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# A Metadata Facility for Java

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# Agenda

- Background and motivation
- JSR 175 specification
  - Source syntax
  - Processing model
  - Runtime API
  - Class file format
  - Standard annotations
  - Annotation type evolution

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# Background

- Java programs are imperative (how), not declarative (what)
- Java has declarations, but only for core language constructs (class, method, *etc*.)
- The programmer can't declare other things about the program
- This limits the scope for tools to help the developer be more productive

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# The Solution

- Allow user-defined metadata annotations to be declared within a Java program
- These annotations can be processed by tools or at runtime
- They aren't part of the program logic but can (in some sense) affect the meaning of the program
- Semantics can be standard or user-defined

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# Benefits

- Productivity – quicker to write
- Clarity – easier to understand
- Flexibility – easier to change
- Correctness – fewer runtime errors

- *Caveat: Keep annotations simple and readable*

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# Other Examples of Metadata in Java

- J2EE deployment descriptors
- Type information in class files
- Descriptive information about images and streams (*e.g.*, JPEG)
- Information about JDBC databases
- Information about JMX Mbeans
- Javadoc comments

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# Examples of Metadata in .NET

- Definition of Web service classes and methods
- Control of data serialization
- Security enforcement
- Design-time support for components

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# Terminology

- Metadata is a very widely used term
- JSR 175 (the subject of this talk) is about program annotations for Java
- Program annotations are a kind of metadata, and JSR 175 was originally entitled "A Metadata Facility for the Java Programming Language"

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# Terminology (Continued)

- To avoid confusion and clarify the intended scope of JSR 175, it is now entitled "A Program Annotation Facility for the Java Programming Language"

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# JSR 175 Annotations

- Simple metadata specified in source code
- Attached to program syntactic elements
- Limited range of types
- Stored in the class file
- Can be read by tools or at runtime
- Introduced in J2SE 1.5

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# Annotation Syntax

```
@WebService(contextRoot = “Demo”,
            style = WRAPPED,
            sei = StockQuote.class,
            serviceElement = “StockQuoteService”)
public class Demo1 {
    ...
    @Operation public float getPrice(String symbol) {
        ...
    }
}

@Namespace(“www.ibm.com/Demo")
public interface StockQuote extends java.rmi.Remote { ... }
```

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# Annotations

- Annotations have types, members, and values
- General syntax, with some shorthand forms for common cases
- Optional defaults for member values

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# Annotation Type Declarations

```
public @interface WebService {
    String contextRoot();
    WSDLStyle style();
    WSDLUse use() default LITERAL;
    Class<? extends java.rmi.Remote> sei();
    String serviceElement();
}
public enum WSDLStyle {WRAPPED, DOC, RPC}
public enum WSDLUse {LITERAL, ENCODED}

public @interface Operation { }

public @interface Namespace { String value(); }
```

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# More on Annotation Type Declarations

- Packaged and imported like other Java types
- Members can be primitive, String, Class, enum, array, or annotation
- Can themselves be annotated using standard meta-annotation types
  - @Target(ElementTypeArray)
  - @Retention(RetentionPolicy)
  - @Inherited
  - @Documented

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# Meta-annotations

```
@Target(TYPE) public @interface WebService {
    String contextRoot();
    WSDLStyle style();
    WSDLUse use() default LITERAL;
    Class<? extends java.rmi.Remote> sei();
    String serviceElement();
}
public enum WSDLStyle {WRAPPED, DOC, RPC}
public enum WSDLUse {LITERAL, ENCODED}

@Target(METHOD) @Retention(RUNTIME)
public @interface Operation { }

@Target({TYPE, METHOD})
public @interface Namespace { String value(); }
```

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# Retention Policy

- Runtime retention
  - annotations are present in source code, the class file, and at runtime
- Class retention (the default)
  - annotations are present in source code and the class file, but are not present at runtime
- Source retention
  - annotations are only present in source code and are not present in the class file or at runtime

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# Complex Annotations

- Annotation types can be used to declare other annotation types

```
public @interface Name {
    String first();
    String last();
}

public @interface Author {
    Name value();
}

public @interface Reviewer {
    Name value();
}
```

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# Using Annotations

- Annotations can be used anywhere that declaration modifiers can appear
  - class, interface, field, method, parameter, constructor, enum, local variable
  - also on enum constants and packages
    - package annotation placed in package-info.java
- No repeated annotations of same type
- By convention, annotations precede other modifiers

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# Writing Annotations

- Three kinds of annotation:
  - Normal annotation
  - Marker annotation
  - Single-value annotation
- The last two are shorthands for the first

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# Writing Annotations

```
// Normal annotations
@Copyright(date = 2003, owner = “IBM Corporation”)
@Author(name = “Simon Nash”)
@Authors(names = {“Tom”, “Dick”, “Harry”})  // array value
@Authors(names = {“Tom”}) // single-element array
@Authors(names = “Tom”)  //shorthand for single-element array
@WebService()

// Marker annotation
@WebService  // same as @WebService()

// Single-value annotation
@Name(“Jane Doe”)  // same as @Name(value = “Jane Doe”)
```

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# Processing Models

- Source based: process annotations from the source file
- Class based: process annotations from the class file

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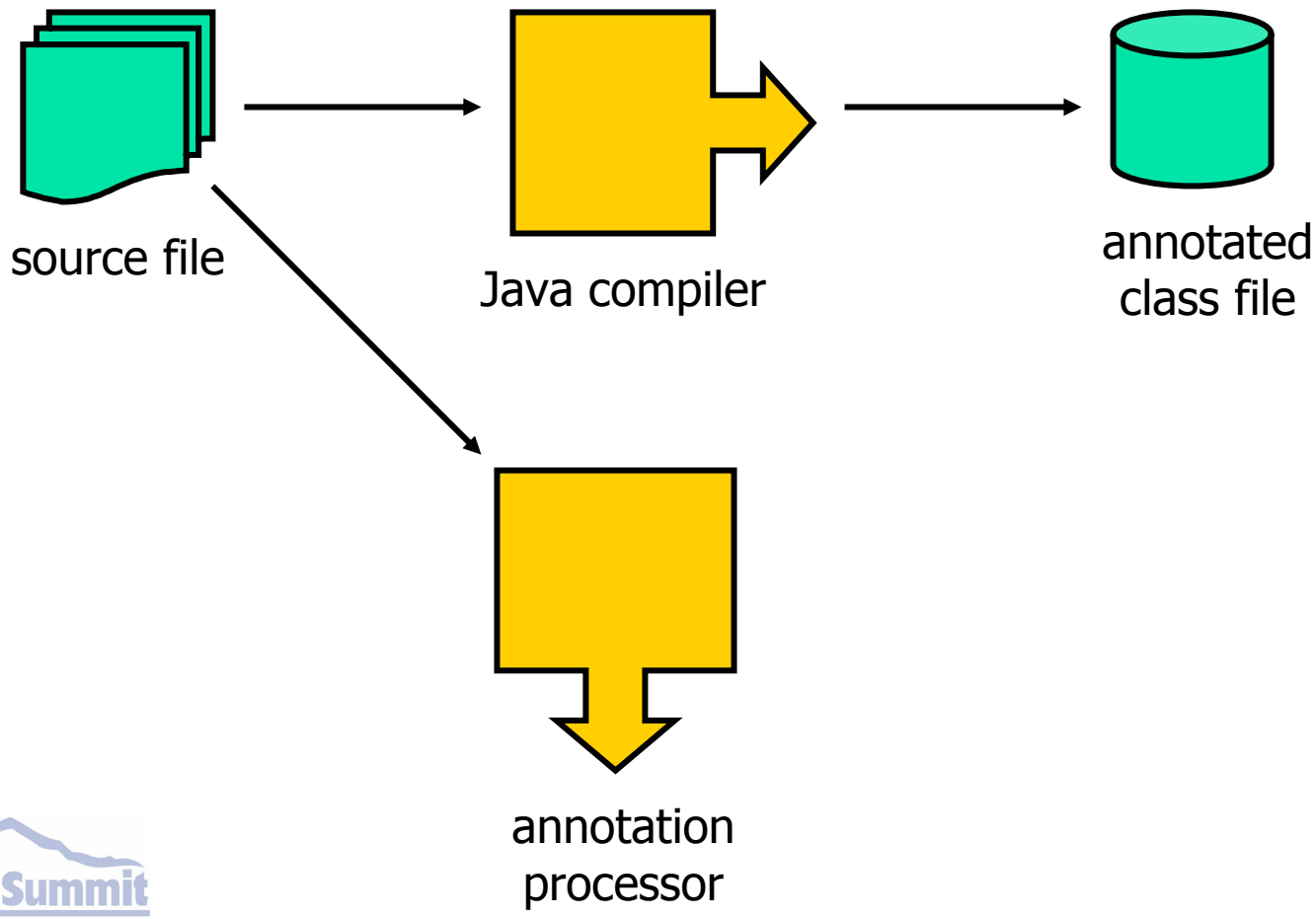
# Source-based Processing



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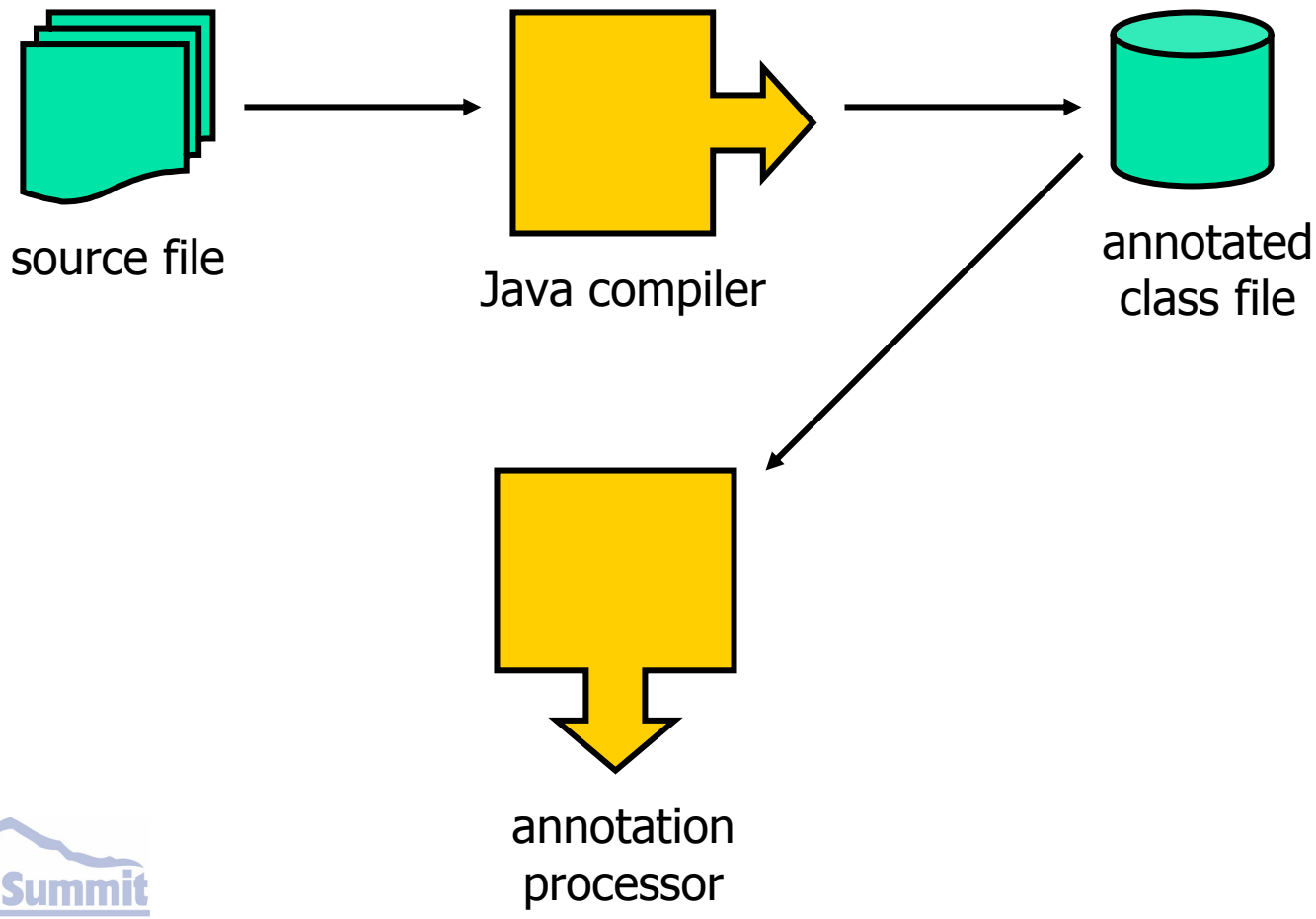
# Class-based Processing



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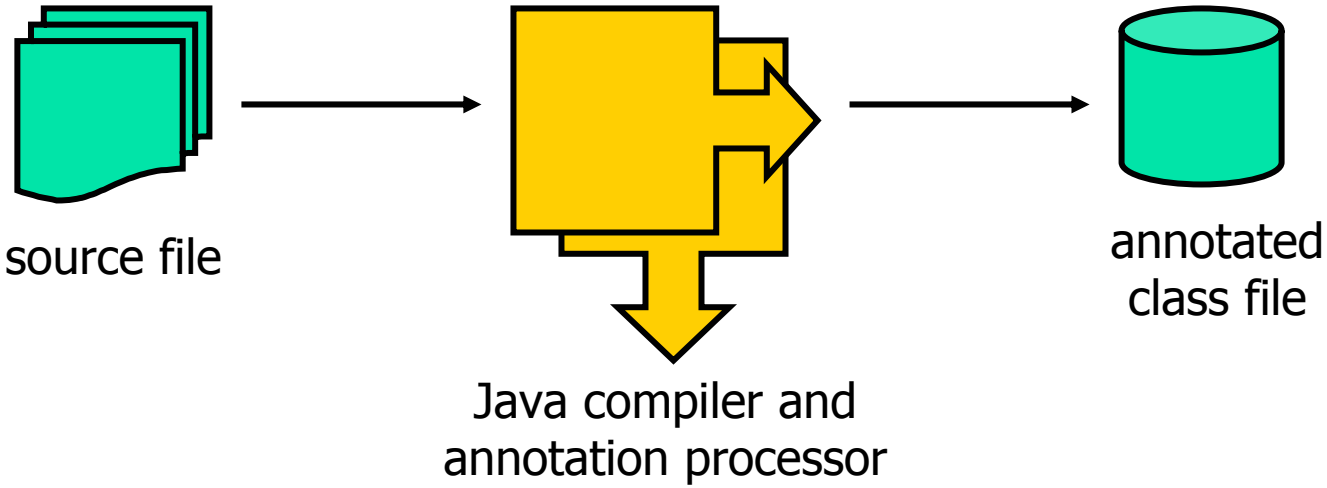
# Integrated Tool Set



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# Source-based Processing

- Use source file to perform annotation-specific error checking, any other required processing, and write annotations to the class file
  - ✓ provides best diagnostics, with line numbers for error locations
  - ✓ can handle all annotation types
  - x requires source file to be available

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# Class-based Processing

- Use standard Java compiler to create class file containing same annotations as source
- Do annotation-specific error checking and any other required processing by reading annotations from the class file
  - ✓ Doesn't need the source to be available
  - x Can't handle annotations with SOURCE retention or on local variables
  - x Difficult to provide line numbers in diagnostics

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# Reading Annotations

- Introspectors: programs that query their own annotations at runtime
  - can load both annotation types and programs
- Specific tools: programs that query known annotation types of arbitrary other programs
  - can load annotation types but not programs
- General tools: programs that query arbitrary annotation types of arbitrary other programs
  - can't load annotation types or programs

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# APIs for Reading Annotations

- Introspectors
  - JSR 175 reflection extensions
- Specific tools
  - JSR 175 reflection extensions may be usable if "class mirror" APIs implement these interfaces
- General tools
  - No standard "arm's length" API available
  - JSR 175 has sketch of Doclet API extensions in non-normative appendix

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# JSR 175 Reflection Extensions

```
// Implemented by java.lang.Class,
// java.lang.reflect.AccessibleObject, and java.lang.Package
public interface AnnotatedElement {
    boolean isAnnotationPresent(
        Class<? extends Annotation> annotationType);

    <T extends Annotation> T getAnnotation(
        Class<T> annotationType);

    Annotation[] getAnnotations();

    Annotation[] getDeclaredAnnotations();
}
```

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# JSR 175 Reflection Extensions

```
// Added to java.lang.reflect.Method and
// java.lang.reflect.Constructor
public Annotation[][] getParameterAnnotations();

// Added to java.lang, thrown by methods on annotation
// interfaces that return Class types
public class ClassNotPresentException
          extends RuntimeException {
    public ClassNotPresentException(String className,
          Throwable cause) { }
    public String className() { }
}

// Added to java.lang.Class
public boolean isAnnotationType();
```

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# Class File Format

- RuntimeVisibleAnnotations attribute
  - contains array of annotation structs
  - each of these contains an array of member-value pairs
  - member_value is a union of all possible types for values
- RuntimeInvisibleAnnotations attribute
- RuntimeVisibleParameterAnnotations attribute
  - in method_info, contains array of annotation structs
- RuntimeInvisibleParameterAnnotations attribute
- AnnotationDefault attribute
- For more details, read the JSR 175 spec

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# Standard Annotations

- Meta-annotations (already described)
- java.lang.Overrides

```
// specifies that the target method must be an override
@Target(METHOD) public @interface Overrides { }
```

- As specified by other JSRs:
  - 181, 207, 224, *etc.*

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# Annotation Type Evolution

- Can add members, should specify default
  - java.lang.IncompleteAnnotationError otherwise
- Removing members is OK if they're not accessed
  - java.lang.NoSuchMethodError otherwise
- Changing member types is problematical
  - AssociationTypeMismatchError

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# Type Evolution (Continued)

- Adding defaults is OK; don't remove them
  - compile failure, IncompleteAnnotationError
- Adding targets is OK; don't remove them
  - compile failure, silently discarded at runtime
- Changing retention policy is OK
  - downgrade takes effect immediately
  - upgrade takes effect on recompile

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# JSR 175 limitations

- Not a general solution for Java metadata
  - no programmatic way to create or update annotations
  - annotations in source and class files only
  - limited set of annotation types
- Not intended for modifying source code (*a.k.a.* preprocessing)
- No support for J2SE 1.4 or earlier
- Annotation type inheritance not permitted

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# JSR 175 limitations (Continued)

- Can't attach annotations to arbitrary Java code blocks or statements
- Some annotations can't be written to the class file
  - local variable annotations are source-only
- No standard "arm's length" API for reading annotations without loading classes

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# Use Cases for Annotations

- Simplified Web services development/deployment
- Simplified EJB or Servlet development/deployment
- Java to XML mapping
- WSDL to Java mapping
- BeanInfo replacement
- Relational database schema mapping
- Custom serialization
- Identifying optimization opportunities
- *etc., etc.*

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# JSR 181

- Web services annotations for simplified development and deployment
- Based on JSR 175 (may include transitional support for J2SE 1.4)
- Example attributes: operation, protocol, target-namespace, wsdl, schema, xmlns
- Can process annotations from source file or from class file
- Other issues still being discussed by Expert Group

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# JSR 181 Example

```
@Protocol(httpSoap=true, soapStyle=documentLiteral)
@TargetNamespace(namespace=http://schemas.myDomain.com/ws/)
public class MyWebService {
    @Operation
    public double zipDistance(
            String fromZip, String toZip) {
        ...
        return distance.getDistance(fromZip, toZip);
    }
    ...
}
```

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# References

- JSR 175: http://www.jcp.org/en/jsr/detail?id=175
- JSR 181: http://www.jcp.org/en/jsr/detail?id=181
- J2SE 1.5 (Tiger): http://www.jcp.org/en/jsr/detail?id=176

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# Summary

- Annotations expand the scope of Java programming
  - more declarative, less imperative
- JSR 175 provides the base framework, but the value comes from the annotations that people create
  - what will be the killer annotations?
- Tools are the key

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# Questions?

?