

Search  
EECS 4315

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JPF contains different search strategies:

- depth first search  
(`gov.nasa.jpf.search.DFSearch`),
- breadth first search  
(`gov.nasa.jpf.search.heuristic.BFSHeuristic`)
- and several other search strategies.

JPF has been designed in such a way that it can easily be extended. For example, a new search strategy can be added to JPF.

# The Search class

The class `Search` of the package `gov.nasa.jpf.search` contains numerous attributes and methods that are useful for implementing search strategies.

By extending the `Search` class, we inherit all these features.

```
import gov.nasa.jpf.search.Search;  
  
public class DFSearch extends Search {  
    ...  
}
```

# Constructor of DFSearch

```
public Search(Config config, VM vm)
```

- The `Config` object contains the JPF properties.
- The `VM` object refers to JPF's virtual machine.

## Question

Implement the constructor of the `DFSearch`.

# Constructor of DFSearch

```
public Search(Config config, VM vm)
```

- The **Config** object contains the JPF properties.
- The **VM** object refers to JPF's virtual machine.

## Question

Implement the constructor of the **DFSearch**.

## Answer

```
public DFSearch(Config config, VM vm) {  
    super(config, vm);  
}
```

# The search method

The method

```
public void search()
```

drives the search.

```
public boolean forward()
```

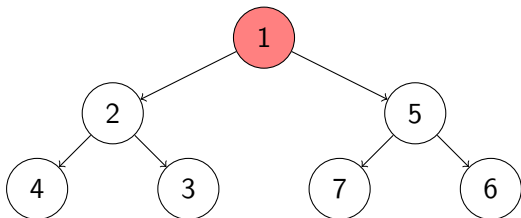
tries to move forward along an unexplored transition and returns whether the move is successful.

```
public boolean backtrack()
```

tries to backtrack and returns whether the backtrack is successful.



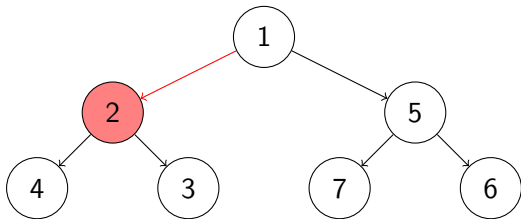
# The search method



## Question

For the above state space, provide the sequence of calls to **forward** and **backward** and the value returned by them corresponding to depth first search started in the top most state.

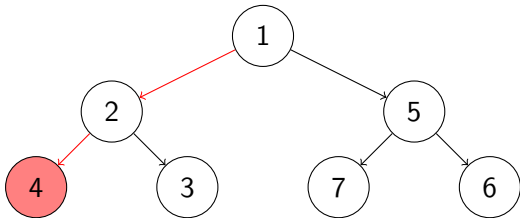
# The search method



Answer

`forward(true)`

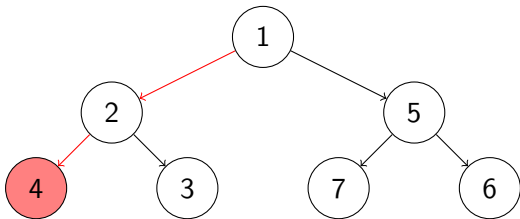
# The search method



Answer

```
forward(true); forward(true)
```

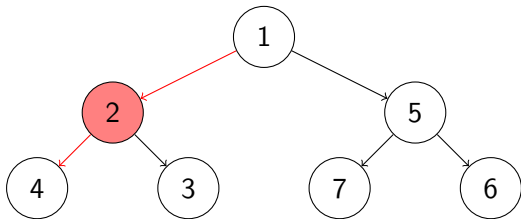
# The search method



Answer

```
forward(true); forward(true); forward(false)
```

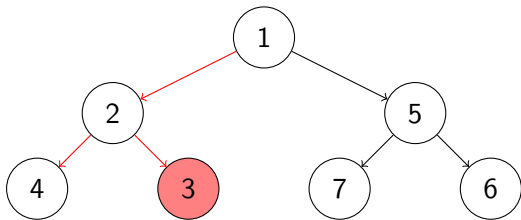
# The search method



Answer

```
forward(true); forward(true); forward(false); backtrack(true)
```

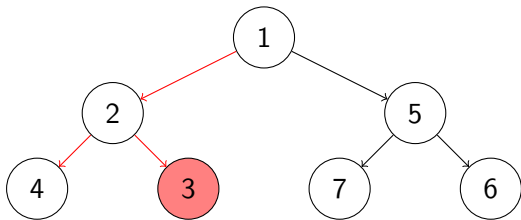
# The search method



## Answer

```
forward(true); forward(true); forward(false); backtrack(true);  
forward(true)
```

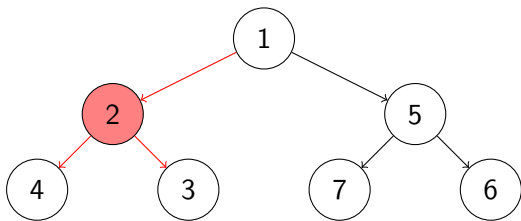
# The search method



## Answer

```
forward(true); forward(true); forward(false); backtrack(true);  
forward(true); forward(false)
```

# The search method

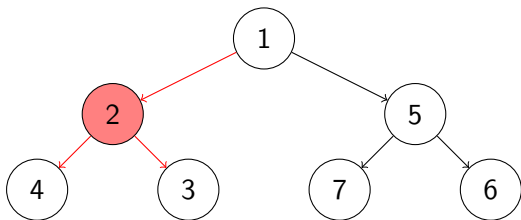


## Answer

```
forward(true); forward(true); forward(false); backtrack(true);  
forward(true); forward(false); backtrack(true)
```



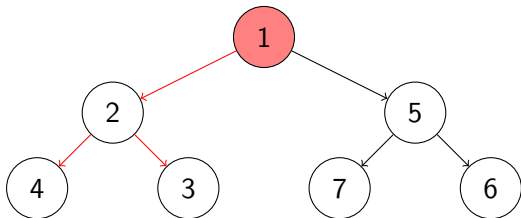
# The search method



## Answer

```
forward(true); forward(true); forward(false); backtrack(true);  
forward(true); forward(false); backtrack(true); forward(false)
```

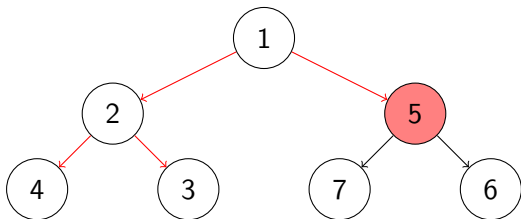
# The search method



## Answer

```
forward(true); forward(true); forward(false); backtrack(true);  
forward(true); forward(false); backtrack(true); forward(false);  
backtrack(true)
```

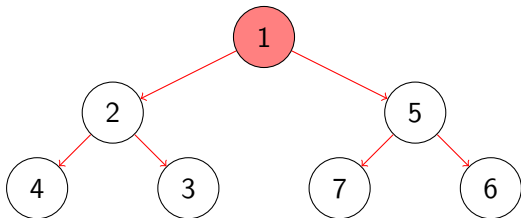
# The search method



## Answer

```
forward(true); forward(true); forward(false); backtrack(true);  
forward(true); forward(false); backtrack(true); forward(false);  
backtrack(true); forward(true)
```

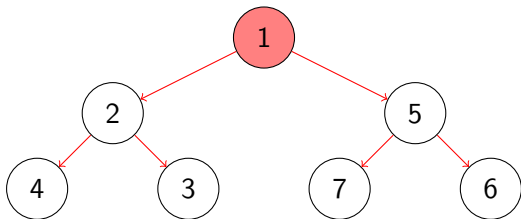
# The search method



## Answer

```
forward(true); forward(true); forward(false); backtrack(true);  
forward(true); forward(false); backtrack(true); forward(false);  
backtrack(true); forward(true); ... ; forward(false)
```

# The search method



## Answer

```
forward(true); forward(true); forward(false); backtrack(true);  
forward(true); forward(false); backtrack(true); forward(false);  
backtrack(true); forward(true); ... ; forward(false);  
backtrack(false)
```

## Question

Write some code consisting only of calls to `forward` and `backward` and loops that gives rise to the sequence on the previous slide.

# The search method

## Question

Write some code consisting only of calls to `forward` and `backward` and loops that gives rise to the sequence on the previous slide.

## Answer

```
while (forward() || backtrack()) {}
```

or

```
do {  
  while (this.forward()) {}  
} while (this.backtrack());
```

```
public boolean isIgnoredState()
```

tests whether the current state can be ignored in the search.

States can, for example, be ignored by using in the system under test the method `ignoreIf(boolean)` of JPF's class `Verify` which is part of the package `gov.nasa.jpf.vm`.

## Question

Incorporate the `isIgnoredState` method into the `search` method of the `DFSearch` class.



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## Question

Incorporate the `isIgnoredState` method into the `search` method of the `DFSearch` class.

## Answer

```
do {  
    while (!this.isIgnoredState() && this.forward()) {}  
} while (this.backtrack());
```

# The done attribute

Other components of JPF can end a search by setting the attribute **done** of the class **Search** to true.

## Question

Modify the **search** method of the **DFSearch** class to incorporate the **done** attribute.

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Other components of JPF can end a search by setting the attribute **done** of the class **Search** to true.

## Question

Modify the **search** method of the **DFSearch** class to incorporate the **done** attribute.

## Answer

```
do {  
    while (!this.isIgnoredState() &&  
           !this.done() &&  
           this.forward()) {}  
} while (!this.done && this.backtrack());
```

# Request backtrack

Other components of JPF can request a search to backtrack by means of the method

```
public boolean checkAndResetBacktrackRequest()
```

## Question

Modify the `search` method of the `DFSearch` class to incorporate the `checkAndResetBacktrackRequest` method.

# Request backtrack

Other components of JPF can request a search to backtrack by means of the method

```
public boolean checkAndResetBacktrackRequest()
```

## Question

Modify the `search` method of the `DFSearch` class to incorporate the `checkAndResetBacktrackRequest` method.

## Answer

```
do {  
    while (!this.isIgnoredState() &&  
           !this.done &&  
           !this.checkAndResetBacktrackRequest() &&  
           this.forward()) {}  
} while (!this.done && this.backtrack());
```

The `Search` class contains the attribute `depth` that can be used to keep track of the depth of the search. It is initialized to zero.

## Question

Modify the `search` method of the `DFSearch` class to keep track of the depth.

## Answer

```
this.depth = 1;
do {
    this.depth--;
    while (!this.isIgnoredState() &&
           !this.done &&
           !this.checkAndResetBacktrackRequest() &&
           this.forward()) {
        this.depth++;
    }
} while (!this.done && this.backtrack());
```

## Limit depth of search

JPF can be configured to limit the depth of the search by setting the JPF property `search.depth_limit`. The default value of `search.depth_limit` is `Integer.MAX_VALUE`. The `Search` class provides the method `getDepthLimit` which returns the maximal allowed depth of the search.

### Question

Add the method `checkDepthLimit` that tests whether the current depth is smaller than the limit. Also modify the `search` method to incorporate this method.



# Limit depth of search

## Answer

```
private boolean checkDepthLimit() {
    return this.depth < this.getDepthLimit();
}

this.depth = 1;
do {
    this.depth--;
    while (!this.isIgnoredState() &&
        !this.done &&
        !this.checkAndResetBacktrackRequest() &&
        this.checkDepthLimit() &&
        this.forward()) {
        this.depth++;
    }
} while (!this.done && this.backtrack());
```

The JPF property `search.min_free` captures the minimal amount of memory, in bytes, that needs to remain free. The default value is  $1024 \ll 10 = 1024^2 = 1,048,576B \approx 1MB$ . By leaving some memory free, JPF can report that it ran out of memory and provide some useful statistics instead of simply throwing an `OutOfMemoryError`. The method `checkStateSpaceLimit` of the class `Search` checks whether the minimal amount of memory that should be left free is still available.

### Question

Modify the `search` method of the `DFSearch` class to limit the memory usage.

## Answer

```
this.depth = 1;
do {
  this.depth--;
  while (!this.isIgnoredState() &&
        !this.done &&
        !this.checkAndResetBacktrackRequest() &&
        this.checkDepthLimit() &&
        this.checkStateSpaceLimit() &&
        this.forward()) {
    this.depth++;
  }
} while (!this.done &&
        this.checkStateSpaceLimit() &&
        this.backtrack());
```

## Multiple errors?

The JPF property `search.multiple_errors` tells us whether the search should report multiple errors (or just the first one). The `forward` method also checks whether any property is violated after the unexplored transition has been traversed. If a violation has been detected then the attribute `done` is set to true if and only if JPF has been configured to report at most one error.

The method `hasPropertyTermination` of the class `Search` checks whether a violation was encountered during the last transition. The method returns true if and only if a violation was encountered and the attribute `done` is set to true.

### Question

Modify the `search` method of the `DFSearch` class to take `search.multiple_errors` into account.

## Answer

```
this.depth = 1;
do {
  this.depth--;
  while (!this.isIgnoredState() &&
        !this.done &&
        !this.checkAndResetBacktrackRequest() &&
        this.checkDepthLimit() &&
        this.checkStateSpaceLimit() &&
        this.forward() &&
        !this.hasPropertyTermination()) {
    this.depth++;
  }
} while (!this.done &&
        this.checkStateSpaceLimit() &&
        this.backtrack());
```

A search should also notify listeners of particular events by invoking to the methods of the interface `SearchListener`, which can be found in the package `gov.nasa.jpf.search`. The `Search` class contains a number of `notify` methods.

## Question

Modify the `search` method of the `DFSearch` class to incorporate following notifications.

- `notifySearchStarted`
- `notifySearchFinished`

## Answer

```
this.notifySearchStarted();
this.depth = 1;
do {
    this.depth--;
    while (!this.isIgnoredState() &&
        !this.done &&
        !this.checkAndResetBacktrackRequest() &&
        this.checkDepthLimit() &&
        this.checkStateSpaceLimit() &&
        this.forward() &&
        !this.hasPropertyTermination()) {
        this.depth++;
    }
} while (!this.done &&
    this.checkStateSpaceLimit() &&
    this.backtrack());
this.notifySearchFinished();
```

## Question

Override the `forward` method and the `backtrack` method of the `Search` class to incorporate following notifications.

- `notifyStateAdvanced`
- `notifyStateBacktracked`
- `notifyStateProcessed`



## Answer

```
protected boolean forward() {
    boolean successful = super.forward();
    if (successful) {
        this.notifyStateAdvanced();
    } else {
        this.notifyStateProcessed();
    }
    return successful;
}
```

```
protected boolean backtrack() {
    boolean successful = super.backtrack();
    if (successful) {
        this.notifyStateBacktracked();
    }
    return successful;
}
```

## Question

Override the `checkStateSpaceLimit` method and modify the `checkDepthLimit` method to incorporate `notifySearchConstraintHit(String)` to notify the following.

- "memory limit reached"
- "depth limit reached"

## Answer

```
public boolean checkStateSpaceLimit() {
    boolean available = super.checkStateSpaceLimit();
    if (!available) {
        this.notifySearchConstraintHit("memory limit reached");
    }
    return available;
}

private boolean checkDepthLimit() {
    boolean below = this.depth < this.getDepthLimit();
    if (!below) {
        this.notifySearchConstraintHit("depth limit reached");
    }
    return below;
}
```

Immediately after an invocation of the `forward` method of the `Search` class, an invocation of the `getCurrentError` method of the `Search` class returns `null` if and only if no property violation has been detected.

## Question

Modify the overridden `forward` method of the `DFSearch` class to include an invocation of the `notifyPropertyViolated` method.

## Answer

```
protected boolean forward() {
    boolean successful = super.forward();
    if (successful) {
        this.notifyStateAdvanced();
        if (this.getCurrentError() != null) {
            this.notifyPropertyViolated();
        }
    } else {
        this.notifyStateProcessed();
    }
    return successful;
}
```

# The search

```
this.notifySearchStarted();
this.depth = 1;
do {
    this.depth--;
    while (!this.isIgnoredState() &&
        !this.done &&
        !this.checkAndResetBacktrackRequest() &&
        this.checkDepthLimit() &&
        this.checkStateSpaceLimit() &&
        this.forward() &&
        !this.hasPropertyTermination()) {
        this.depth++;
    }
} while (!this.done &&
    this.checkStateSpaceLimit() &&
    this.backtrack());
this.notifySearchFinished();
```