



# Summary

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- ▶ The JGraphT library
- ▶ Creating graphs

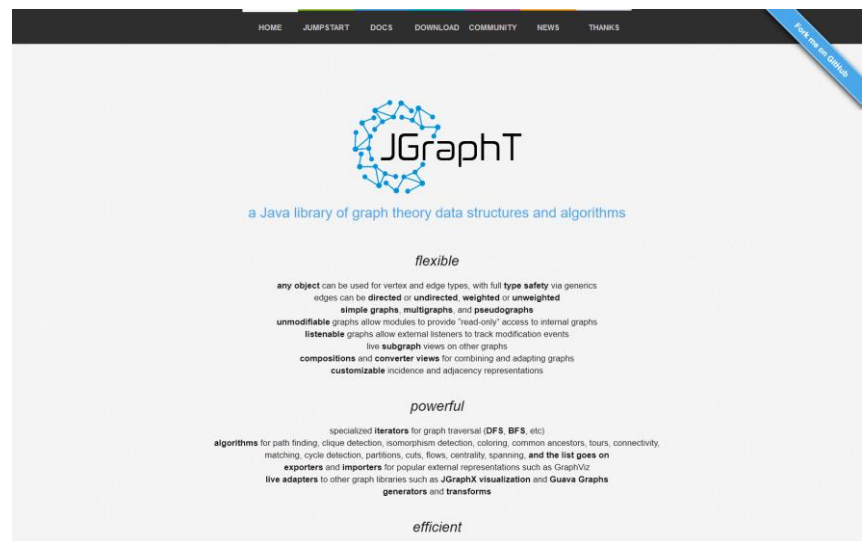
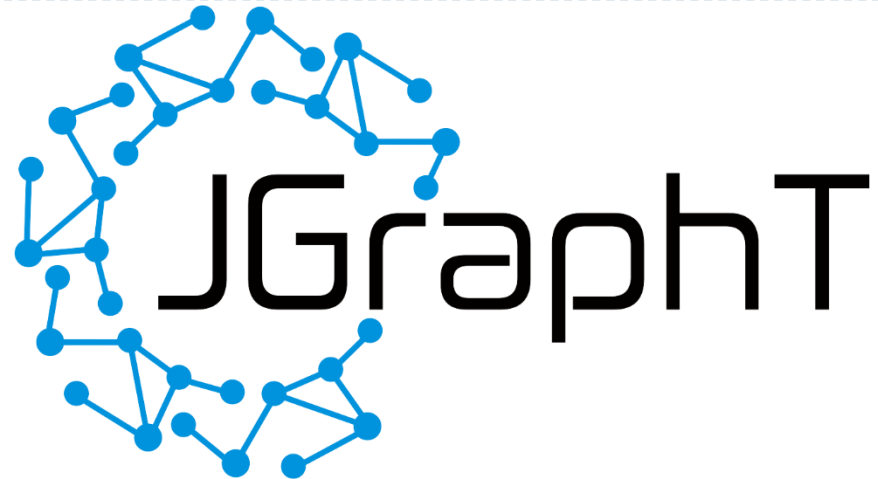


# Introduction to jGraphT

The jGraphT library

# JGraphT

- ▶ <http://jgrapht.org>
  - ▶ (do not confuse with [jgraph.com](http://jgraph.com))
- ▶ Free Java graph library that provides graph objects and algorithms
- ▶ Easy, type-safe and extensible thanks to `<generics>`
- ▶ Just add **jGraphT 1.5.1** to your project
  - ▶ Already in our Maven Archetype



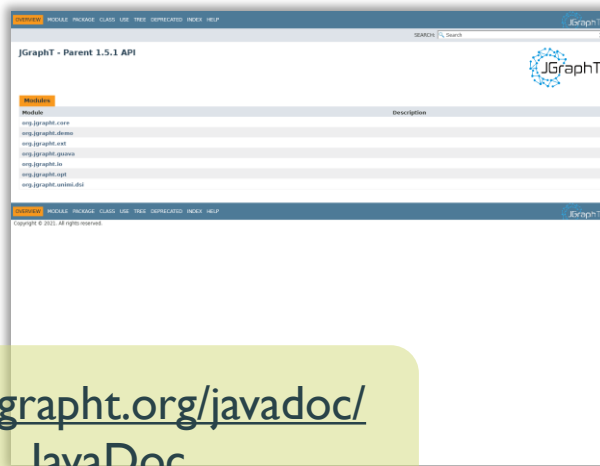
# jGraphT Pointers



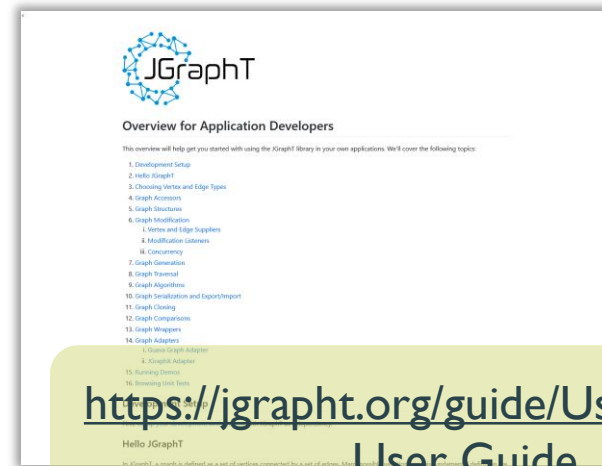
<https://jgrapht.org/>  
Main website



<https://github.com/jgrapht/jgrapht>  
GitHub repository



<https://jgrapht.org/javadoc/>  
JavaDoc



<https://jgrapht.org/guide/UserOverview>  
User Guide

# JGraphT structure

<https://jgrapht.org/javadoc/>

## Packages in the module org.jgrapht.core

org.jgrapht	The front-end API's interfaces and classes, including <a href="#">Graph</a> .
<b>org.jgrapht.alg</b>	Algorithms provided with <b>JGraphT</b> .
org.jgrapht.event	Event classes and listener interfaces, used to provide a change notification mechanism on graph modification events.
org.jgrapht.generate	Generators for graphs of various topologies.
<b>org.jgrapht.graph</b>	Implementations of various graphs.
org.jgrapht.graph.builder	Various builder for graphs.
org.jgrapht.graph.specifics	Implementations of specifics for various graph types.
org.jgrapht.traverse	Graph traversal means.
org.jgrapht.util	Non-graph-specific data structures, algorithms, and utilities used by <b>JGraphT</b> .

# JGraphT algorithms

<https://jgrapht.org/javadoc/>

## Packages org.jgrapht.alg.

<b>.clique</b>	Clique related algorithms.
<b>.clustering</b>	Graph clustering algorithms.
<b>.color</b>	Graph coloring algorithms.
<b>.connectivity</b>	Algorithms dealing with various connectivity aspects.
<b>.cycle</b>	Algorithms related to graph cycles.
<b>.decomposition</b>	Algorithms for computing decompositions.
<b>.flow</b>	Flow related algorithms.
<b>.mincost</b>	Algorithms for minimum cost flow
<b>.independentset</b>	Algorithms for <a href="#">Independent Set</a> in a graph.
<b>.interfaces</b>	Algorithm related interfaces.
<b>.isomorphism</b>	Algorithms for (sub)graph isomorphism.
<b>.lca</b>	Algorithms for computing lowest common ancestors.
<b>.matching</b>	Algorithms for the computation of matchings.
<b>.partition</b>	Algorithm for computing partitions.
<b>.scoring</b>	Vertex and/or edge scoring algorithms.
<b>.shortestpath</b>	Shortest-path related algorithms.
<b>.spanning</b>	Spanning tree and spanner algorithms.
<b>.tour</b>	Graph tours related algorithms.
<b>.transform</b>	Package for graph transformers
<b>.vertexcover</b>	Vertex cover algorithms.

# Graph objects

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- ▶ All graphs derive from:
  - ▶ Interface `org.jgrapht.Graph<V, E>`
- ▶ **V = type of vertices**
  - ▶ Any class
- ▶ **E = type of edges**
  - ▶ `org.jgrapht.graph.DefaultEdge`
  - ▶ `org.jgrapht.graph.DefaultWeightedEdge`
  - ▶ Your own custom subclass



## <V, E>

---

- ▶ User-defined objects, depending on the problem
- ▶ Must properly define hashCode and equals
  - ▶ The Graph implementation and many graph algorithms use HashSet and HashMap internally!
- ▶ Vertex type V
  - ▶ Your own object
  - ▶ Define hashCode and equals
- ▶ Edge type E
  - ▶ Subclass of DefaultEdge or DefaultWeightedEdge
  - ▶ Do not redefine (override) the provided hashCode and equals

# What is a Graph?

---

```
<<interface>>  
org.jgrapht::Graph  
  
+ addVertex(v : V) : boolean  
+ addEdge(sourceVertex : V, targetVertex : V) : E  
+ addEdge(sourceVertex : V, targetVertex : V, e : E) : boolean  
+ setEdgeWeight(e : E, weight : double) : void  
+ vertexSet() : Set<V>  
+ edgeSet() : Set<E>  
+ containsVertex(v : V) : boolean  
+ containsEdge(e : E) : boolean  
+ containsEdge(sourceVertex : V, targetVertex : V) : boolean  
+ getAllEdges(sourceVertex : V, targetVertex : V) : Set<E>  
+ getEdge(sourceVertex : V, targetVertex : V) : E  
+ getEdgeSource(e : E) : V  
+ getEdgeTarget(e : E) : V  
+ getEdgeWeight(e : E) : double  
+ incomingEdgesOf(vertex : V) : Set<E>  
+ outgoingEdgesOf(vertex : V) : Set<E>  
+ edgesOf(v : V) : Set<E>  
+ inDegreeOf(vertex : V) : int  
+ outDegreeOf(vertex : V) : int  
+ degreeOf(v : V) : int  
+ removeAllEdges(edges : Collection<E>) : boolean  
+ removeAllEdges(sourceVertex : V, targetVertex : V) : Set<E>  
+ removeAllVertices(vertices : Collection<V>) : boolean  
+ removeEdge(e : E) : boolean  
+ removeEdge(sourceVertex : V, targetVertex : V) : E  
+ removeVertex(v : V) : boolean
```

# Graph classes

org.jgrapht

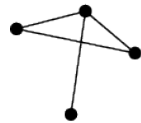
Graph

I

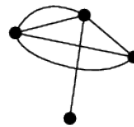
org.jgrapht.graph

DefaultDirectedGraph

DefaultDirectedWeightedGraph



*simple graph*



*multigraph*



*pseudograph*

SimpleGraph

SimpleWeightedGraph

SimpleDirectedGraph

SimpleDirectedWeightedGraph

DirectedMultigraph

Multigraph

DirectedWeightedMultigraph

WeightedMultigraph

DirectedPseudograph

DirectedWeightedPseudograph  
Pseudograph

WeightedPseudograph

# Graph Implementation Classes

Class Name	Edges	Self-loops	Multiple edges	Weighted
DefaultUndirectedWeightedGraph	undirected	yes	no	yes
SimpleGraph	undirected	no	no	no
Multigraph	undirected	no	yes	no
Pseudograph	undirected	yes	yes	no
DefaultUndirectedGraph	undirected	yes	no	no
SimpleWeightedGraph	undirected	no	no	yes
WeightedMultigraph	undirected	no	yes	yes
WeightedPseudograph	undirected	yes	yes	yes
DefaultUndirectedWeightedGraph	undirected	yes	no	yes
SimpleDirectedGraph	directed	no	no	no
DirectedMultigraph	directed	no	yes	no
DirectedPseudograph	directed	yes	yes	no
DefaultDirectedGraph	directed	yes	no	no
SimpleDirectedWeightedGraph	directed	no	no	yes
DirectedWeightedMultigraph	directed	no	yes	yes
DirectedWeightedPseudograph	directed	yes	yes	yes
DefaultDirectedWeightedGraph	directed	yes	no	yes

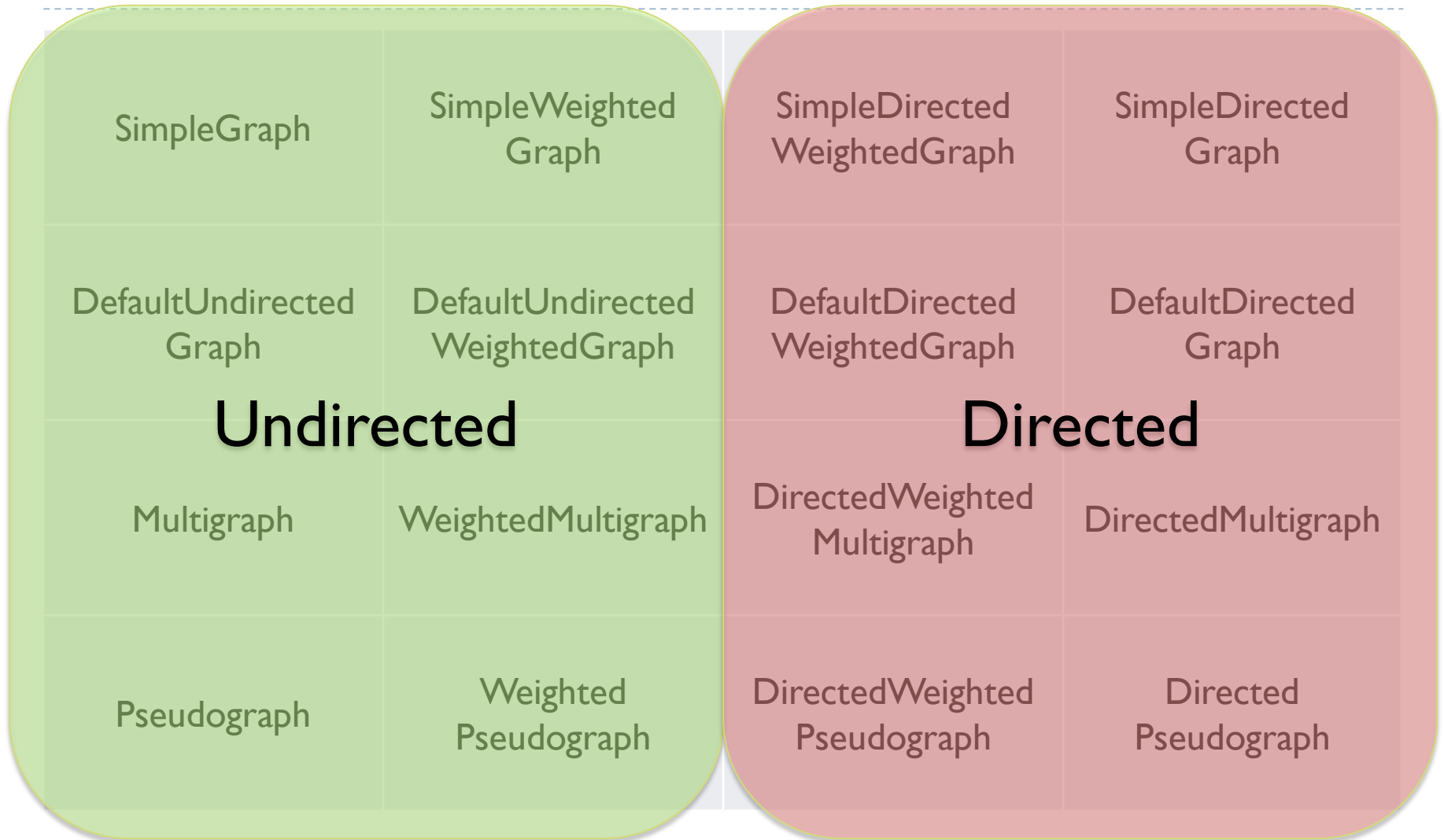
<https://jgrapht.org/guide/UserOverview#graph-structures>

# Graph Implementation Classes

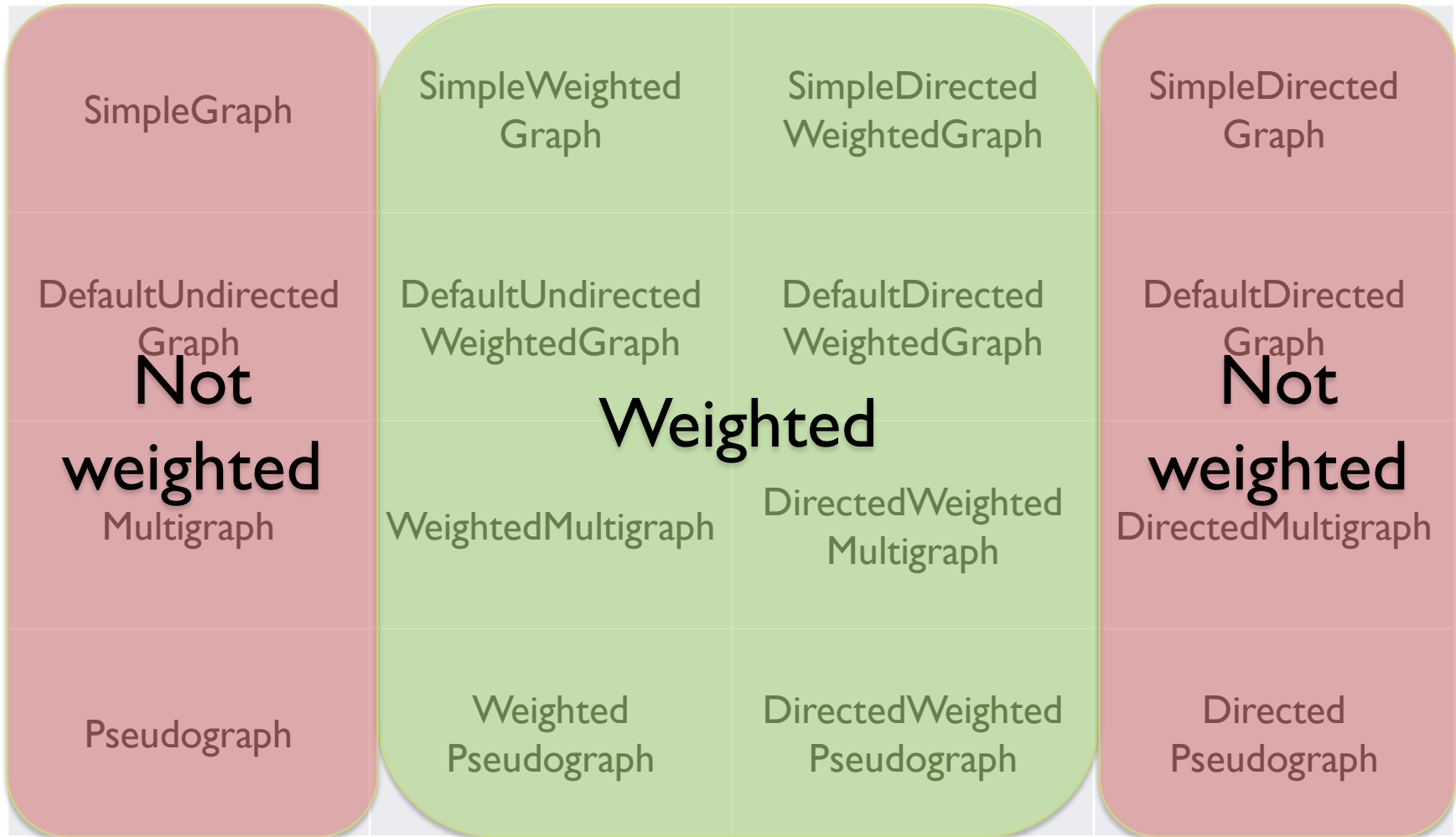
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SimpleGraph	SimpleWeighted Graph	SimpleDirected WeightedGraph	SimpleDirected Graph
DefaultUndirected Graph	DefaultUndirected WeightedGraph	DefaultDirected WeightedGraph	DefaultDirected Graph
Multigraph	WeightedMultigraph	DirectedWeighted Multigraph	DirectedMultigraph
Pseudograph	Weighted Pseudograph	DirectedWeighted Pseudograph	Directed Pseudograph

# Graph Implementation Classes



# Graph Implementation Classes



# Graph Implementation Classes

SimpleGraph	SimpleWeighted Graph	SimpleDirected WeightedGraph	SimpleDirected Graph
DefaultUndirected Graph	DefaultUndirected WeightedGraph	DefaultDirected WeightedGraph	DefaultDirected Graph
Multigraph	WeightedMultigraph	DirectedWeighted Multigraph	DirectedMultigraph
Pseudograph	Weighted Pseudograph	DirectedWeighted Pseudograph	Directed Pseudograph

**Simple**

**Simple with self-loops**

**Multi**

**Pseudo (Multi+Self)**





# Creating graphs (1 / 2)

- ▶ Decide what is the vertex class  $V$
- ▶ Decide which graph **class** suits your needs
  - ▶ For unweighted graphs, use **DefaultEdge** as  $E$
  - ▶ For weighted graphs, use **DefaultWeightedEdge** as  $E$
- ▶ Create the graph object
  - ▶ `Graph<V, E> graph = new SimpleGraph<V, E>(E.class) ;`

Class Name	Edges	Self-loops	Multiple edges	Weighted
DefaultUndirectedWeightedGraph	undirected	yes	no	yes
SimpleGraph	undirected	no	no	no
Multigraph	undirected	no	yes	no
Pseudograph	undirected	yes	yes	no
DefaultUndirectedGraph	undirected	yes	no	no
SimpleWeightedGraph	undirected	no	no	yes
WeightedMultigraph	undirected	no	yes	yes
WeightedPseudograph	undirected	yes	yes	yes
DefaultUndirectedWeightedGraph	undirected	yes	no	yes
SimpleDirectedGraph	directed	no	no	no
DirectedMultigraph	directed	no	yes	no
DirectedPseudograph	directed	yes	yes	no
DefaultDirectedGraph	directed	yes	no	no
SimpleDirectedWeightedGraph	directed	no	no	yes
DirectedWeightedMultigraph	directed	no	yes	yes
DirectedWeightedPseudograph	directed	yes	yes	yes
DefaultDirectedWeightedGraph	directed	yes	no	yes

# Alternative: GraphTypeBuilder

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- ▶ Use the `GraphTypeBuilder` class, and specify the variants of the graph you need:
  - ▶ `Graph<Integer, DefaultEdge> g =`  
`GraphTypeBuilder`
    - `.<Integer, DefaultEdge> undirected()`
    - `.allowingMultipleEdges(false)`
    - `.allowingSelfLoops(false)`
    - `.edgeClass(DefaultEdge.class)`
    - `.weighted(false)`
    - `.buildGraph();`
  - ▶ See:  
<https://jgrapht.org/javadoc/org/jgrapht/graph/builder/GraphTypeBuilder.html>

# Creating graphs (2/2)

---

- ▶ Add vertices
  - ▶ boolean **addVertex**(V v)
- ▶ Add edges
  - ▶ E **addEdge**(V sourceVertex, V targetVertex)
  - ▶ boolean **addEdge**(V sourceVertex, V targetVertex, E e)
  - ▶ void **setEdgeWeight**(E e, double weight)
- ▶ Print graph (for debugging)
  - ▶ toString()
- ▶ Remember: E and V should correctly implement **.equals()** and **.hashCode()**

# Example

---

```
Graph<String, DefaultEdge> graph = new  
SimpleGraph<>(DefaultEdge.class) ;
```

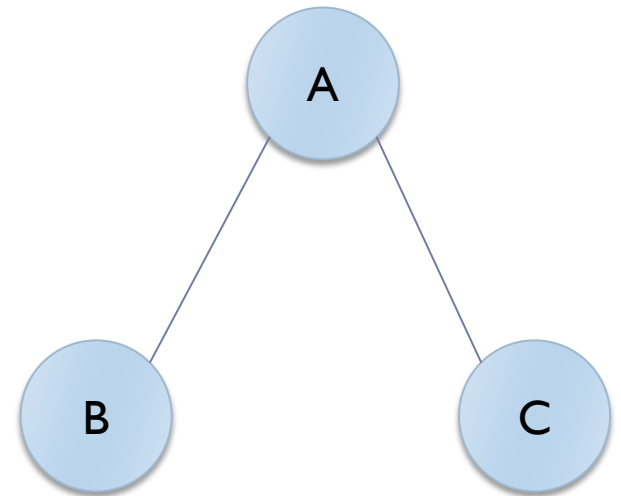
```
graph.addVertex("A") ;
```

```
graph.addVertex("B") ;
```

```
graph.addVertex("C") ;
```

```
graph.addEdge("A", "B") ;
```

```
graph.addEdge("A", "C") ;
```



# Querying graph structure

---

## ▶ Navigate structure

- ▶ `java.util.Set<V> vertexSet()`
- ▶ `boolean containsVertex(V v)`
- ▶ `boolean containsEdge(V sourceVertex, V targetVertex)`
- ▶ `java.util.Set<E> edgesOf(V vertex)`
- ▶ `java.util.Set<E> getAllEdges(V sourceVertex, V targetVertex)`

## ▶ Query Edges

- ▶ `V getEdgeSource(E e)`
- ▶ `V getEdgeTarget(E e)`
- ▶ `double getEdgeWeight(E e)`

# Graph manipulation functions

---

```
<<interface>>  
org.jgrapht::Graph  
  
+ addVertex(v : V) : boolean  
+ addEdge(sourceVertex : V, targetVertex : V) : E  
+ addEdge(sourceVertex : V, targetVertex : V, e : E) : boolean  
+ setEdgeWeight(e : E, weight : double) : void  
+ vertexSet() : Set<V>  
+ edgeSet() : Set<E>  
+ containsVertex(v : V) : boolean  
+ containsEdge(e : E) : boolean  
+ containsEdge(sourceVertex : V, targetVertex : V) : boolean  
+ getAllEdges(sourceVertex : V, targetVertex : V) : Set<E>  
+ getEdge(sourceVertex : V, targetVertex : V) : E  
+ getEdgeSource(e : E) : V  
+ getEdgeTarget(e : E) : V  
+ getEdgeWeight(e : E) : double  
+ incomingEdgesOf(vertex : V) : Set<E>  
+ outgoingEdgesOf(vertex : V) : Set<E>  
+ edgesOf(v : V) : Set<E>  
+ inDegreeOf(vertex : V) : int  
+ outDegreeOf(vertex : V) : int  
+ degreeOf(v : V) : int  
+ removeAllEdges(edges : Collection<E>) : boolean  
+ removeAllEdges(sourceVertex : V, targetVertex : V) : Set<E>  
+ removeAllVertices(vertices : Collection<V>) : boolean  
+ removeEdge(e : E) : boolean  
+ removeEdge(sourceVertex : V, targetVertex : V) : E  
+ removeVertex(v : V) : boolean
```

# The Graphs utility class

## *Graphs*

+ addEdge(g : Graph<V,E>, sourceVertex : V, targetVertex : V, weight : double) : E  
+ addAllVertices(destination : Graph<V,E>, vertices : Collection<V>) : boolean  
+ neighborListOf(g : Graph<V,E>, vertex : V) : List<V>  
+ predecessorListOf(g : Graph<V,E>, vertex : V) : List<V>  
+ successorListOf(g : Graph<V,E>, vertex : V) : List<V>  
+ getOppositeVertex(g : Graph<V,E>, e : E, v : V) : V  
+ testIncidence(g : Graph<V,E>, e : E, v : V) : boolean  
+ vertexHasSuccessors(graph : Graph<V,E>, vertex : V) : boolean  
+ vertexHasPredecessors(graph : Graph<V,E>, vertex : V) : boolean  
+ addAllEdges(destination : Graph<V,E>, source : Graph<V,E>, edges : Collection<E>) : boolean  
+ addAllVertices(destination : Graph<V,E>, vertices : Collection<V>) : boolean  
+ addEdgeWithVertices(targetGraph : Graph<V,E>, sourceGraph : Graph<V,E>, edge : E) : boolean  
+ addEdgeWithVertices(g : Graph<V,E>, sourceVertex : V, targetVertex : V, weight : double) : E  
+ addGraph(destination : Graph<V,E>, source : Graph<V,E>) : boolean  
+ addGraphReversed(destination : Graph<V,E>, source : Graph<V,E>) : void  
+ addAllEdges(destination : Graph<V,E>, source : Graph<V,E>, edges : Collection<E>) : boolean  
+ undirectedGraph(g : Graph<V,E>) : Graph<V,E>  
+ addOutgoingEdges(graph : Graph<V,E>, source : V, targets : Iterable<V>) : void  
+ addIncomingEdges(graph : Graph<V,E>, target : V, sources : Iterable<V>) : void  
+ removeVertexAndPreserveConnectivity(graph : Graph<V,E>, v : V) : boolean  
+ removeVertexAndPreserveConnectivity(graph : Graph<V,E>, vertices : Iterable<V>) : boolean



# Utility functions

---

- ▶ Static class **org.jgrapht.Graphs**
- ▶ Easier creation
  - ▶ public static  $\langle V, E \rangle$  E **addEdge**(Graph $\langle V, E \rangle$  g, V sourceVertex, V targetVertex, double weight)
  - ▶ public static  $\langle V, E \rangle$  E **addEdgeWithVertices**(Graph $\langle V, E \rangle$  g, V sourceVertex, V targetVertex)

# Utility functions

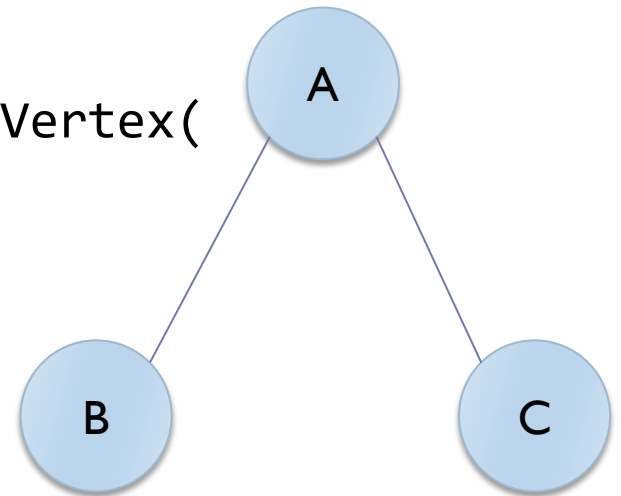
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- ▶ Static class **org.jgrapht.Graphs**
- ▶ Easier navigation
  - ▶ public static <V,E> java.util.List<V>  
**neighborListOf**(Graph<V,E> g, V vertex)
  - ▶ public static String **getOppositeVertex**(Graph<String, DefaultEdge> g, DefaultEdge e, String v)
  - ▶ public static <V,E> java.util.List<V>  
**predecessorListOf**(DirectedGraph<V,E> g, V vertex)
  - ▶ public static <V,E> java.util.List<V>  
**successorListOf**(DirectedGraph<V,E> g, V vertex)

# Example

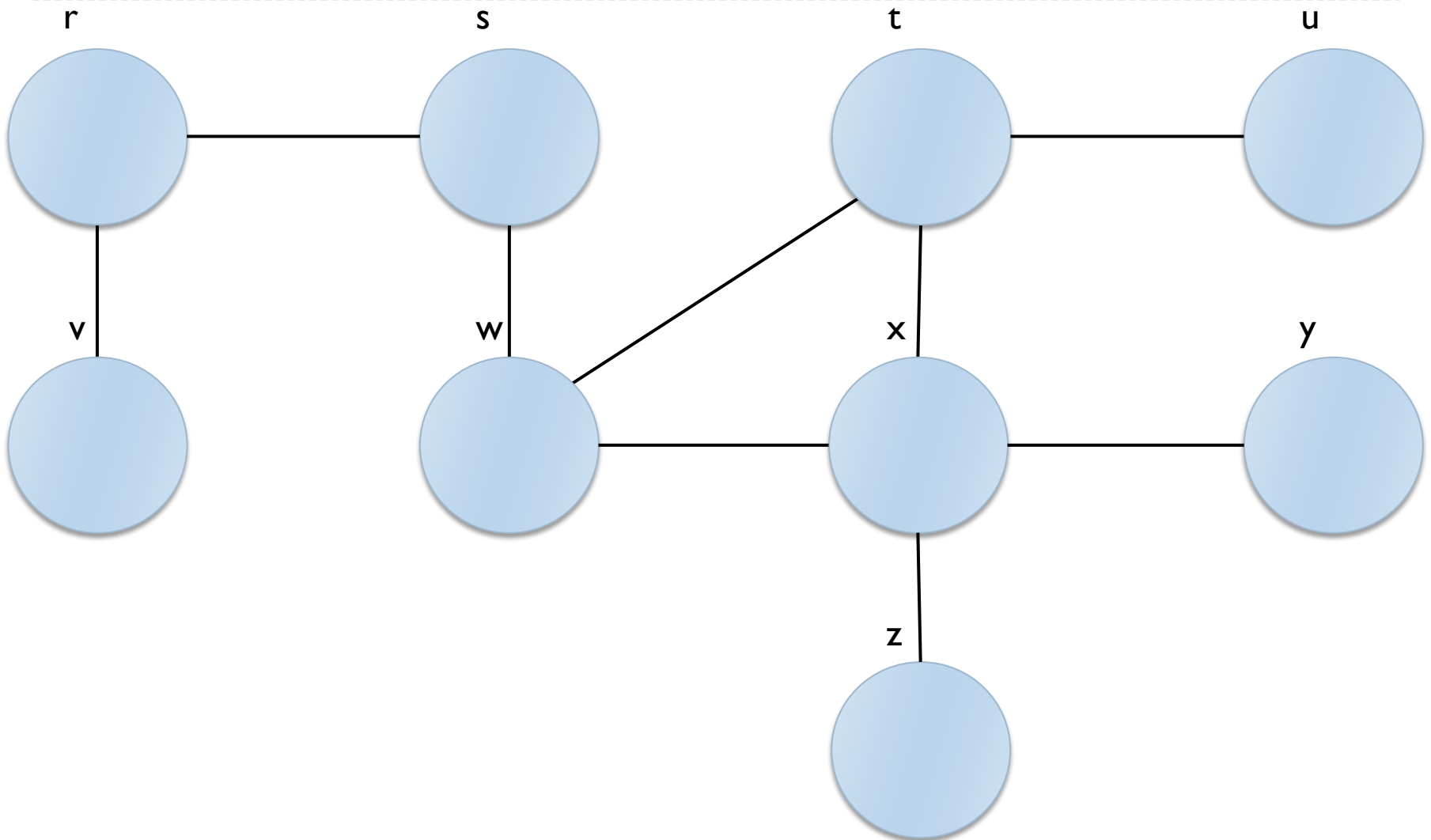
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```
for( String s: graph.vertexSet() ) {  
    System.out.println("Vertex "+s) ;  
    for( DefaultEdge e: graph.edgesOf(s) ) {  
        System.out.println("Degree: “  
            +graph.degreeOf(s)) ;  
        System.out.println(  
            Graphs.getOppositeVertex(  
                graph, e, s)) ;  
    }  
}
```

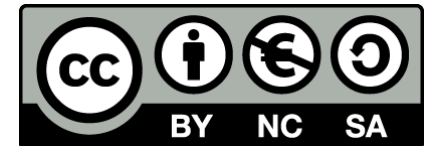






# Example

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