
JavaOne™

Jump-Starting Lambda

Stuart Marks @stuartmarks
Mike Duigou @mjduigou

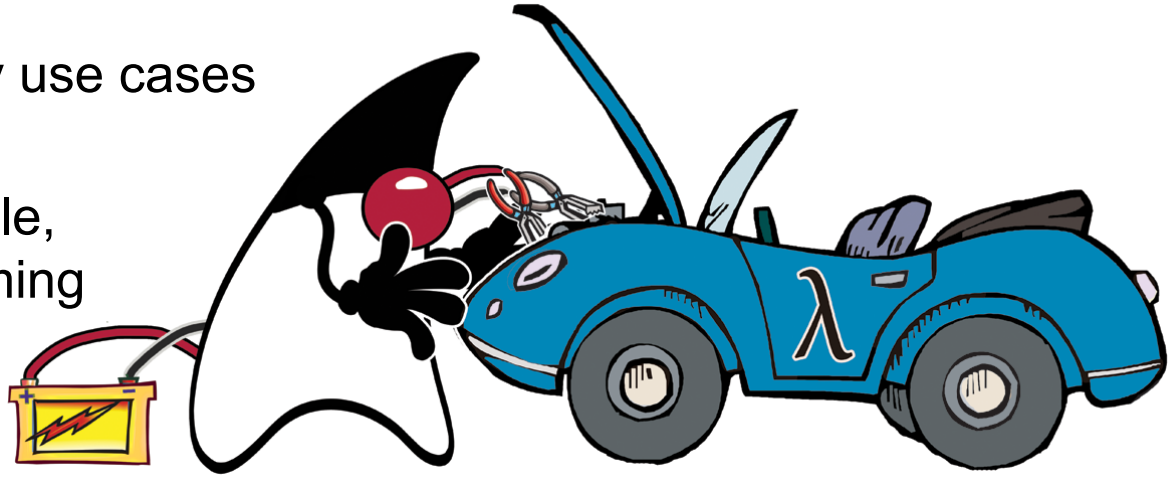
Oracle JDK Core Libraries Team

What is Lambda?

- Essentially an anonymous function
  - allows one to treat code as data
  - provides parameterization of ***behavior*** as opposed to ***values*** or ***types***
  - provides “closures” (but we’re not exploring closure properties here)
- Combined with JVM and class library changes, supports
  - high productivity, flexible, “fluent” style of programming
  - explicit but unobtrusive parallelism
  - useful for simple, everyday programming
  - also heavy (parallel) lifting

Presentation Overview

- Exploring programming techniques leading toward Lambda
- Little emphasis on syntax and language definition
- Examples driven by use cases
- Illustrate lambda's usefulness for simple, everyday programming tasks



Example Overview

- Person object
- Using a collection of Person objects (e.g. a List)
- Selecting some of these Person objects
  - e.g., by age or sex
- Operations using Person objects
  - e.g., making an automated phone call (“robocall”)

Canonical Example Object

```
class Person {
    int getAge();
    Sex getSex();
    PhoneNumber getPhoneNumber();
    EmailAddr getEmailAddr();
    PostalAddr getPostalAddr();
    /* ... */
}
```


Robocall Every Person

```
void robocallEveryPerson() {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        PhoneNumber num = p.getPhoneNumber();
        robocall(num);
    }
}
```


Some Use Cases

- Select only eligible drivers
  - in California, must be 16 years or older
- Select only eligible voters
  - in the U.S., must be 18 years or older
- Select only persons of legal drinking age
  - in California, must be 21 years or older

Robocall Eligible Drivers

```
void robocallEligibleDrivers() {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (p.getAge() >= 16) {
            PhoneNumber num = p.getPhoneNumber();
            robocall(num);
        }
    }
}
```


Robocall Eligible Voters

```
void robocallEligibleVoters() {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (p.getAge() >= 18) {
            PhoneNumber num = p.getPhoneNumber();
            robocall(num);
        }
    }
}
```


Robocall Persons of Legal Drinking Age

```
void robocallLegalDrinkers() {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (p.getAge() >= 21) {
            PhoneNumber num = p.getPhoneNumber();
            robocall(num);
        }
    }
}
```


Duplicated code!
Notice a pattern?

Solution: Add a Parameter!

```
void robocallPersonsOlderThan(int age) {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (p.getAge() >= age) {
            PhoneNumber num = p.getPhoneNumber();
            robocall(num);
        }
    }
}
```


Using Parameters

```
void robocallDrivers() {
    robocallPersonsOlderThan(16);
}

void robocallVoters() {
    robocallPersonsOlderThan(18);
}

void robocallDrinkers() {
    robocallPersonsOlderThan(21);
}
```


Additional Use Case

- Commercial pilots have mandatory retirement age of 65
- Previously we parameterized a ***value***
- Now, we want to parameterize ***less-than*** or ***greater-than***
  - Add a boolean?

Boolean Parameter Encodes Less-or-Greater

```
void robocallPersonsWithAgeLimit(int age, boolean lessThan)
{
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if ( lessThan && (p.getAge() < age) ||
             !lessThan && (p.getAge() >= age)) {
            PhoneNumber num = p.getPhoneNumber();
            robocall(num);
        }
    }
}
```


Using the Boolean Parameter

```
void robocallEligibleDrivers()
    { robocallPersonsWithAgeLimit(16, false); }

void robocallEligibleVoters()
    { robocallPersonsWithAgeLimit(18, false); }

void robocallLegalDrinkers()
    { robocallPersonsWithAgeLimit(21, false); }

void robocallEligiblePilots()
    { robocallPersonsWithAgeLimit(65, true); }
```


Let's face it, this sucks

Corrected Use Case

- Commercial pilots also have a ***minimum*** age of 23
  - as well as a mandatory retirement age of 65
- Use an age range instead...

Parameters for Age Range

```
void robocallPersonsInAgeRange(int low, int high) {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (low <= p.getAge() && p.getAge() < high) {
            PhoneNumber num = p.getPhoneNumber();
            robocall(num);
        }
    }
}
```


Using Age Range


```
void robocallEligibleDrivers()
    { robocallPersonsInAgeRange(16, MAX); }

void robocallEligibleVoters()
    { robocallPersonsInAgeRange(18, MAX); }

void robocallLegalDrinkers()
    { robocallPersonsInAgeRange(21, MAX); }

void robocallEligiblePilots()
    { robocallPersonsInAgeRange(23, 65);  }
```

Additional Use Case

- United States Selective Service (national service program)
  - Age range 18 to 25 (inclusive)

```
void robocallSelectiveService() {
    robocallPersonsInAgeRange(18, 26);
}
```


Corrected Use Case

- United States Selective Service
  - Age range 18 to 25 (inclusive), ***men only***
- Change to:

```
void robocallSelectiveService() {
    robocallPersonsInAgeRange(18, 26, MALE);
}
```

```
enum Sex { MALE, FEMALE }
```

- Works, but what about queries that don't care about sex?
  - Add `DONT_CARE` to enum Sex? Mixes data with query value.
  - Use null? (Yes, enums can be null; weird special case.)

Parameterized Computation

- Value parameterization is useful, but only to a certain point
  - Problem: meta-information is communicated “in-band”
  - In these cases we need a value that means “don’t care”
  - Sometimes special values can be found that work:
    - `0, -1, Integer.MAX_VALUE, null`
  - If not, add more boolean, enum parameters
- Just age and sex, but already we sort of need a query language
- A giant leap: parameterize ***behavior*** instead of values
  - Make a method’s parameter be a ***function*** instead of a ***value***

Functions: Parameters and Return Values

(int, int) → int	example: addition
String → int	example: length
Person → boolean	example: several, let's revisit

Examples of Person → boolean Functions

```
boolean checkIfPersonIsEligibleToDrive(Person p) {
    return p.getAge() >= 16;
}

boolean checkIfPersonIsEligibleToVote(Person p) {
    return p.getAge() >= 18;
}

boolean checkIfPersonIsLegalToDrink(Person p) {
    return p.getAge() >= 21;
}
```


Examples of Person → boolean Functions

```
boolean checkIfPersonIsEligiblePilot(Person p) {
    return p.getAge >= 23 && p.getAge() < 65;
}

boolean checkIfPersonEligibleForSelectiveService(Person p)
{
    return p.getSex() == MALE &&
           p.getAge() >= 18 &&
           p.getAge() <= 25;
}
```


How To Pass a Function in Java?

- Use anonymous inner classes:

```
new Thread(
    new Runnable() {
        public void run() {
            System.out.println("I'm another thread!");
        }
    }
).start();
```


What is the Type of a Function in Java?

( ) → void

```
interface Runnable {
    public void run();
}
```

empty argument list

*This is a **functional interface** — an interface with a single method **

* To be precise, we should say *single abstract method,* since in Java 8 it is now possible for interfaces to have implementations via the *default method* feature.

Predicate: Function Returning Boolean

Person → boolean

```
interface PersonPredicate {
    boolean testPerson(Person p);
}
```


A Generalized Predicate

T → boolean

```
interface Predicate<T> {
    boolean test(T t);
}
```


Using a Function Passed as a Parameter

```
void robocallMatchingPersons(Predicate<Person> pred) {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (pred.test(p)) {
            PhoneNumber num = p.getPhoneNumber();
            robocall(num);
        }
    }
}
```


Passing a Function as a Parameter

```
void robocallEligibleDrivers() {
    robocallMatchingPersons(
        new Predicate<Person>() {
            public boolean test(Person p) {
                return p.getAge() >= 16;
            }
        });
}
```


Passing a Function as a Parameter

```
void robocallEligibleVoters()  {
    robocallMatchingPersons(
        new Predicate<Person>() {
            public boolean test(Person p) {
                return p.getAge() >= 18;
            }
        });
}
```


Passing a Function as a Parameter

```
void robocallLegalDrinkers()   {
    robocallMatchingPersons(
        new Predicate<Person>() {
            public boolean test(Person p) {
                return p.getAge() >= 21;
            }
        });
}
```


Passing a Function as a Parameter

```
void robocallEligiblePilots()  {
    robocallMatchingPersons(
        new Predicate<Person>() {
            public boolean test(Person p) {
                return p.getAge() >= 23 &&
                       p.getAge() < 65;
            }
        });
}
```


Passing a Function as a Parameter

```
void robocallSelectiveServiceCandidates()  {
    robocallMatchingPersons(
        new Predicate<Person>() {
            public boolean test(Person p) {
                return p.getSex() == MALE &&
                       p.getAge() >= 18 &&
                       p.getAge() <= 25;
            }
        });
}
```


Powerful, but verbose, and very, very painful

The Significant Part

```
void robocallEligibleDrivers() {
    robocallMatchingPersons(
        new Predicate<Person>() {
            public boolean test(Person p) {
                return p.getAge() >= 16;
            }
        });
}
```


The Boilerplate

```
void robocallEligibleDrivers() {
    robocallMatchingPersons(
        new Predicate<Person>() {
            public boolean test(Person p) {
                return p.getAge() >= 16;
            }
        });
}
```


Erase the Boilerplate

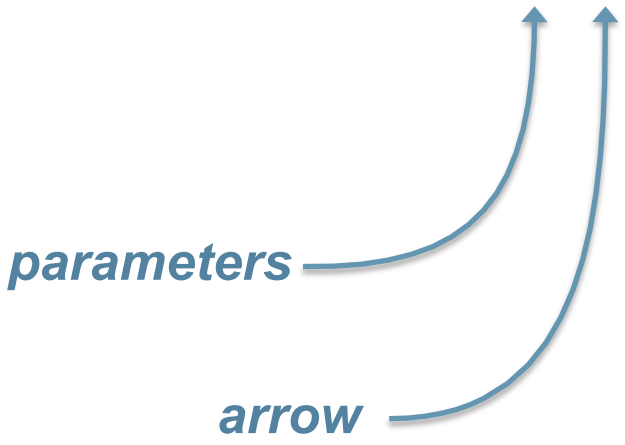
```
void robocallEligibleDrivers() {
    robocallMatchingPersons(

                                        p
                    -> p.getAge() >= 16

        );
}
```


Our First Lambda Expression!

```
void robocallEligibleDrivers() {
    robocallMatchingPersons(p -> p.getAge() >= 16);
}
```

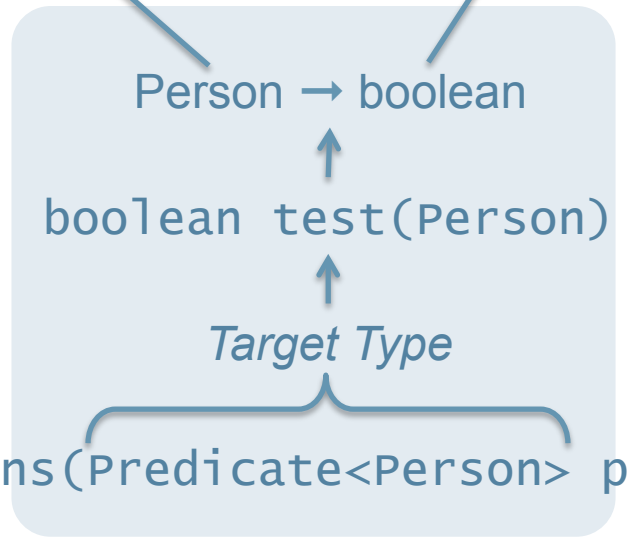


Lambda expressions are converted to instances of functional interfaces

Our First Lambda Expression!

```
void robocallEligibleDrivers() {
    robocallMatchingPersons(p -> p.getAge() >= 16);
}
```

Type Inference:




```
void robocallMatchingPersons(Predicate<Person> pred) {
    ...
}
```

Rewrites Using Lambda

```
void robocallEligibleDrivers() {
    robocallMatchingPersons(p -> p.getAge() >= 16);
}

void robocallEligibleVoters()  {
    robocallMatchingPersons(p -> p.getAge() >= 18);
}

void robocallLegalDrinkers()   {
    robocallMatchingPersons(p -> p.getAge() >= 21);
}
```


Rewrites Using Lambda

```
void robocallEligiblePilots()  {
    robocallMatchingPersons(
        p -> p.getAge() >= 23 && p.getAge() < 65);
}

void robocallSelectiveServiceCandidates()  {
    robocallMatchingPersons(p -> p.getSex() == MALE &&
                                 p.getAge() >= 18 &&
                                 p.getAge() <= 25);
}
```


Where Else Can We Use Lambda?

```
void robocallMatchingPersons(Predicate<Person> pred) {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (pred.test(p)) {
            PhoneNumber num = p.getPhoneNumber();
            robocall(num);
        }
    }
}
```


Where Else Can We Use Lambda?

```
void txtmsgMatchingPersons(Predicate<Person> pred) {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (pred.test(p)) {
            PhoneNumber num = p.getPhoneNumber();
            txtmsg(num);
        }
    }
}
```


Functional Interface: Block

PhoneNumber → void

T → void

```
interface Block<T> {
    void apply(T t);
}
```


Extract & Parameterize Block Function

```
void processMatchingPersons(Predicate<Person> pred,
                            Block<PhoneNumber> block) {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (pred.test(p)) {
            PhoneNumber num = p.getPhoneNumber();
            block.apply(num);
        }
    }
}
```


Examples of Block

```
processMatchingPersons(p -> p.getAge() >= 16,
                       num -> { robocall(num); });

processMatchingPersons(p -> p.getAge() >= 18,
                       num -> { txtmsg(num); });
```

These are "statement lambdas" as opposed to "expression lambdas"

What Else Can We Extract?

```
void processMatchingPersons(Predicate<Person> pred,
                            Block<PhoneNumber> block) {
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (pred.test(p)) {
            PhoneNumber num = p.getPhoneNumber();
            block.apply(num);
        }
    }
}
```


Functional Interface: Mapper

Person → PhoneNumber

T → U

```
interface Mapper<T,U> {
    U map(T t);
}
```


Extract & Parameterize Mapper Function

```
void processMatchingPersons(Predicate<Person> pred,
                            Mapper<Person,PhoneNumber> mapper,
                            Block<PhoneNumber> block)
{
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (pred.test(p)) {
            PhoneNumber num = mapper.map(p);
            block.apply(num);
        }
    }
}
```

Examples of Mapper

```
processMatchingPersons(p -> p.getAge() >= 16,
                       p -> p.getHomePhoneNumber(),
                       num -> { robocall(num); });

processMatchingPersons(p -> p.getAge() >= 18,
                       p -> p.getMobilePhoneNumber(),
                       num -> { txtmsg(num); });
```


Refactoring & Cleanup

```
void processMatchingPersons(Predicate<Person> pred,
                            Mapper<Person,PhoneNumber> mapper,
                            Block<PhoneNumber> block)
{
    List<Person> list = gatherPersons();
    for (Person p : list) {
        if (pred.test(p)) {
            PhoneNumber num = mapper.map(p);
            block.apply(num);
        }
    }
}
```


Refactoring & Cleanup

```
void processMatchingPersons(List<Person> list,
                            Predicate<Person> pred,
                            Mapper<Person,PhoneNumber> mapper,
                            Block<PhoneNumber> block)
{
    for (Person p : list) {
        if (pred.test(p)) {
            PhoneNumber num = mapper.map(p);
            block.apply(num);
        }
    }
}
```


Refactoring & Cleanup

```
void processMatchingPersons(Iterable<Person> source,
                            Predicate<Person> pred,
                            Mapper<Person,PhoneNumber> mapper,
                            Block<PhoneNumber> block)
{
    for (Person p : source) {
        if (pred.test(p)) {
            PhoneNumber num = mapper.map(p);
            block.apply(num);
        }
    }
}
```


Usage After Refactoring

```
// robocall eligible drivers
processMatchingPersons(gatherPersons(),
                       p -> p.getAge() >= 16,
                       p -> p.getHomePhoneNumber(),
                       num -> { robocall(num); });

// text-message eligible voters
processMatchingPersons(gatherPersons(),
                       p -> p.getAge() >= 18,
                       p -> p.getMobilePhoneNumber(),
                       num -> { txtmsg(num); });
```

What Does processMatchingPersons Really Do?

```
void processMatchingPersons(Iterable<Person> source,
                            Predicate<Person> pred,
                            Mapper<Person,PhoneNumber> mapper,
                            Block<PhoneNumber> block)
{
    for (Person p : source) {
        if (pred.test(p)) {
            PhoneNumber num = mapper.map(p);
            block.apply(num);
        }
    }
}
```

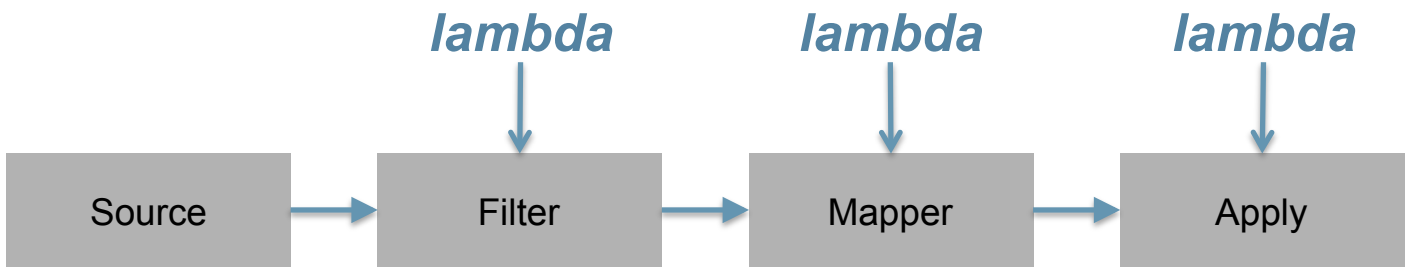

What Does processMatchingPersons Really Do?

```
<< source provides Person objects >> {
    << filter each Person through a predicate >> {
        << map each Person to a PhoneNumber >>
        << apply a function to each PhoneNumber >>
    }
}
```


A General Form of processMatchingPersons

```
<< source provides elements >> {
    << filter each through a predicate >> {
        << map each value to another value >>
        << apply a function to each value >>
    }
}
```


A General Form of processMatchingPersons



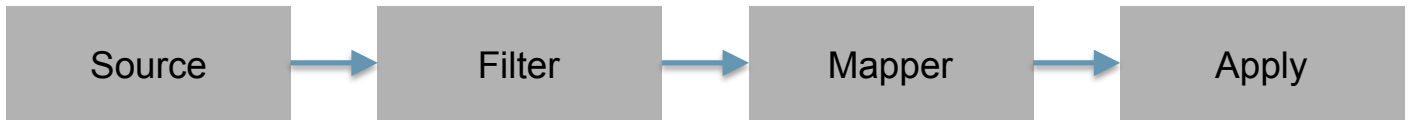
OK great, but can we really write the code this way?

Building a Pipeline for Robocalling

```
void robocallEligibleDrivers() {
    gatherPersons()
```

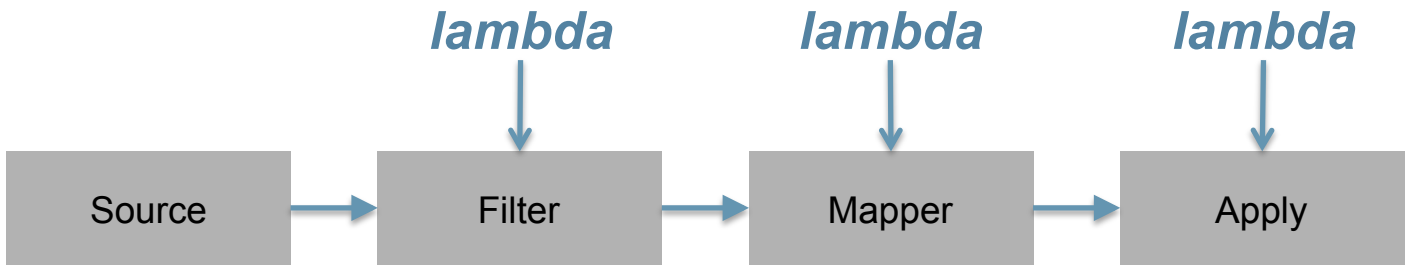

Building a Pipeline for Robocalling

```
void robocallEligibleDrivers() {
    gatherPersons().stream()
        .filter(...)
        .map(...)
        .forEach(...);
}
```



Building a Pipeline

```
void robocallEligibleDrivers() {
    gatherPersons().stream()
        .filter(p -> p.getAge() >= 16)
        .map(p -> p.getHomePhoneNumber())
        .forEach(num -> { robocall(num); });
}
```



Changing the Pipeline

```
void robocallEligibleDrivers() {
    gatherPersons().stream()
        .filter(p -> p.getAge() >= 16)
        .map(p -> p.getHomePhoneNumber())
        .filter(num -> !num.isOnDoNotCallList())
        .forEach(num -> { robocall(num); });
}
```

Changing the Pipeline

```
void textMessageEligibleDrivers() {
    gatherPersons().stream()
        .filter(p -> p.getAge() >= 16)
        .map(p -> p.getMobilePhoneNumber())
        .filter(num -> !num.isOnDoNotCallList())
        .forEach(num -> { txtmsg(num); });
}
```

Changing the Pipeline

```
void spamEligibleDrinkers() {
    gatherPersons().stream()
        .filter(p -> p.getAge() >= 21)
        .map(p -> p.getEmailAddr())
        .forEach(addr -> { sendEmail(addr); });
}
```


Changing the Pipeline

```
void bulkMailEligiblePilots() {
    gatherPersons().stream()
        .filter(p -> p.getAge() >= 23 && p.getAge() < 65)
        .map(p -> p.getPostalAddr())
        .forEach(addr -> { sendBulkMail(addr); });
}
```


Changing the Pipeline

```
void recruitSelectiveServiceCandidates() {
    gatherPersons().stream()
        .filter(p -> p.getSex() == MALE &&
                p.getAge() >= 18 &&
                p.getAge() <= 25)
        .map(p -> p.getHomeAddr())
        .forEach(addr -> { sendArmyRecruiter(addr); });
}
```

How To Do Stuff in Parallel?

```
void robocallEligibleDrivers() {
    gatherPersons().parallelStream()
        .filter(p -> p.getAge() >= 16)
        .map(p -> p.getHomePhoneNumber())
        .forEach(num -> { robocall(num); });
}
```


Functional Interfaces in java.util.functions

`BinaryOperator<T>`	(T, T) → T
`Block<T>`	T → void
`Combiner<T,U,V>`	(T, U) → V
`Factory<T>`	() → T
`FlatMapper<T,R>`	T → R*
`Mapper<T,U>`	T → U
`Predicate<T>`	T → boolean
`UnaryOperator<T>`	T → T

Stream Operations

java.util.stream.Stream

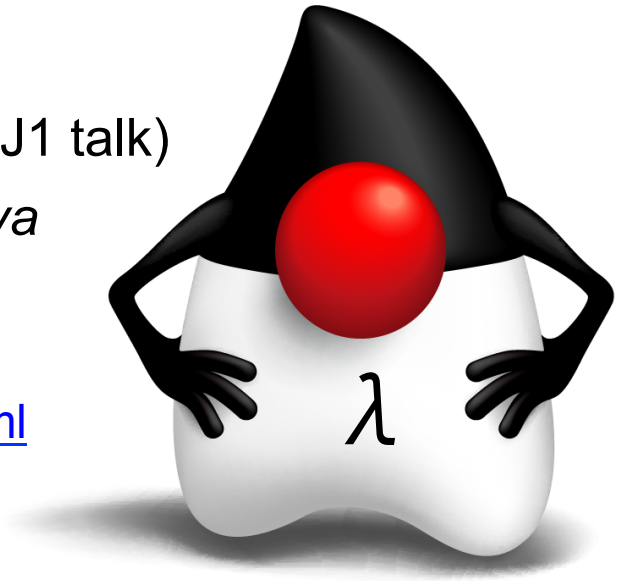
- filter(pred)
- map(mapper)
- forEach(block)
- flatMap(flat-mapper)
- tee(block)
- uniqueElements()
- sorted(comparator)
- into(collection)
- toArray(array-factory)
- any / all / noneMatch(pred)
- findFirst / Any(pred)
- cumulate(binop)
- reduce(binop) / reduce(base, binop)
- fold(base-factory, reducer, combiner)
- groupBy(mapper)
- reduceBy(mapper, base-factory, reducer)

Summary

- Lambdas are anonymous functions
  - They enable parameterization of behavior
- Lambda expressions are converted to functional interfaces
  - A functional interface is an interface with a single (abstract) method
- Two kinds: expression lambdas and statement lambdas
- Compiler type inference reduces boilerplate
- Lambda + new library APIs enable writing programs that are:
  - ***powerful, fluid, expressive, parallel***

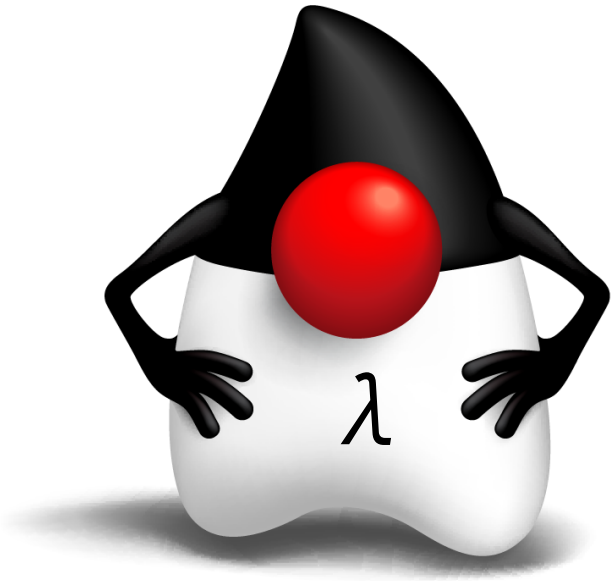
Related Talks – All Brian Goetz, All The Time

- *The Road To Lambda* (earlier J1 talk)
- *Lambda: A Peek Under the Hood* (earlier J1 talk)
- *Implementing Lambda Expressions in Java*
  - JVM Language Summit 2012
  - http://www.oracle.com/technetwork/java/javase/community/jvmls2012-1840099.html
- *Language / Library / VM Co-evolution in Java SE 8,* Devoxx 2011
  - https://blogs.oracle.com/briangoetz/entry/slides_from_devoxx_talk_on

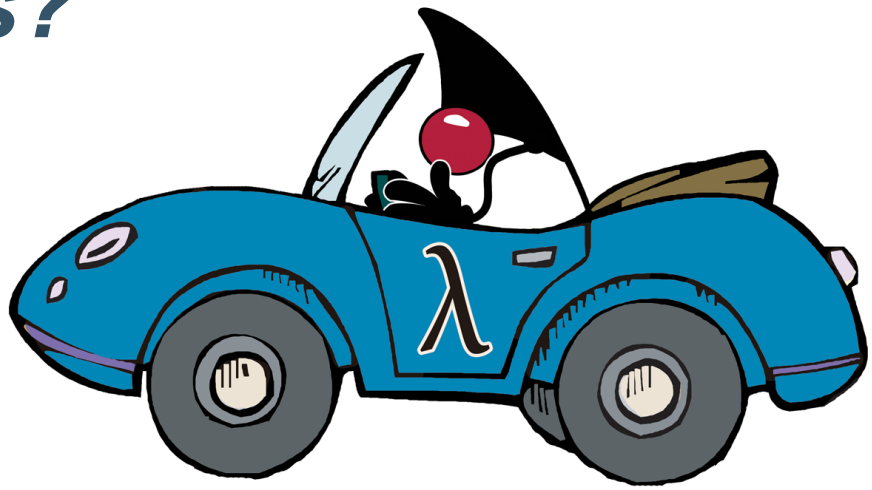


Links

- Lambda project page:
  http://openjdk.java.net/projects/lambda/
- Source code:
  http://hg.openjdk.java.net/lambda/lambda
- Binaries:
  http://jdk8.java.net/lambda/
- FAQ (Maurice Naftalin):
  http://www.lambdafaq.org/



Any Questions?



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