**Script** generated by TTT

Title: Petter: Programmiersprachen (30.11.2016)

Date: Wed Nov 30 14:16:35 CET 2016

Duration: 97:54 min

Pages: 68

## Dispatching - Outline

**Dispatching**

1. Motiviation
2. Formal Model
3. Quiz
4. Dispatching from the Inside

**Solutions in Single-Dispatching**

1. Type introspection
2. Generic interface

**Multi-Dispatching**

1. Formal Model
2. Multi-Java
3. Multi-dispatched compare in Java
4. Multi-dispatching in Clojure

Section 1

## Direct Function Calls

## Function Dispatching (ANSI C89)

```
#include <stdio.h>

void fun(int i) {  }
void bar(int i, double j) {  }

int main(){
  fun(1);
  bar(1,1.2);
  void (*foo)(int);
  foo = fun;
  return 0;
}
```

Section 2

## Overloading Function Names

## Function Dispatching (ANSI C89)

```
#include <stdio.h>

void println(int i)   { print("%d\n",i); };
void println(float f) { print("%f\n",f); };

int main(){
  println(1.2);
  println(1);
  return 0;
}
```

## Function Dispatching (ANSI C89)

```
#include <stdio.h>

void println(int i)   { print("%d\n",i); };
void println(float f) { print("%f\n",f); };

int main(){
  println(1.2);
  println(1);
  return 0;
}
```

⚠ Functions with same names but different parameters not legal

## Generic Selection (C11)

*generic-selection* ↦ `_Generic` ( *exp*, *generic-assoclist* )

*generic-assoclist* ↦ ( *generic-assoc* , )* *generic-assoc*

*generic-assoc* ↦ `typename` : *exp* | `default` : *exp*

## Generic Selection (C11)

*generic-selection* ↦ `_Generic`(*exp*, *generic-assoclist*)

*generic-assoclist* ↦ (*generic-assoc*, )* *generic-assoc*

*generic-assoc* ↦ `typename` : *exp* | `default` : *exp*

### Example:

```c
#include <stdio.h>
#define printf_dec_format(x) _Generic((x), \
    signed int: "%d", \
    float: "%f" )
#define println(x) printf(printf_dec_format(x), x), printf("\n");

int main(){
  println(1.2);
  println(1);
  return 0;
}
```

## Overloading (Java/C++)

```java
class D {
  public static void p(Object o) { System.out.print(o); }
  public          int f(int i)      { p("f(int): ");    return i+1; }
  public       double f(double d) { p("f(double): "); return d+1.3;}
}

public static void main() {
  D d = new D();
  B.p(d.f(2)+"\n");
  B.p(d.f(2.3)+"\n");
}
```

## Overloading (Java/C++)

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  public static void p(Object o) { System.out.print(o); }
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public static void main() {
  D d = new D();
  B.p(d.f(2)+"\n");
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}
```

```
>$ javac Overloading.java; java Overloading
f(int): 3
f(double): 3.6
```

## Overloading with Inheritance (Java)

```java
class B {
  public static void p(Object o) { System.out.print(o); }
  public          int f(int i)      { p("f(int): ");    return i+1; }
}
class D extends B {
  public       double f(double d) { p("f(double): "); return d+1.3;}
}

public static void main() {
  D d = new D();
  D.p(d.f(2)+"\n");
  D.p(d.f(2.3)+"\n");
}
```

f(int) 3        f(double) 3.3

f(double) 3.6   ←

## Overloading with Inheritance (Java)

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  public static void p(Object o) { System.out.print(o); }
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}
class D extends B {
  public      double f(double d) { p("f(double): "); return d+1.3;}
}

public static void main() {
  D d = new D();
  D.p(d.f(2)+"\n");
  D.p(d.f(2.3)+"\n");
}
```

```
>$ javac Overloading.java; java Overloading
f(int): 3
f(double): 3.6
```

## Overloading Hassles

```
class D {
  public static void p(Object o) { System.out.print(o); }
  public          int f(int i, double j) { p("f(i,d): "); return i;}
  public          int f(double i, int j) { p("f(d,i): "); return j;}
}

public static void main() {
  D d = new D();
  D.p(d.f(2,2)+"\n");
}
```

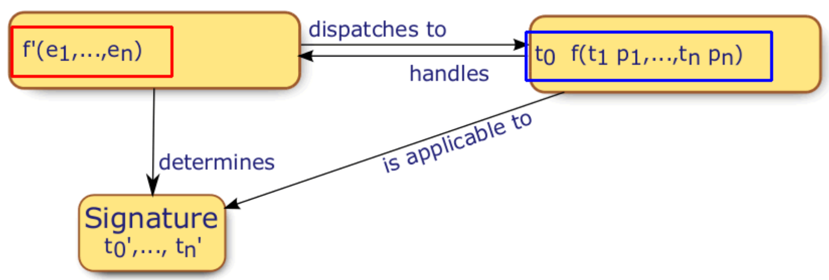
## Overloading Hassles

```
class D {
  public static void p(Object o) { System.out.print(o); }
  public          int f(int i, double j) { p("f(i,d): "); return i;}
  public          int f(double i, int j) { p("f(d,i): "); return j;}
}

public static void main() {
  D d = new D();
⚠ D.p(d.f(2,2)+"\n");
}
```

```
>$ javac Overloading.java
Overloading.java:(?): error: reference to f is ambiguous
```

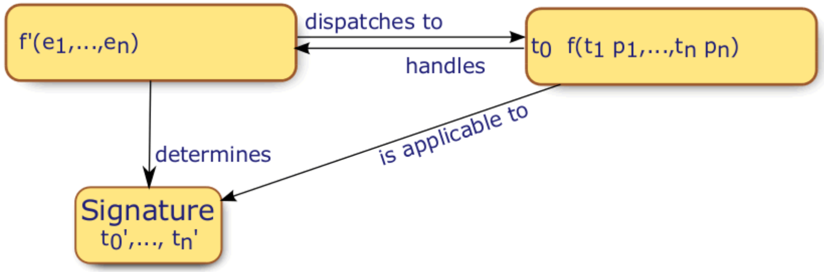
## Static Methods are *Statically Dispatched*



## Static Methods are *Statically Dispatched*

**Function Call Expression**

Function to be dispatched




**Signature**

- Function Name
- *Static* Types of Parameters
- Return Type

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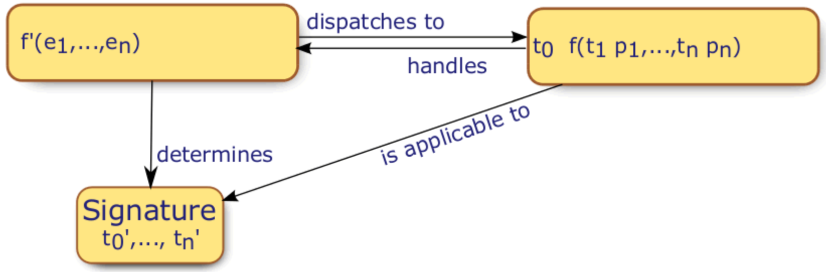
**Concrete Method**

Provides calling target for a call signature

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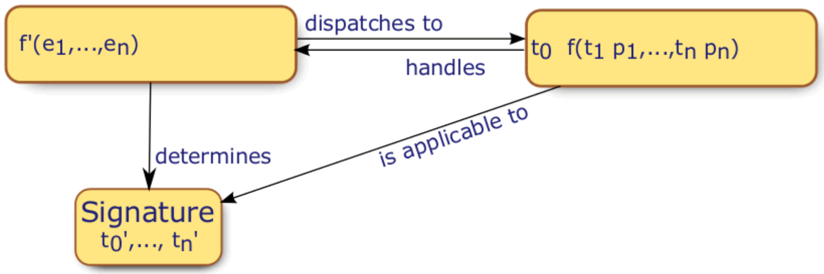


**Signature**

- Function Name
- *Static* Types of Parameters
- Return Type

**$f$ is applicable to $f'$ $\Leftrightarrow$ $f' \leq f$:**

$\leq$ is the *subtype relation*:

$$R\ f(T_1, \ldots, T_n) \leq R'\ f'(T_1', \ldots, T_2')$$

$$\Longrightarrow R \leq R' \wedge T_i' \leq T_i$$

## Inside the Javac – Predicates

Concept of methods being *applicable* for arguments:

```
// true if the given method is applicable to the given arguments
boolean isApplicable(MemberDefinition m, Type args[]) {
    // Sanity checks:
    Type mType = m.getType();
    if (!mType.isType(TC_METHOD))                    return false;

    Type mArgs[] = mType.getArgumentTypes();
    if (args.length != mArgs.length)                 return false;

    for (int i = args.length ; --i >= 0 ;)
        if (!isMoreSpecific(args[i], mArgs[i]))      return false;
    return true;
}
boolean isMoreSpecific(Type moreSpec, Type lessSpec) //... type based specialization
```

Concept of method signatures being *more specific* then others:

```
// true if "more" is in every argument at least as specific as "less"
boolean isMoreSpecific(MemberDefinition more, MemberDefinition less) {
    Type moreType = more.getClassDeclaration().getType();
    Type lessType = less.getClassDeclaration().getType();
    return isMoreSpecific(moreType, lessType) // return type based comparison
        && isApplicable(less, more.getType().getArgumentTypes()); // parameter type based
}
```

## Finding the Most Specific Concrete Method

```java
MemberDefinition matchMethod(Environment env, ClassDefinition accessor,
                             Identifier methodName, Type[] argumentTypes) throws ... {
    // A tentative maximally specific method.
    MemberDefinition tentative = null;
    // A list of other methods which may be maximally specific too.
    List candidateList = null;
    // Get all the methods inherited by this class which have the name `methodName'
    for (MemberDefinition method : allMethods.lookupName(methodName)) {
        // See if this method is applicable.
        if (!env.isApplicable(method, argumentTypes)) continue;
        // See if this method is accessible.
        if ((accessor != null) && (!accessor.canAccess(env, method))) continue;
        if ((tentative == null) || (env.isMoreSpecific(method, tentative)))
            // `method' becomes our tentative maximally specific match.
            tentative = method;
        else {  // If this method could possibly be another maximally specific
                // method, add it to our list of other candidates.
                if (!env.isMoreSpecific(tentative,method)) {
                    if (candidateList == null) candidateList = new ArrayList();
                    candidateList.add(method);
    }   }     }
    if (tentative != null && candidateList != null)
        // Find out if our `tentative' match is a uniquely maximally specific.
        for (MemberDefinition method : candidateList )
            if (!env.isMoreSpecific(tentative, method))
                throw new AmbiguousMember(tentative, method);
    return tentative;
}
```

## Overloading with Scopes – C++

```cpp
#include<iostream>
using namespace std;
class B { public:
  int f(int i) { cout << "f(int): "; return i+1; }
};
class D : public B { public:

  double f(double d) { cout << "f(double): "; return d+1.3; }
};

int main() {
  D* pd = new D;
  cout << pd->f(2) << '\n';
  cout << pd->f(2.3) << '\n';
}
```

## Overloading with Scopes – C++

```cpp
#include<iostream>
using namespace std;
class B { public:
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};

int main() {
  D* pd = new D;
  cout << pd->f(2) << '\n';
  cout << pd->f(2.3) << '\n';
}
```

```
>$ ./overloading
f(double): 3.3
f(double): 3.6
```

## Overloading with Scopes – C++

```cpp
#include<iostream>
using namespace std;
class B { public:
  int f(int i) { cout << "f(int): "; return i+1; }
};
class D : public B { public:
  using B::f;
  double f(double d) { cout << "f(double): "; return d+1.3; }
};

int main() {
  D* pd = new D;
  cout << pd->f(2) << '\n';
  cout << pd->f(2.3) << '\n';
}
```

```
>$ ./overloading
f(int): 3
f(double): 3.6
```

Section 3

## Overwriting Methods

## Object Orientation

**Emphasizing the *Receiver* of a Call**

In Object Orientation, we see objects associating strongly with particular procedures, a.k.a. *Methods*.

```
class Natural {
  int value;
}
void incBy(Natural n,int i){
  n.value += Math.abs(i);
}

...
incBy(nat,42);
```

⟹

```
class Natural {
  int value;

  void incBy(int i){
    this.value += Math.abs(i);
  }
}
...
nat.incBy(42);
```

- Associating the first parameter as *Receiver* of the method, and pulling it out of the parameters list
- Implicitely binding the first parameter to the fixed name *this*

## Subtyping in Object Orientation

**Emphasizing the *Receiver*'s Responsibility**

An Object Oriented Subtype is supposed to take responsibility for calls to Methods that are associated with the type, that it specializes.

```
class Integral {
  int i;
  void incBy(int delta){
      i += delta;
  }
}
class Natural extends Integral {
  int value;
  void incBy(int i){
    this.value += Math.abs(i);
  }
}
```

```
Integral i = new Integral(-5);
i.incBy(42);
Natural n = new Natural(42);
n.incBy(42);
i = n;
i.incBy(42);
```

⚠ In OO, at runtime subtypes can inhabit statically more general typed variables

⇝ Implicitely call the specialized method!

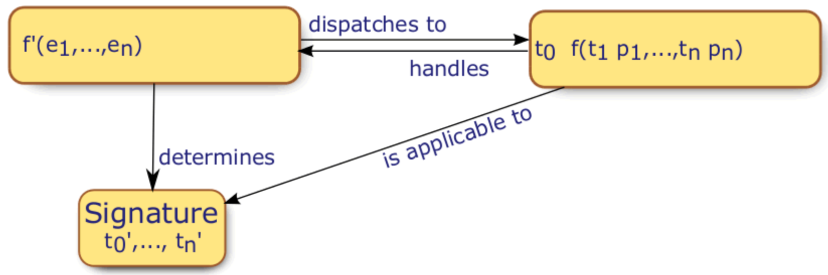
## Methods are *dynamically dispatched*

**Function Call Expression**

Call expression to be dispatched.

**Concrete Method**

Provides calling target for a call signature




**Signature**

Static types of actual parameters.

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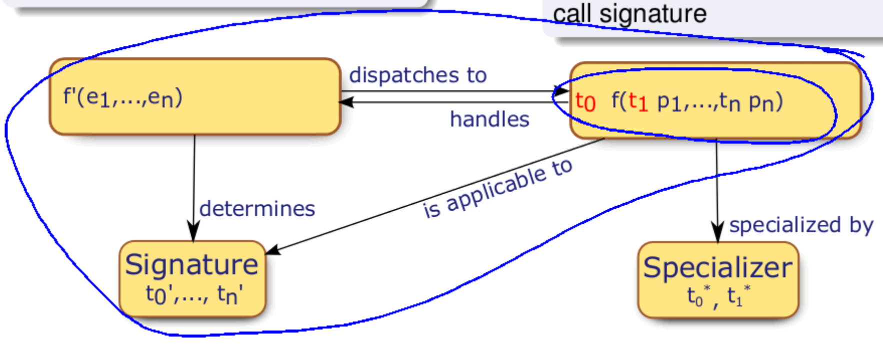


**Signature**
Static types of actual parameters.

**Specializer**
Specialized types to be matched at the call

# How can we implement that?

**Let's look at what Java does!**
The Java platform as example for state of the art OO systems:
- Static Javac-based compiler
- Dynamic Hotspot JIT-Compiler/Interpreter

Let's watch the following code on its way to the CPU:

```
public static void main(String[] args){
    Integral i = new Natural(1);
    i.incBy(42);
}
```

# Bytecode

⇝ `matchMethod` returns the statically most specific signature
⇝ Codegeneration hardcodes `invokevirtual` with this signature

```
Code:
   0: new           #4                  // class Natural
   3: dup
   4: iconst_1
   5: invokespecial #5                  // Method "<init>":(I)V
   8: astore_1
   9: aload_1
  10: bipush        42
  12: invokevirtual #6                  // Method Integral.incBy:(I)V
  15: return
```

**?** What is the semantics of `invokevirtual`?

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   9: aload_1
  10: bipush        42
  12: invokevirtual #6                  // Method Integral.incBy:(I)V
  15: return
```

? What is the semantics of `invokevirtual`?

⇝ Check the runtime interpreter: Hotspot VM calls `resolve_method`!

# Inside the Hotspot VM

```
void LinkResolver::resolve_method(methodHandle& resolved_method, KlassHandle resolved_klass,
                                  Symbol* method_name, Symbol* method_signature,
                                  KlassHandle current_klass) {

  // 1. check if klass is not interface
  if (resolved_klass->is_interface()) ;//... throw "Found interface, but class was expected"

  // 2. lookup method in resolved klass and its super klasses
  lookup_method_in_klasses(resolved_method, resolved_klass, method_name, method_signature);
      // calls klass::lookup_method() -> next slide

  if (resolved_method.is_null()) { // not found in the class hierarchy
    // 3. lookup method in all the interfaces implemented by the resolved klass
    lookup_method_in_interfaces(resolved_method, resolved_klass, method_name, method_signature);

    if (resolved_method.is_null()) {
      // JSR 292:  see if this is an implicitly generated method MethodHandle.invoke(*...)
      lookup_implicit_method(resolved_method, resolved_klass, method_name, method_signature, current_klass);
    }

    if (resolved_method.is_null()) { // 4. method lookup failed
      // ... throw  java_lang_NoSuchMethodError()
  } }

  // 5. check if method is concrete
  if (resolved_method->is_abstract() && !resolved_klass->is_abstract()) {
    // ... throw java_lang_AbstractMethodError()
  }

  // 6. access checks, etc.
}
```

# Inside the Hotspot VM

The method lookup recursively traverses the super class chain:

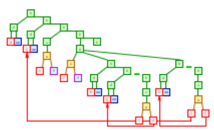
```
MethodDesc* klass::lookup_method(Symbol* name, Symbol* signature) {
  for (KlassDesc* klas = as_klassOop(); klas != NULL; klas = klass::cast(klas)->super()) {
    MethodDesc* method = klass::cast(klass)->find_method(name, signature);
    if (method != NULL) return method;
  }
  return NULL;
}
```

# Inside the Hotspot VM

```
MethodDesc* klass::find_method(ObjArrayDesc* methods, Symbol* name, Symbol* signature) {
  int len = methods->length();
  // methods are sorted, so do binary search
  int i, l = 0 , h = len - 1;
  while (l <= h) {
    int mid = (l + h) >> 1;
    MethodDesc* m = (MethodDesc*)methods->obj_at(mid);
    int res = m->name()->fast_compare(name);
    if (res == 0) {
      // found matching name; do linear search to find matching signature
      // first, quick check for common case
      if (m->signature() == signature) return m;
      // search downwards through overloaded methods
      for (i = mid - 1; i >= l; i--) {
        MethodDesc* m = (MethodDesc*)methods->obj_at(i);
        if (m->name() != name) break;
        if (m->signature() == signature) return m;
      }
      // search upwards
      for (i = mid + 1; i <= h; i++) {
        MethodDesc* m = (MethodDesc*)methods->obj_at(i);
        if (m->name() != name) break;
        if (m->signature() == signature) return m;
      }
      return NULL; // not found
    } else if (res < 0) l = mid + 1;
           else         h = mid - 1;
  }
  return NULL;
}
```

# Single-Dispatching: Summary

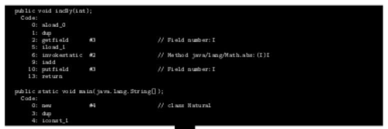
**Compile Time**



**Javac**

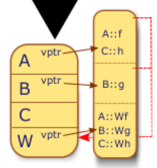
Matches a method call expression *statically* to the *most specific* method signature via `matchMethod( ... )`

**Runtime**



**Hotspot VM**

Interprets `invokevirtual` via `resolve_method(...)`, scanning the superclass chain with `find_method(...)` for the statically fixed `signature`



## Mini-Quiz: Java Method Dispatching

```
class A {
    public static  void p  (Object o) { System.out.println(o); }
    public         void m1 (A a) {      p("m1(A) in A");       }
    public         void m1 () {         m1(new B());           }
    public         void m2 (A a) {      p("m2(A) in A");       }
    public         void m2 () {         m2(this);              }
}
class B extends A {
    public         void m1 (B b) {      p("m1(B) in B");       }
    public         void m2 (A a) {      p("m2(A) in B");       }
    public         void m3 () {         super.m1(this);        }
}
```

`B b = new B(); A a = b; a.m1(b);` m1(B) in B

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`B b = new B(); B a = b; b.m1(a);`

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   public         void m1 () {         m1(new B());            }
   public         void m2 (A a) {      p("m2(A) in A");        }
   public         void m2 () {         m2(this);               }
}
class B extends A {
   public         void m1 (B b) {      p("m1(B) in B");        }
   public         void m2 (A a) {      p("m2(A) in B");        }
   public         void m3 () {         super.m1(this);         }
}
```

| | |
|---|---|
| `B b = new B(); A a = b; a.m1(b);` | m1(A) in A |
| `B b = new B(); B a = b; b.m1(a);` | m1(B) in B |
| `B b = new B(); b.m2();` | |

*m2(A) in A*
*in B*

## Mini-Quiz: Java Method Dispatching

```java
class A {
   public static  void p  (Object o) { System.out.println(o); }
   public         void m1 (A a) {      p("m1(A) in A");        }
   public         void m1 () {         m1(new B());            }
   public         void m2 (A a) {      p("m2(A) in A");        }
   public         void m2 () {         m2(this);               }
}
class B extends A {
   public         void m1 (B b) {      p("m1(B) in B");        }
   public         void m2 (A a) {      p("m2(A) in B");        }
   public         void m3 () {         super.m1(this);         }
}
```

*this*

| | |
|---|---|
| `B b = new B(); A a = b; a.m1(b);` | m1(A) in A |
| `B b = new B(); B a = b; b.m1(a);` | m1(B) in B |
| `B b = new B(); b.m2();` | m2(A) in B |

*invoke A.m1(A) m2(A)*

## Mini-Quiz: Java Method Dispatching

```java
class A {
   public static  void p  (Object o) { System.out.println(o); }
   public         void m1 (A a) {      p("m1(A) in A");        }
   public         void m1 () {         m1(new B());            }
   public         void m2 (A a) {      p("m2(A) in A");        }
   public         void m2 () {         m2(this);               }
}
class B extends A {
   public         void m1 (B b) {      p("m1(B) in B");        }
   public         void m2 (A a) {      p("m2(A) in B");        }
   public         void m3 () {         super.m1(this);         }
}
```

| | |
|---|---|
| `B b = new B(); A a = b; a.m1(b);` | m1(A) in A |
| `B b = new B(); B a = b; b.m1(a);` | m1(B) in B |
| `B b = new B(); b.m2();` | m2(A) in B |
| `B b = new B(); b.m1();` | |

*A.m1(B)*

## Mini-Quiz: Java Method Dispatching

```java
class A {
   public static  void p  (Object o) { System.out.println(o); }
   public         void m1 (A a) {      p("m1(A) in A");        }
   public         void m1 () {         m1(new B());            }
   public         void m2 (A a) {      p("m2(A) in A");        }
   public         void m2 () {         m2(this);               }
}
class B extends A {
   public         void m1 (B b) {      p("m1(B) in B");        }
   public         void m2 (A a) {      p("m2(A) in B");        }
   public         void m3 () {         super.m1(this);         }
}
```

| | |
|---|---|
| `B b = new B(); A a = b; a.m1(b);` | m1(A) in A |
| `B b = new B(); B a = b; b.m1(a);` | m1(B) in B |
| `B b = new B(); b.m2();` | m2(A) in B |
| `B b = new B(); b.m1();` | m1(A) in A |

*A m1(B)*

## Mini-Quiz: Java Method Dispatching

```
class A {
   public static  void p  (Object o) { System.out.println(o); }
   public         void m1 (A a) {      p("m1(A) in A");       }
   public         void m1 () {         m1(new B());           }
   public         void m2 (A a) {      p("m2(A) in A");       }
   public         void m2 () {         m2(this);              }
}
class B extends A {
   public         void m1 (B b) {      p("m1(B) in B");       }
   public         void m2 (A a) {      p("m2(A) in B");       }
   public         void m3 () {         super.m1(this);        }
}
```

```
B b = new B(); A a = b; a.m1(b);                  m1(A) in A
B b = new B(); B a = b; b.m1(a);                  m1(B) in B
B b = new B(); b.m2();                            m2(A) in B
B b = new B(); b.m1();                            m1(A) in A
B b = new B(); b.m3();                            m1(A) in A
```

Section 4

## Multi-Dispatching

## Can we expect more than Single-Dispatching?

Mainstream languages support specialization of first parameter:

C++, Java, C#, Smalltalk, Lisp

**So how do we solve the `equals()` problem?**

1. introspection?
2. generic programming?

## Introspection

```
class Natural {
  Natural(int n){ number=Math.abs(n); }
  int number;
  public boolean equals(Object n){
    if (!(n instanceof Natural)) return false;
    return ((Natural)n).number == number;
  }
}
...
  Set<Natural> set = new HashSet<>();
  set.add(new Natural(0));
  set.add(new Natural(0));
  System.out.println(set);
```

## Introspection

```java
class Natural {
  Natural(int n){ number=Math.abs(n); }
  int number;
  public boolean equals(Object n){
    if (!(n instanceof Natural)) return false;
    return ((Natural)n).number == number;
  }
}
...
  Set<Natural> set = new HashSet<>();
  set.add(new Natural(0));
  set.add(new Natural(0));
  System.out.println(set);
```

```
>$ java Natural
[0]
```

✓ Works ⚠ but burdens programmer with type safety

## Generic Programming

```java
interface Equalizable<T>{
  boolean equals(T other);
}
class Natural implements Equalizable<Natural> {
  Natural(int n){ number=Math.abs(n); }
  int number;
  public boolean equals(Natural n){
    return n.number == number;
  }
}
...
  EqualizableAwareSet<Natural> set = new MyHashSet<>();
  set.add(new Natural(0));
  set.add(new Natural(0));
  System.out.println(set);
```

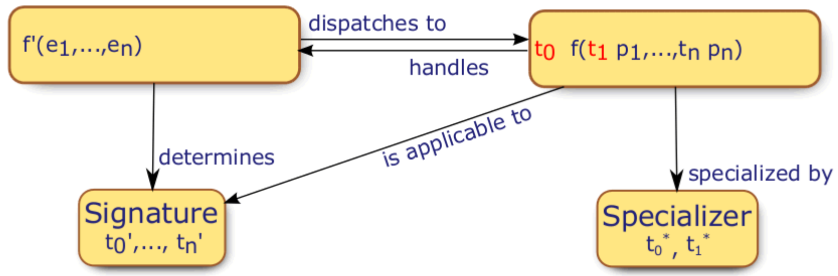
## Generic Programming

```java
interface Equalizable<T>{
  boolean equals(T other);
}
class Natural implements Equalizable<Natural> {
  Natural(int n){ number=Math.abs(n); }
  int number;
  public boolean equals(Natural n){
    return n.number == number;
  }
}
...
  EqualizableAwareSet<Natural> set = new MyHashSet<>();
  set.add(new Natural(0));
  set.add(new Natural(0));
  System.out.println(set);
```

⚠ needs another Set implementation and... ⚠ does not compile

```
>$ javac Natural.java
Natural.java:2: error: name clash: equals(T) in Equalizable and equals(Object)
in Object have the same erasure, yet neither overrides the other
```

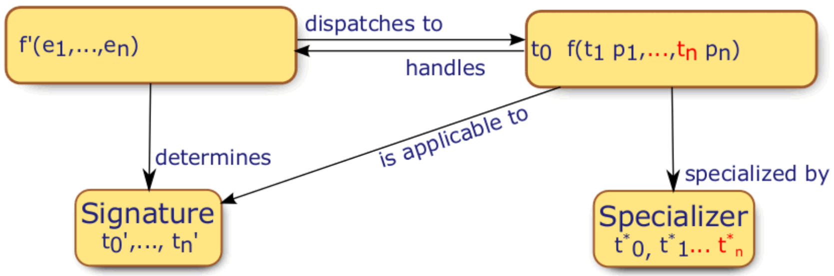
## Formal Model of Multi-Dispatching [7]



# Formal Model of Multi-Dispatching [7]

**Idea**

Introduce Specializers for all parameters

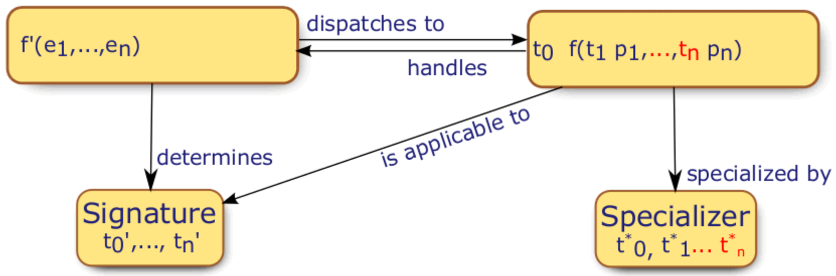




# Formal Model of Multi-Dispatching [7]

**Idea**

Introduce Specializers for all parameters


**How it works**

1. Specializers as subtype annotations to parameter types
2. Dispatcher selects *Most Specific* Concrete Method

# Implications of the implementation

**Type-Checking**

1. Typechecking families of concrete methods introduces checking the existance of unique most specific methods for all *valid visible type tuples*.
2. Multiple-Inheritance or interfaces as specializers introduce ambiguities, and thus induce runtime ambiguity exceptions

**Code-Generation**

1. Specialized methods generated separately
2. Dispatcher method calls specialized methods
3. Order of the dispatch tests determines the most specialized method

**Performance penalty**

The runtime-penalty for multi-dispatching is related to the number of parameters of a multi-method many `instanceof` tests.

# Natural Numbers in Multi-Java [3]

```
class Natural {
  public Natural(int n){ number=Math.abs(n); }
  private int number;
  public boolean equals(Object@Natural n){
    return n.number == number;
  }
}
...
  Set<Natural> set = new HashSet<>();
  set.add(new Natural(0));
  set.add(new Natural(0));
  System.out.println(set);
```

## Natural Numbers Behind the Scenes

```
>$ javap -c Natural
```

```
public boolean equals(java.lang.Object);
 Code:
  0:   aload_1
  1:   instanceof      #2; //class Natural
  4:   ifeq    16
  7:   aload_0
  8:   aload_1
  9:   checkcast       #2; //class Natural
  12:  invokespecial   #28; //Method equals$body3$0:(LNatural;)Z
  15:  ireturn
  16:  aload_0
  17:  aload_1
  18:  invokespecial   #31; //Method equals$body3$1:(LObject;)Z
  21:  ireturn
```

Section 5

## Natively multidispatching Languages

## Clojure

... is a *lisp* dialect for the JVM with:

- Prefix notation
- () – Brackets for lists
- :: – Userdefined keyword constructor ::keyword
- [] – Vector constructor
- `fn` – Creates a lambda expression
  `(fn [x y] (+ x y))`
- `derive` – Generates hierarchical relationships
  `(derive ::child ::parent)`
- `defmulti` – Creates new generic method
  `(defmulti name dispatch-fn)`
- `defmethod` – Creates new concrete method
  `(defmethod name dispatch-val &fn-tail)`

## Principle of Multidispatching in Clojure

```
(derive ::child ::parent)

(defmulti fun (fn [a b] [a b]))
(defmethod fun [::child  ::child ] [a b] "child  equals")
(defmethod fun [::parent ::parent] [a b] "parent equals")

(pr (fun ::child ::child))
```

## Principle of Multidispatching in Clojure

```
(derive ::child ::parent)

(defmulti fun (fn [a b] [a b]))
(defmethod fun [::child  ::child ] [a b] "child  equals")
(defmethod fun [::parent ::parent] [a b] "parent equals")

(pr (fun ::child ::child))
```

```
child equals
```

## Natural Numbers in Clojure

Instanciating the dispatching function as follows approximates the desired behaviour in the Java Natural Numbers case:

```
(defmulti equ (fn [a b] [(::Class a) (::Class b)]))
(defmethod equ [::Natural ::Natural] [c1 c2]
           (== (::number c1) (::number c2)))
(defmethod equ :default [x y] false)
(defn natural [i] {::Class ::Natural ::number i})
(defn object [] {::Class ::Object})
(def n1 (natural 42))
(def n2 (natural 42))
(def o (object ))
(pr (equ n1 n2))
(pr (equ o n1))
```

## More Creative dispatching in Clojure

```
(defn salary [amount]
        (cond (< amount 600)     ::poor
              (>= amount 5000)   ::boss
              :else              ::assi))
(defrecord UniPerson [name wage])

(defmulti  print (fn [person] (salary (:wage person)) ))
(defmethod print ::poor [person] (str "HiWi  " (:name person)))
(defmethod print ::assi [person] (str "Dr.   " (:name person)))
(defmethod print ::boss [person] (str "Prof. " (:name person)))

(pr (print (UniPerson. "Simon" 4000)))
(pr (print (UniPerson. "Stefan" 500)))
(pr (print (UniPerson. "Seidl" 6000)))
```

## Multidispatching

**Pro**

- Generalization of an established technique
- Directly solves problem
- Eliminates boilerplate code
- Compatible with modular compilation/type checking

**Con**

- Counters privileged 1st parameter
- Runtime overhead
- New exceptions when used with multi-inheritance
- *Most Specific Method* ambiguous

**Other Solutions (extract)**

- Dylan
- Scala

# Lessons Learned

## Lessons Learned

1. Dynamically dispatched methods are complex interaction of static and dynamic techniques
2. Single Dispatching as in major OO-Languages
3. Making use of Open Source Compilers
4. Multi Dispatching generalizes single dispatching
5. Multi Dispatching Java
6. Multi Dispatching Clojure