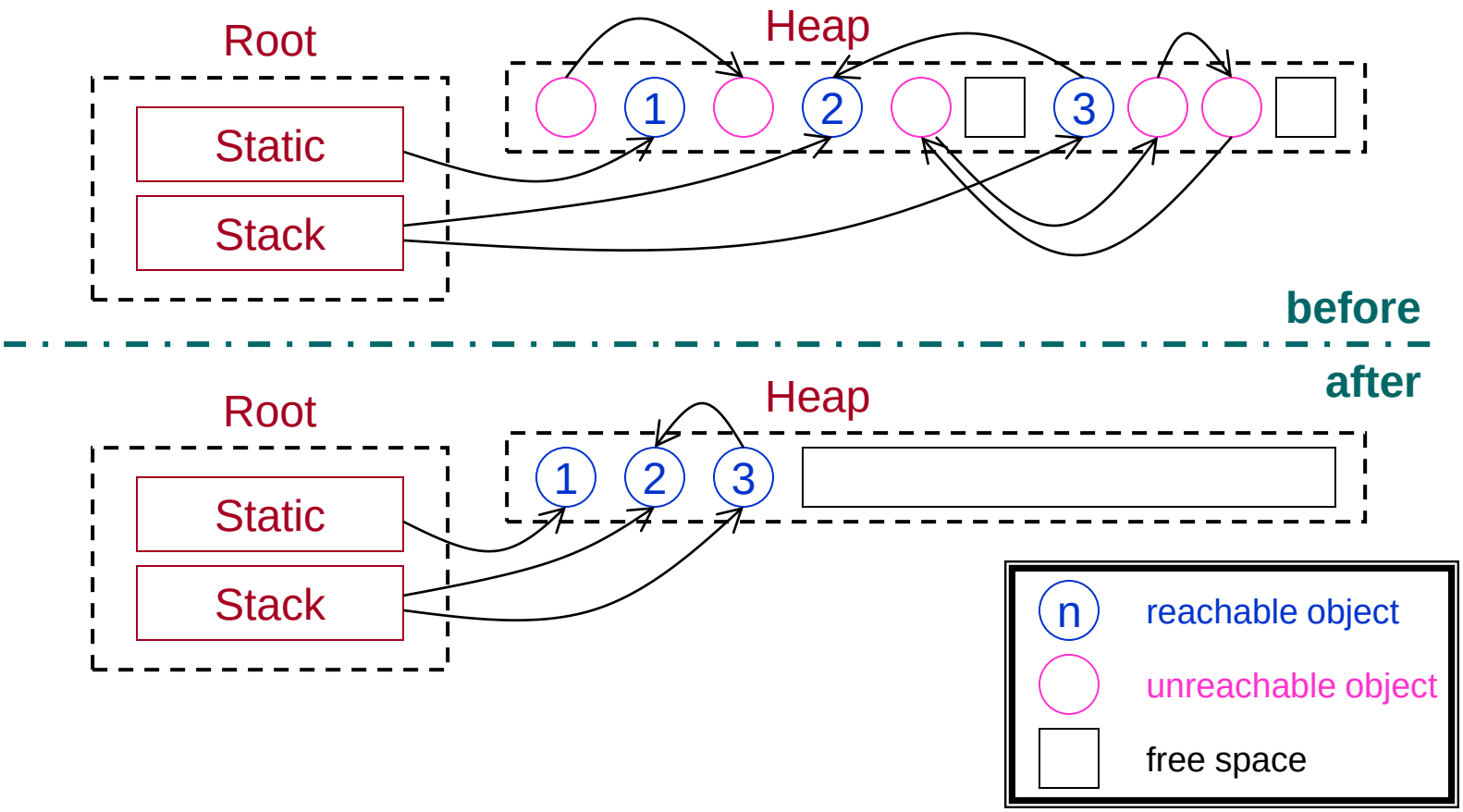


Mark-and-Sweep (cont')

- Pros
  - High efficiency if little garbage exist.
  - Be able to collect cyclic references.
- Cons
  - Low efficiency with large amount of garbage
    - Improvement by H. Baker (1992)
    - Keep a list of all allocated objects.
  - Pause of the mutator (program) make it difficult to apply to real-time applications. 两个程序并行
  - Leads to fragmentation in the heap.

Mark-and-Compact

- Before vs. after

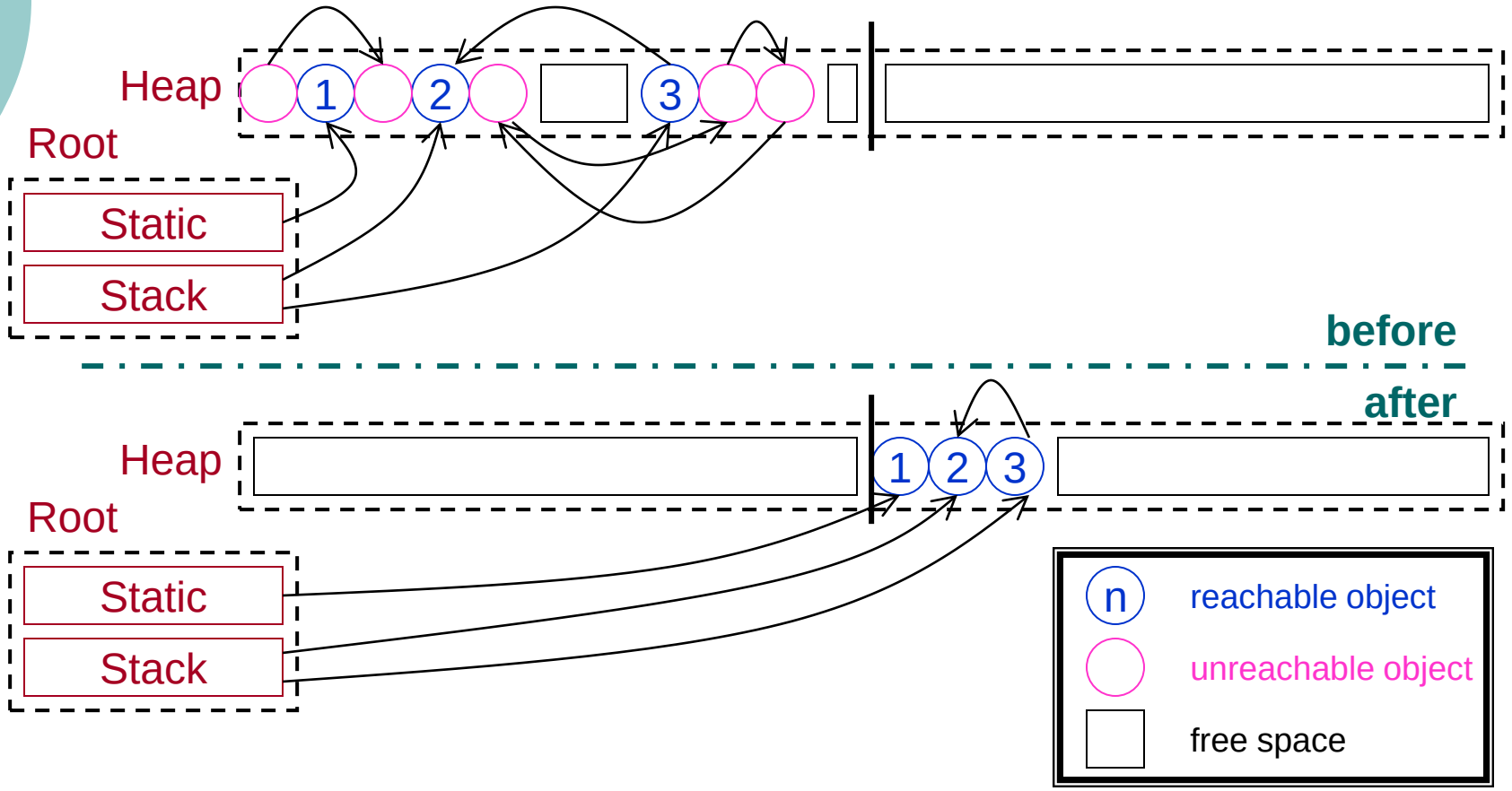


Mark-and-Compact (cont')

- 3 steps
  1. Marking phase: similar to Mark-and-Sweep.
  2. For each reachable object, computes a new address from the low end of the heap.
  3. Copies objects to new locations and updates all references in the root area and objects.
- Pros and cons
  - Pro: avoids fragmentation.
    - So as to improve the space usage and program locality.
  - Con: step 3 (copying in the compacting) is expensive.
    - Updating references is simple and fast.

Copying Collector

- Before vs. after



Copying Collector (cont')

- Heap is partitioned into 2 semispaces
  - Reachable objects are moved as soon as they are discovered.
  - Does not touch any unreachable objects.
- Pros
  - More efficient and popular.
- Cons
  - Only a half of heap memory can be utilized.

Comparing Costs

- Mark-and-Sweep
  - Number of chunks in the heap
- Baker's Improvement
  - Number of reached objects
- Mark-and-Compact
  - Number of chunks in the heap +
  - **Total size of the reached objects**
- Copying Collector
  - **Total size of the reached objects**

Generational Garbage Collection

- Motivation
  - Difference between handling short-lived and long-lived objects.
- Approach
  - Objects are divided into multiple generations based on some criteria.
    - Usually related to the age of the objects.
  - GC can be done at different time intervals and even using different techniques, based on the generations.

Implementation in JVM

- Use a two-generation (young and old) approach
- Young generation: copying collector
  - Newly created objects tend to die young.
- Old generation: Mark-and-Compact
  - A good mix of technologies for performance

Exercise 10.1

- Surf the Internet and write a short paper to compare GC on Java platform with GC on Microsoft .Net platform.

Further Reading

- Dragon Book, 2nd Edition (DBv2)
  - Comprehensive Reading:
    - Section 7.2-7.3 on control stack and activation records.
    - Section 7.4 on heap management.
    - Section 7.5-7.7 on garbage collection.
  - Skip Reading:
    - Section 7.1 on introduction to storage management.
    - Section 7.8 on advanced topics in garbage collection.
    - More on garbage collection: R. Jones and R. Lins. **Garbage Collection: Algorithms for Automatic Dynamic Memory Management**. Wiley, 1996, ISBN 0-471-94148-4

Enjoy the Course!