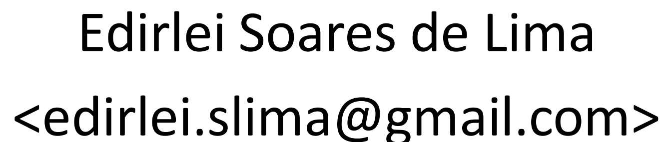
Artificial Intelligence

Lecture 08 – Behavior Trees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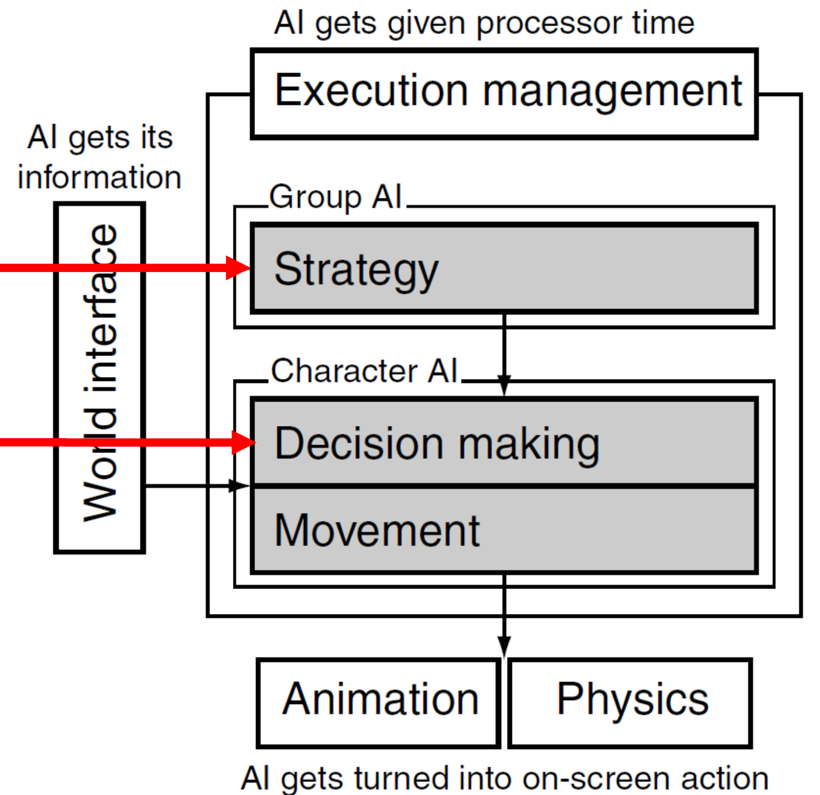
Game AI – Model

- Pathfinding
- Steering behaviours
- Finite state machines
- Automated planning
- **Behaviour trees**
- Randomness
- Sensor systems
- Machine learning



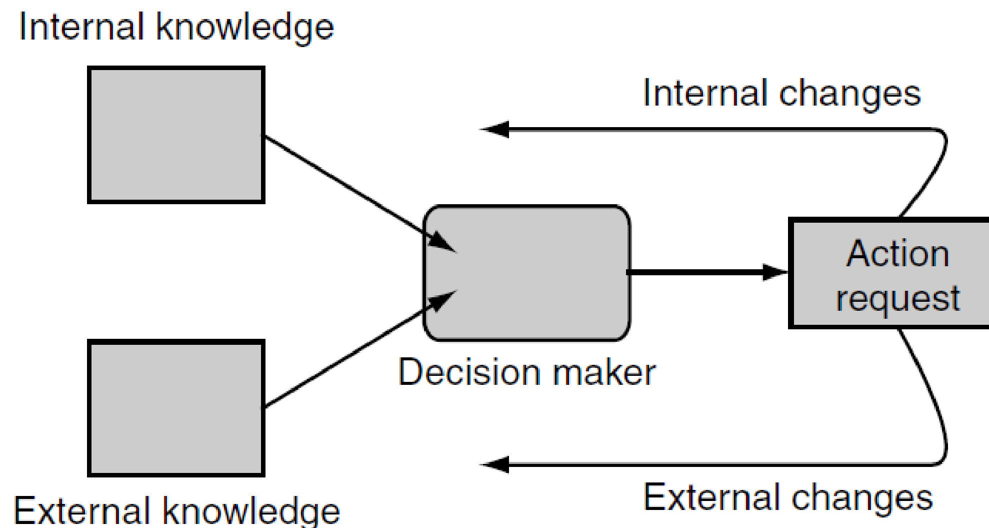
Decision Making

- In game AI, decision making is the ability of a character/agent to decide what to do.

- The agent processes a set of information that it uses to generate an action that it wants to carry out.
  - **Input:** agent's knowledge about the world;
  - **Output:** an action request;

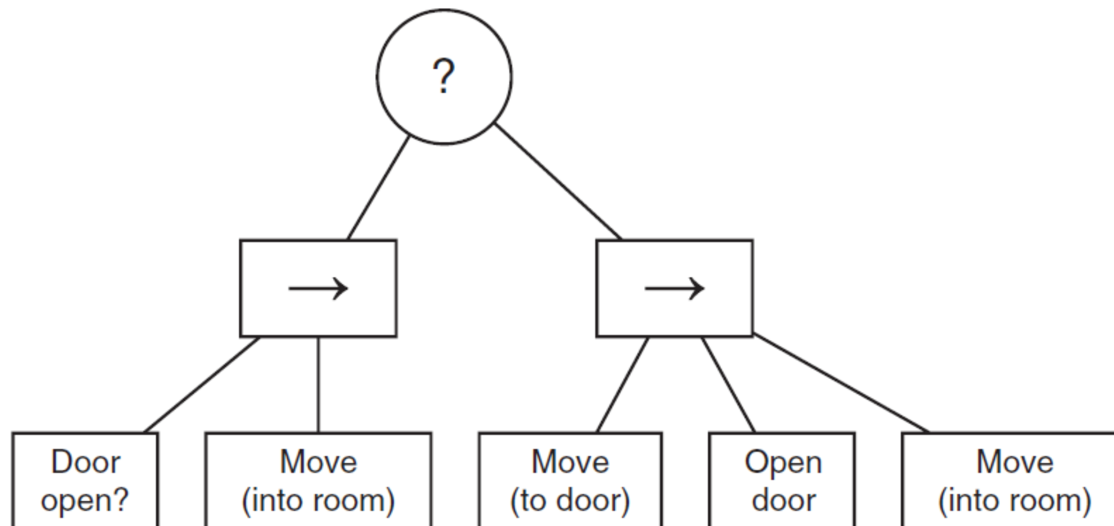
Decision Making

- The knowledge can be broken down into external and internal knowledge.
  - **External knowledge:** information about the game environment (e.g. characters' positions, level layout, noise direction).
  - **Internal knowledge:** information about the character's internal state (e.g. health, goals, last actions).



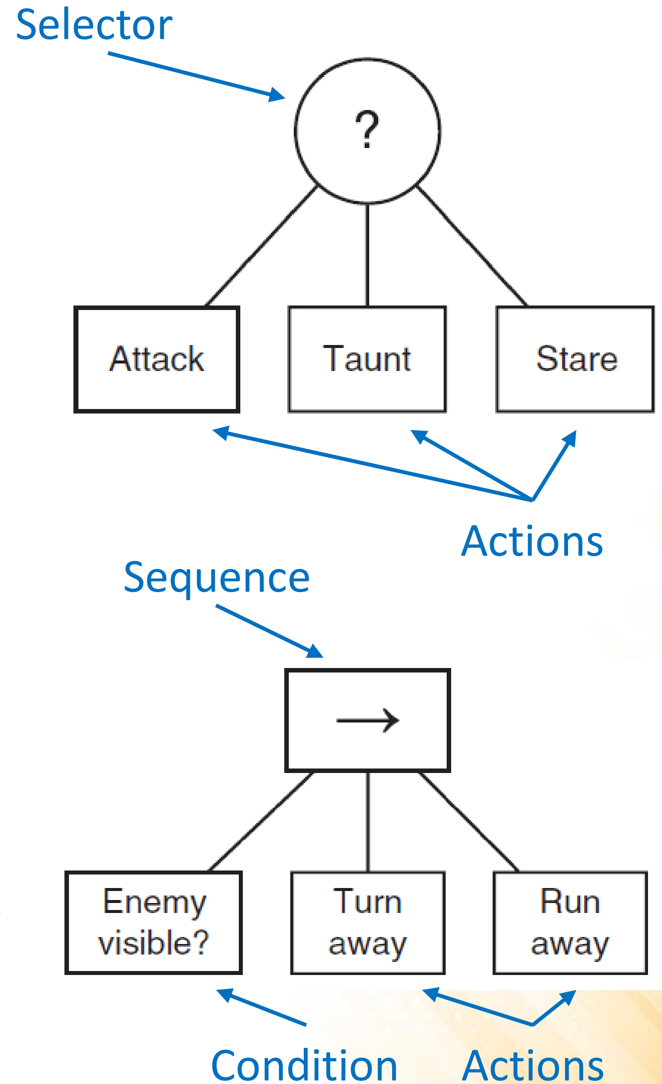
Behavior Tree

- Behavior trees have a lot in common with Hierarchical State Machines but, instead of a state, the main building block of a behavior tree is a task.
  - A task can be something as simple as looking up the value of a variable in the game state, or executing an animation.
  - Tasks can be composed into sub-trees to represent more complex actions.

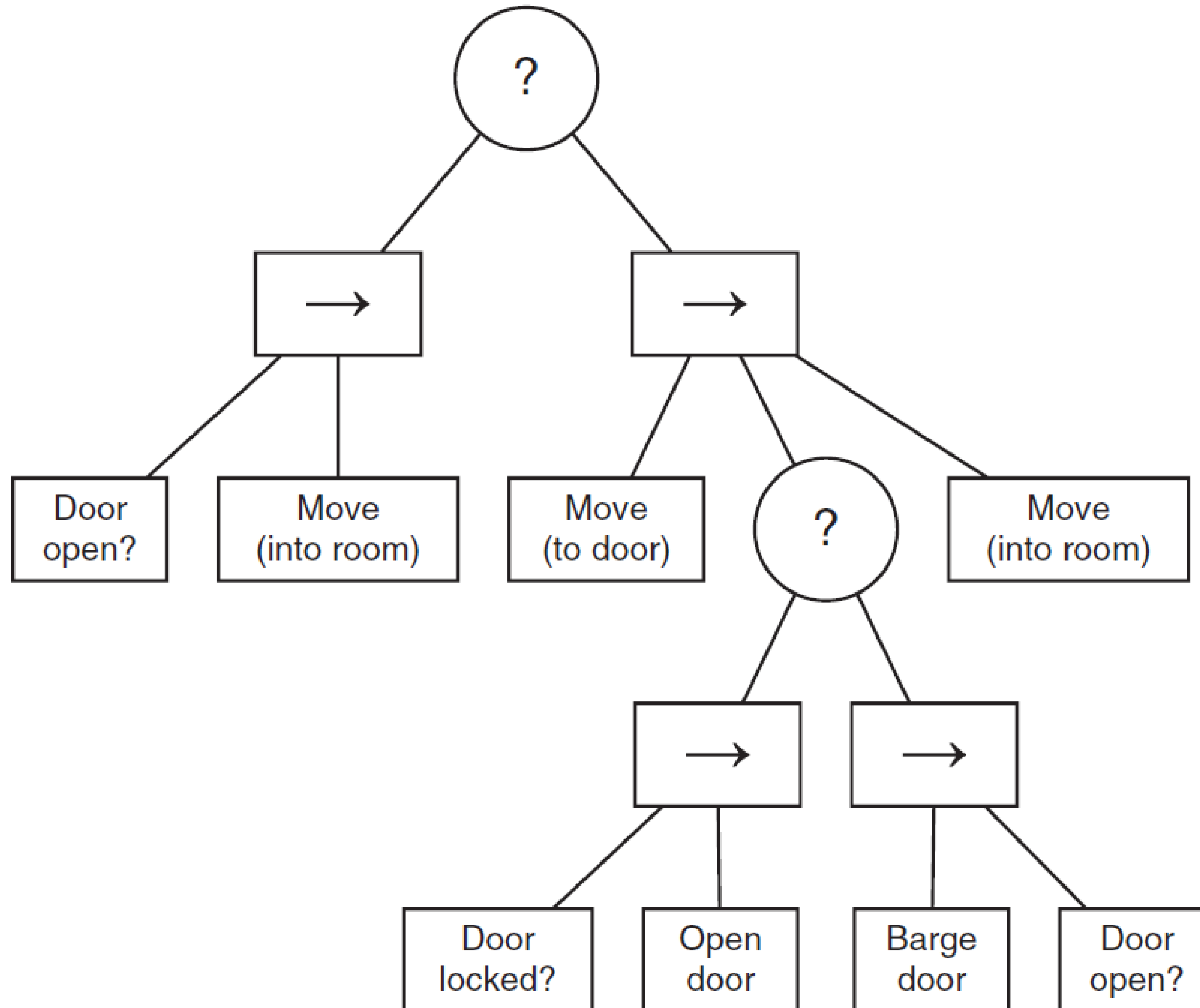


Behavior Tree – Tasks

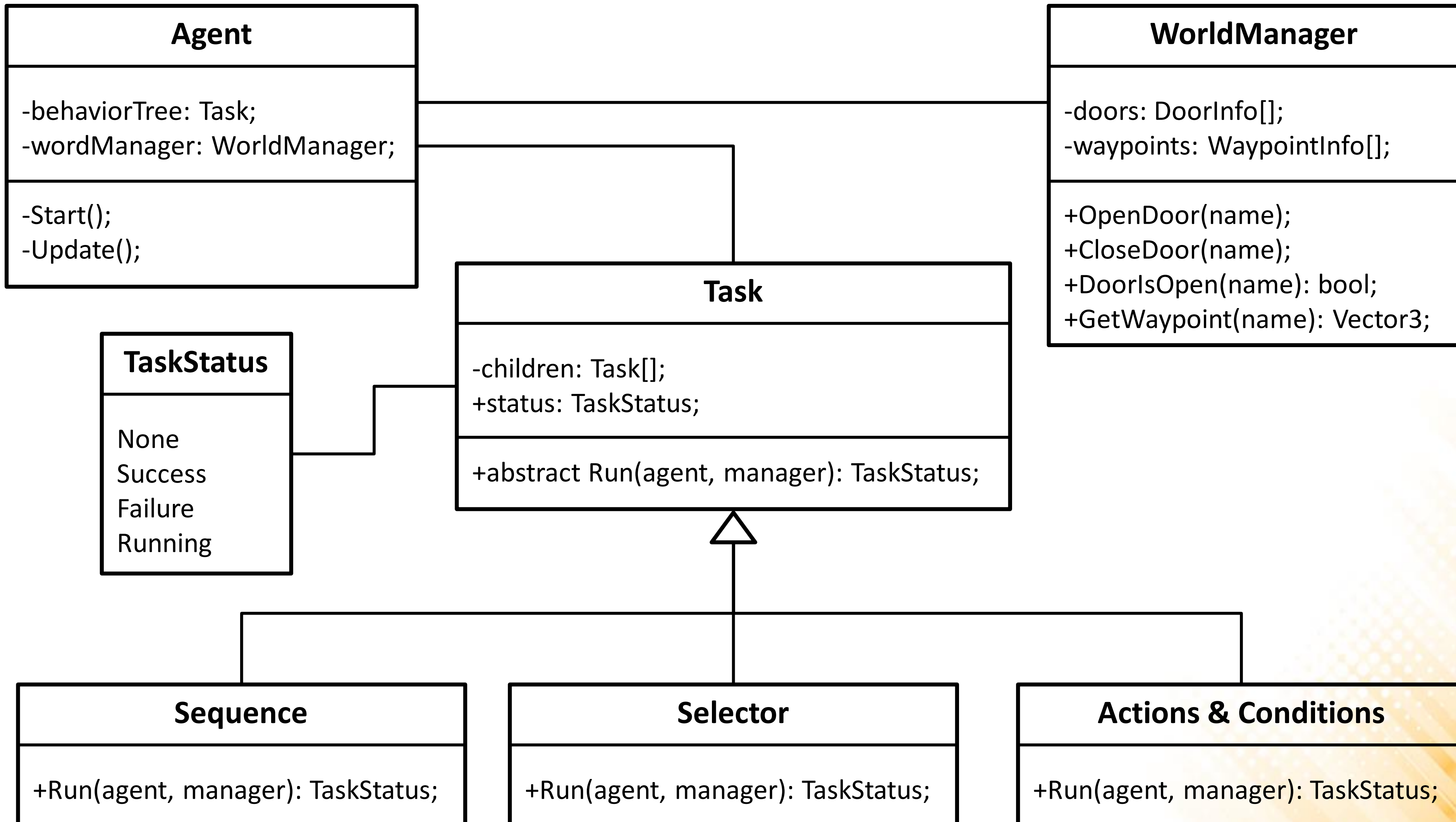
- Behavior trees are composed of three types of tasks:
  - Conditions: test some property of the game (e.g. proximity, line of sight, state of the character).
  - Actions: alter the state of the game (e.g. animation, movement, state change, dialog).
  - Composites: Selector and Sequence.
    - Selector: returns immediately with a success status code when one of its children runs successfully.
    - Sequence: returns immediately with a failure status code when one of its children fails. As long as its children are succeeding, it will keep going.



Behavior Tree – Example



Unity Implementation – Class Diagram



Base Task Class

- **Task Class:**

```
public abstract class Task
{
  protected List<Task> children;
  public TaskStatus status;

  public abstract TaskStatus Run(Agent agent,
                                 WorldManager wordManager);

  public Task(){
    children = new List<Task>();
    status = TaskStatus.None;
  }

  public void AddChildren(Task task){
    children.Add(task);
  }
}
```

Composite Classes

- **Sequence Class:**

```
public class Sequence : Task {

  public override TaskStatus Run(Agent agent,
                                 WorldManager wordManager){
    int successCount = 0;
    foreach (Task task in children){
      if (task.status != TaskStatus.Success){
        TaskStatus childrenStatus = task.Run(agent, wordManager);
        if (childrenStatus == TaskStatus.Failure){
          status = TaskStatus.Failure;
          return status;
        }
        else if (childrenStatus == TaskStatus.Success){
          successCount++;
        }

        ...
```

Composite Classes

```
        ...

        else{
          break;
        }
      }
      else{
        successCount++;
      }
    }
    if (successCount == children.Count)
      status = TaskStatus.Success;
    else
      status = TaskStatus.Running;
    return status;
  }
}
```

Composite Classes

- **Selector Class:**

```
public class Selector : Task {

  public override TaskStatus Run(Agent agent,
                                 WorldManager wordManager){
    int failureCount = 0;
    foreach (Task task in children){
      if (task.status != TaskStatus.Failure){
        TaskStatus childrenStatus = task.Run(agent, wordManager);
        if (childrenStatus == TaskStatus.Success){
          status = TaskStatus.Success;
          return status;
        }
        else if (childrenStatus == TaskStatus.Failure){
          failureCount++;
        }

        ...
```

Composite Classes

```
        ...

        else{
          break;
        }
      }
    }
    if (failureCount == children.Count)
      status = TaskStatus.Failure;
    else
      status = TaskStatus.Running;
    return status;
  }
}
```

Condition Classes

- **DoorOpenCondition Class:**

```
public class DoorOpenCondition : Task {
  private string doorName;

  public DoorOpenCondition(string door){
    doorName = door;
  }

  public override TaskStatus Run(Agent agent,
                                 WorldManager wordManager){
    if (wordManager.DoorIsOpen(doorName)){
      status = TaskStatus.Success;
    }
    else{
      status = TaskStatus.Failure;
    }
    return status;
  }
}
```

Action Classes

- **MoveAction Class:**

```
public class MoveAction : Task{
  private string destionation;

  public MoveAction(string dest){
    destionation = dest;
  }

  public override TaskStatus Run(Agent agent,
                                 WorldManager wordManager){
    NavMeshAgent navMeshAgent = agent.GetComponent<NavMeshAgent>();
    Vector3 dest = wordManager.GetWaypoint(destionation).position;
    if (status == TaskStatus.None){
      navMeshAgent.destination = dest;
      status = TaskStatus.Running;
    }
    else if (IsAtDestionation(navMeshAgent)){
      status = TaskStatus.Success;
    }
    return status;
  }
```

Action Classes

```
  ...

  private bool IsAtDestionation(NavMeshAgent navMeshAgent){
    if (!navMeshAgent.pathPending){
      if (navMeshAgent.remainingDistance <=
                                   navMeshAgent.stoppingDistance){
        if (!navMeshAgent.hasPath ||
                         navMeshAgent.velocity.sqrMagnitude == 0f){
          return true;
        }
      }
    }
    return false;
  }
}
```

Action Classes

- **OpenDoorAction Class:**

```
public class OpenDoorAction : Task{
  private string doorName;

  public OpenDoorAction(string door){
    doorName = door;
  }

  public override TaskStatus Run(Agent agent,
                              GameWorldManager wordManager){
    if (!wordManager.DoorIsOpen(doorName)){
      wordManager.OpenDoor(doorName);
    }
    status = TaskStatus.Success;
    return status;
  }
}
```

World Manager Class

```
public class WorldManager : MonoBehaviour {
  [SerializeField] private DoorInfo[] doors;
  [SerializeField] private WaypointInfo[] waypoints;

  public void OpenDoor(string doorName){
    for (int x = 0; x < doors.Length; x++){
      if (doors[x].name == doorName){
        doors[x].transform.Translate(Vector3.right * 2f);
        doors[x].open = true;
        break;
      }
    }
  }
  public void CloseDoor(string doorName){
    for (int x = 0; x < doors.Length; x++){
      if (doors[x].name == doorName){
        doors[x].transform.Translate(Vector3.left * 2f);
        doors[x].open = false;
        break;
      }
    }
  }
```

World Manager Class

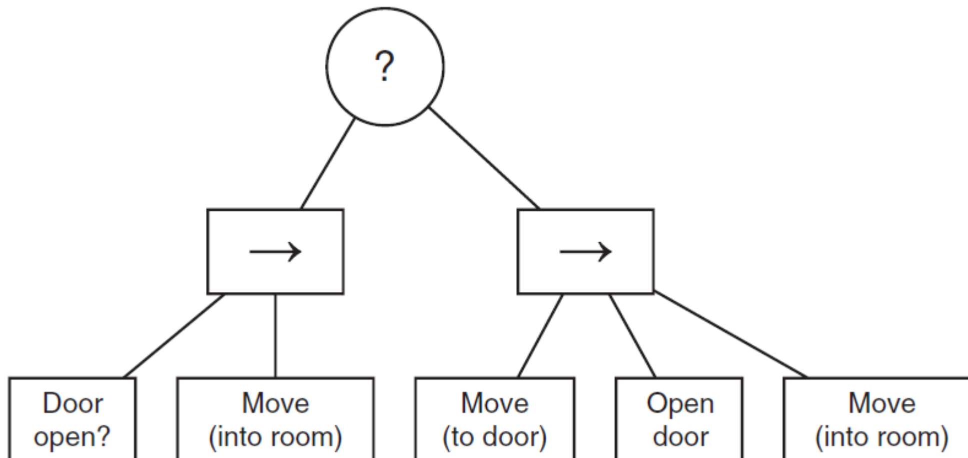
```
  ...

  public bool DoorIsOpen(string doorName){
    for (int x = 0; x < doors.Length; x++){
      if (doors[x].name == doorName){
        return doors[x].open;
      }
    }
    return false;
  }

  public Transform GetWaypoint(string name){
    foreach (WpInfo wp in waypoints){
      if (wp.name == name)
        return wp.transform;
    }
    return null;
  }
}
```

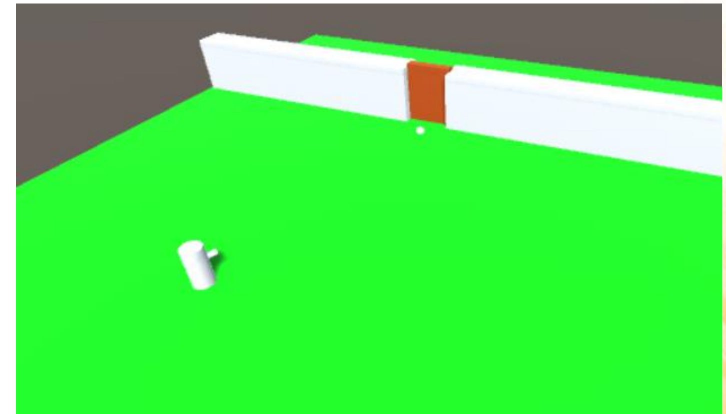
Agent Class

```
public class Agent : MonoBehaviour
{
  [SerializeField] private WorldManager wordManager;
  private Task behaviorTree;
  private TaskStatus behaviorTreeStatus = TaskStatus.None;

  void Start(){
    Task sequenceMoveToRoom = new Sequence();
    sequenceMoveToRoom.AddChildren(new DoorOpenCondition("Door1"));
    sequenceMoveToRoom.AddChildren(new MoveAction("Room1"));

    Task sequenceOpenDoorMoveToRoom = new Sequence();
    sequenceOpenDoorMoveToRoom.AddChildren(new MoveAction("Door1"));
    sequenceOpenDoorMoveToRoom.AddChildren(new OpenDoorAction("Door1"));
    sequenceOpenDoorMoveToRoom.AddChildren(new MoveAction("Room1"));

    behaviorTree = new Selector();
    behaviorTree.AddChildren(sequenceMoveToRoom);
    behaviorTree.AddChildren(sequenceOpenDoorMoveToRoom);
  }
```

Agent Class

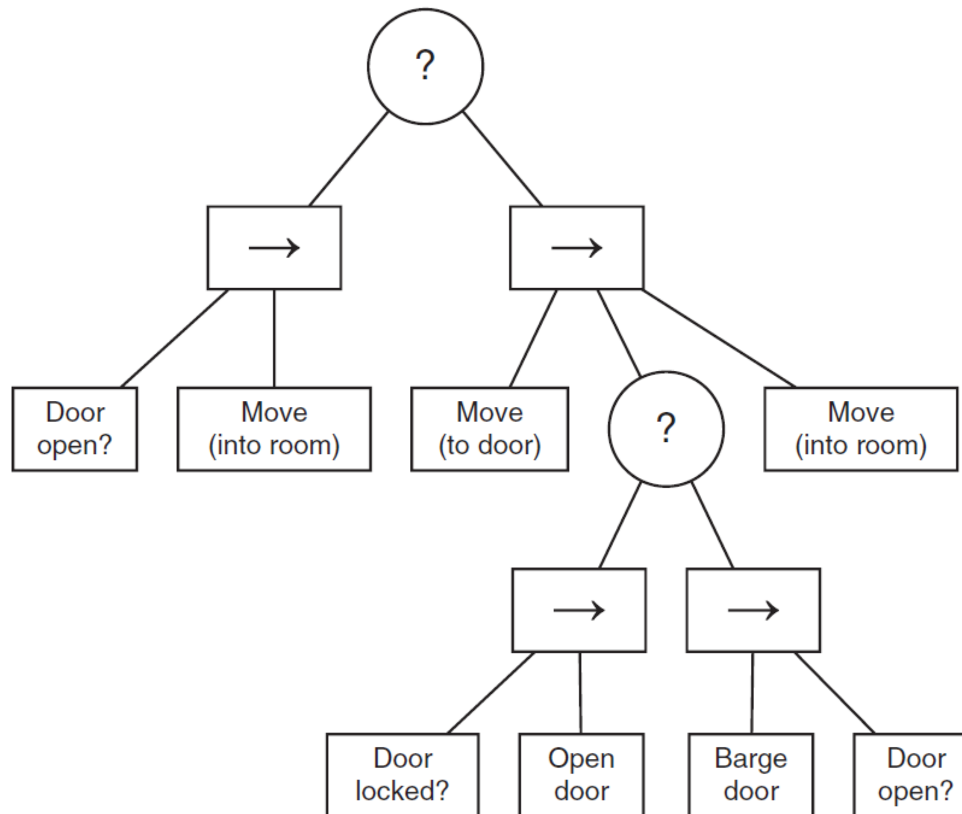
```
  ...


  void Update(){
    if ((behaviorTreeStatus == TaskStatus.None) ||
        (behaviorTreeStatus == TaskStatus.Running)){
      behaviorTreeStatus = behaviorTree.Run(this, wordManager);
    }
  }
}
```





Exercise 1

1) Implement and test the following behavior tree:

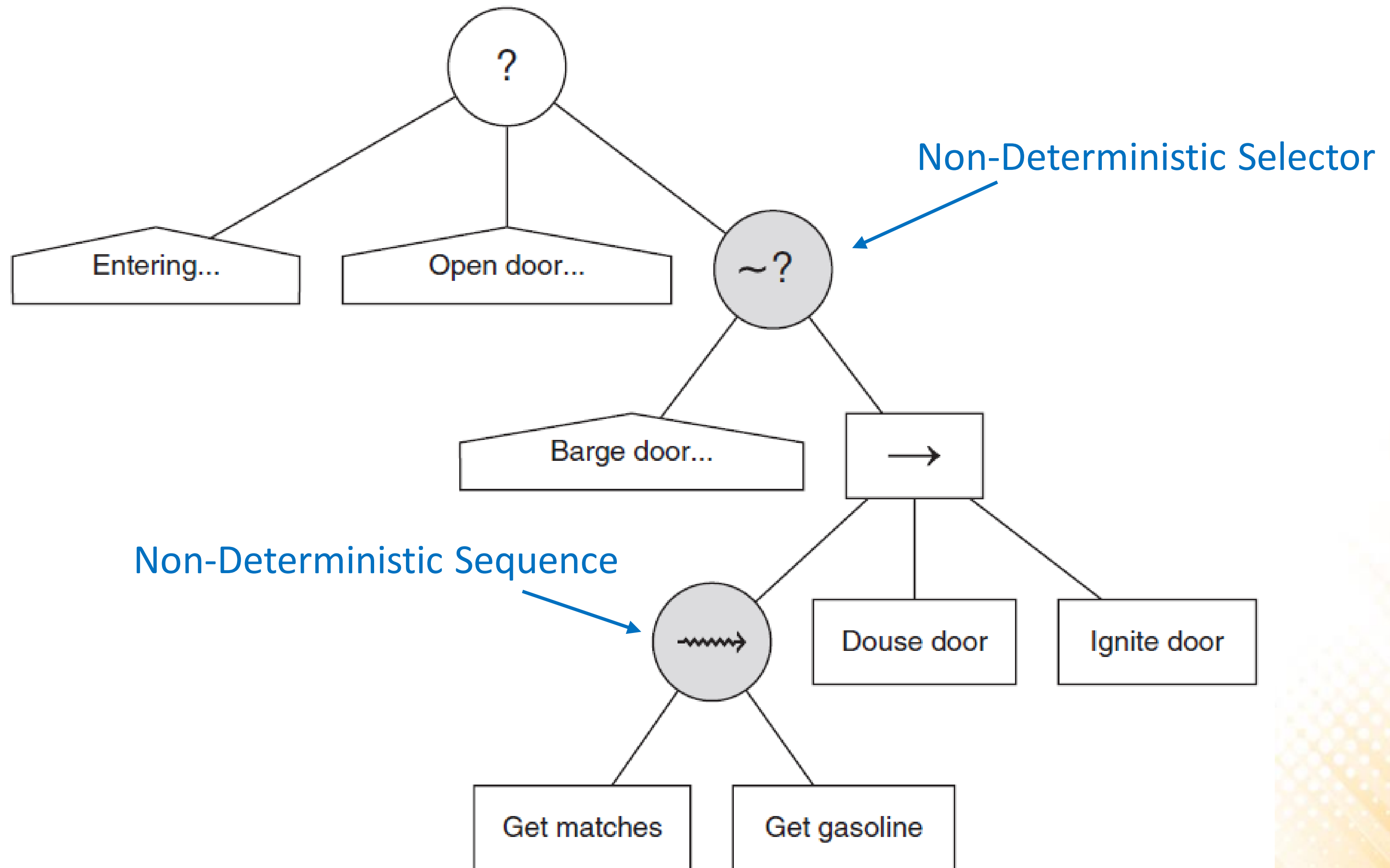


Non-Deterministic Composite Tasks

- Sometimes the order in which tasks are executed is extremely important. But there are some tasks that don't need to be executed in a particular order.
  - Executing tasks in same order can lead to predictable AI who always try the same things.
  - Example (sequence): get matches and gasoline to burn the door.
  - Example (selector): invade the room through the door or through the window.

- Non-deterministic composites can be implemented by shuffling the order of the children nodes before iterating through them.

Non-Deterministic Composite Tasks



Non-Deterministic Composite Tasks

- **NonDeterministicSequence Class:**

```
public class NonDeterministicSequence : Task {

  private bool shuffledOrder;

  public NonDeterministicSequence()
  {
    shuffledOrder = false;
  }

  public override TaskStatus Run(Agent agent,
                               WorldManager wordManager){
    if (!shuffledOrder){
      Shuffle(children);
      shuffledOrder = true;
    }
    ...
  }
}
```

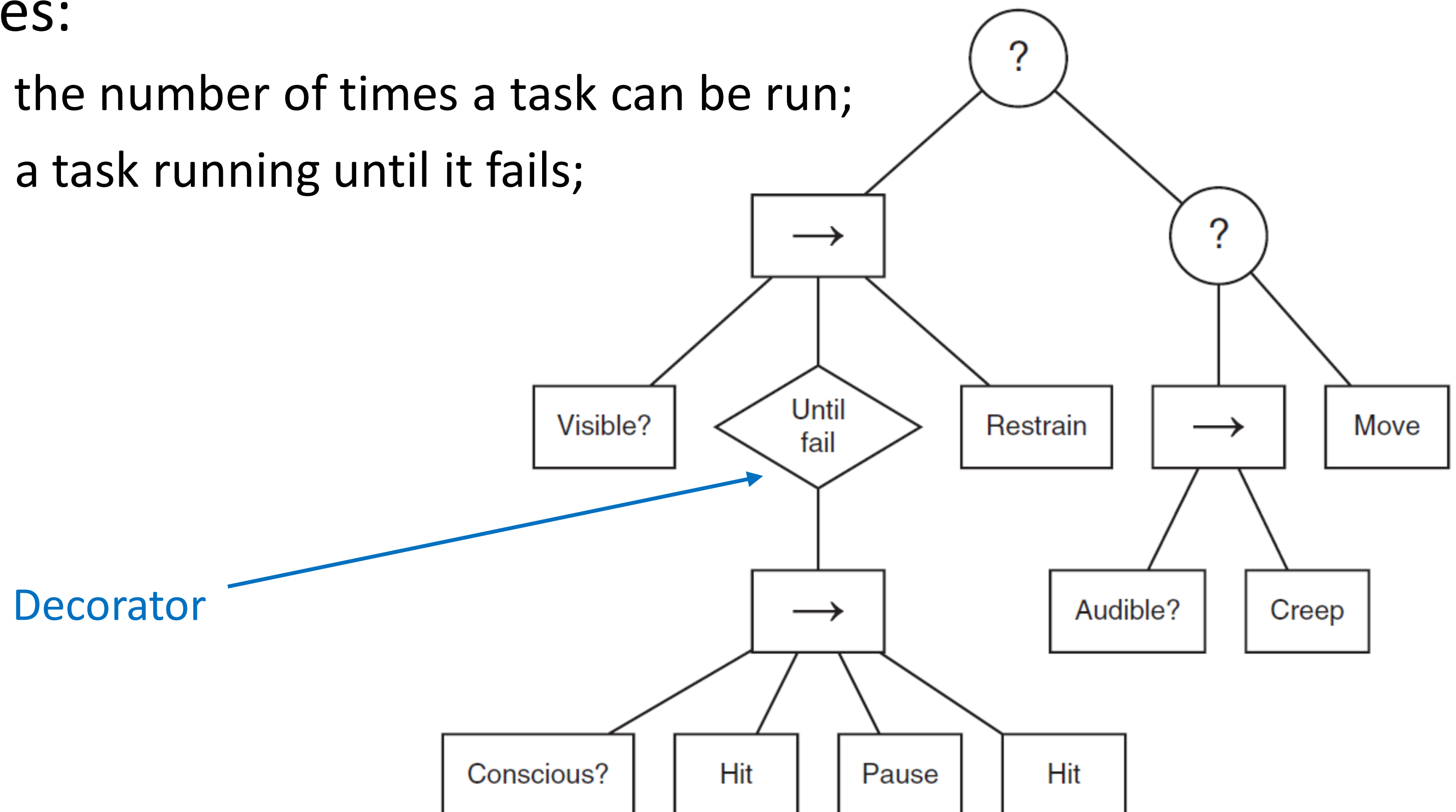
Non-Deterministic Composite Tasks

- **Simple Shuffle method:**

```
  public void Shuffle(List<Task> list)
  {
    int n = list.Count;
    while (n > 1)
    {
      int k = Random.Range(0, n);
      Task value = list[k];
      list[k] = list[n];
      list[n] = value;
      n--;
  }
}
```

Decorators

- Decorator is a type of task that has one single child task and modifies its behavior in some way.
- Examples:
  - Limit the number of times a task can be run;
  - Keep a task running until it fails;



Decorator Classes

- **Decorator Class:**

```
public abstract class Decorator : Task {
  protected Task child;

  new public void AddChildren(Task task)
  {
    child = task;
  }
}
```

- **UntilFailDecorator Class:**

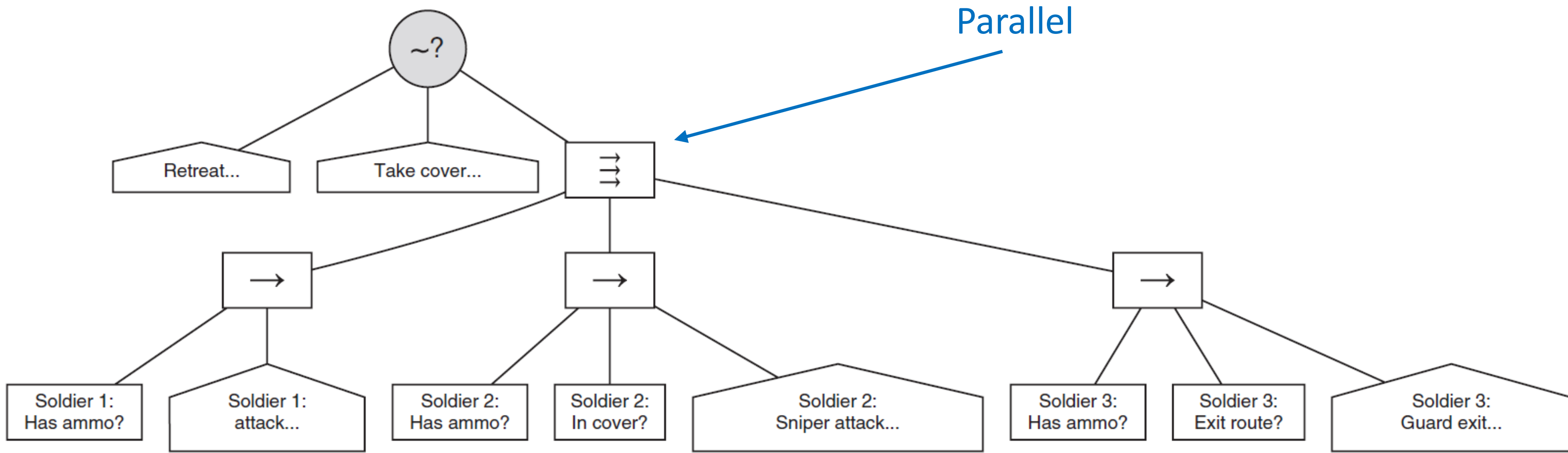
```
public class UntilFailDecorator : Decorator{
  public override TaskStatus Run(Agent agent,
                               WorldManager wordManager){
    if (status == TaskStatus.None)
      status = TaskStatus.Running;
    if (child.Run(agent, wordManager) == TaskStatus.Failure)
      status = TaskStatus.Success;
    return status;
  }
}
```

Parallel Tasks

- When parallel actions are necessary, we can add a third type of composite tasks to the behavior tree: Parallel.
- Rather than running all children tasks one at a time, it runs them all simultaneously.
  - Example: a character rolling into cover at the same time as shouting an insult and changing primary weapon.
- The Parallel task acts in a similar way to the Sequence task. It has a set of child tasks, and it runs them simultaneously until one of them fails.

Parallel Tasks

- At a higher level, we can also use Parallel tasks to <u>control the behavior of a group of characters</u>.

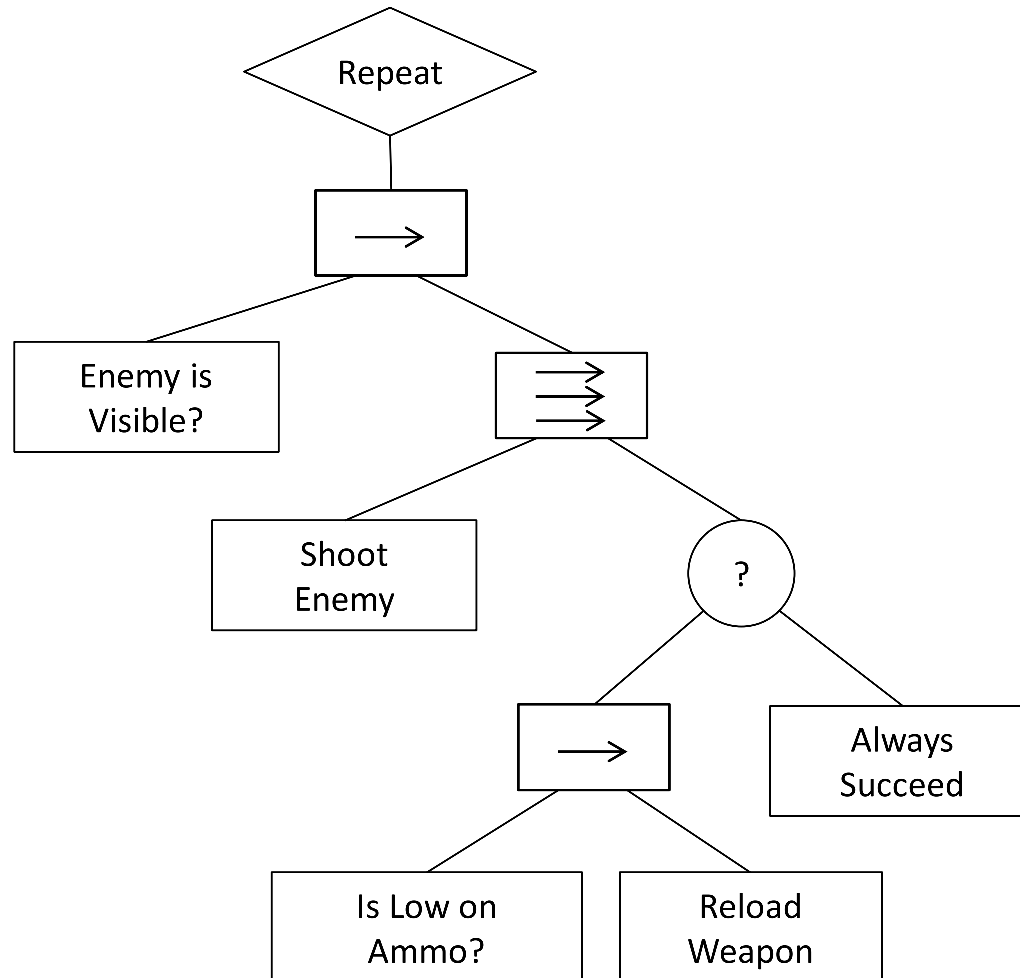


Parallel Class

```
public class Parallel : Task {
  public override TaskStatus Run(Agent agent, WorldManager wordManager){
    int successCount = 0;
    foreach (Task task in children){
      if (task.status != TaskStatus.Success){
        TaskStatus childrenStatus = task.Run(agent, wordManager);
        if (childrenStatus == TaskStatus.Failure){
          status = TaskStatus.Failure;
          return status;
        }
        else if (childrenStatus == TaskStatus.Success)
          successCount++;
      }
      else
        successCount++;
    }
    if (successCount == children.Count)
      status = TaskStatus.Success;
    else
      status = TaskStatus.Running;
    return status;
  }
}
```

Exercise 2

2) Implement and test the following behavior tree:



Further Reading

- Millington, I., Funge, J. (2009). **Artificial Intelligence for Games** (2nd ed.). CRC Press. ISBN: 978-0123747310.
  - **Chapter 5.4: Behavior Trees**