An Introduction to the Ubitrack Library

Daniel Pustka, Manuel Huber, Peter Keitler

June 28th, 2007

Department of Informatics | Technische Universität München

Purpose of this Introduction

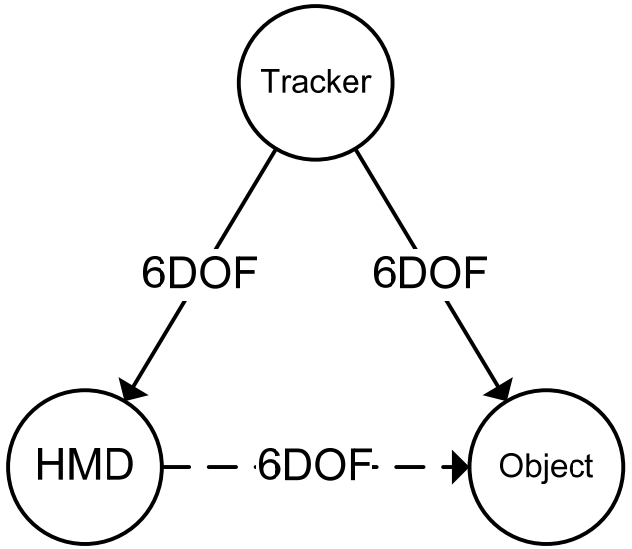
- After the introduction, everybody should
  - have a compiled Ubitrack on his hard drive
  - know how to write and run data flow descriptions in UTQL
  - know how to use Ubitrack in his/her own programs

Outline

- **General Introduction**
  - Spatial Relationship Graphs and Patterns
  - Library Overview
- Download and compile session
- Writing and running data flow descriptions in UTQL
- Using the API in C++ and Java
- Outlook
  - Ubitrack Server

Basics: Spatial Relationship Graphs

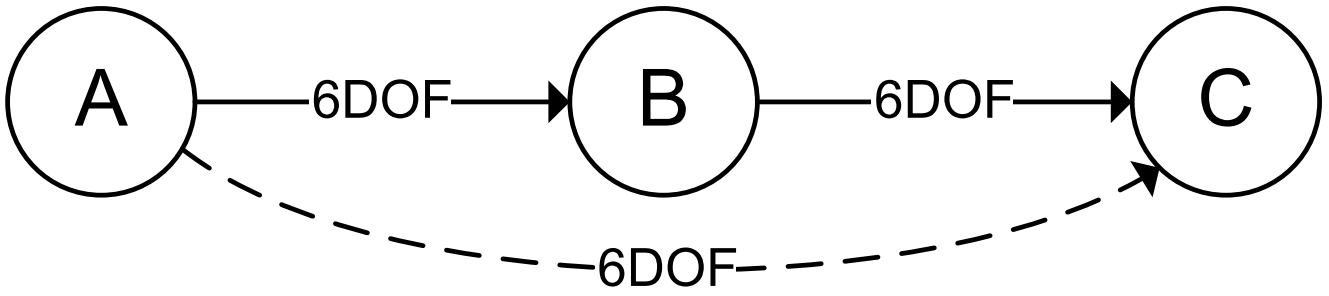
- Spatial Relationship Graphs describe the tracking situation
- Nodes represent coordinate systems
- Edges represent known transformations
  - Usually directed!



Basics: Spatial Relationship Patterns

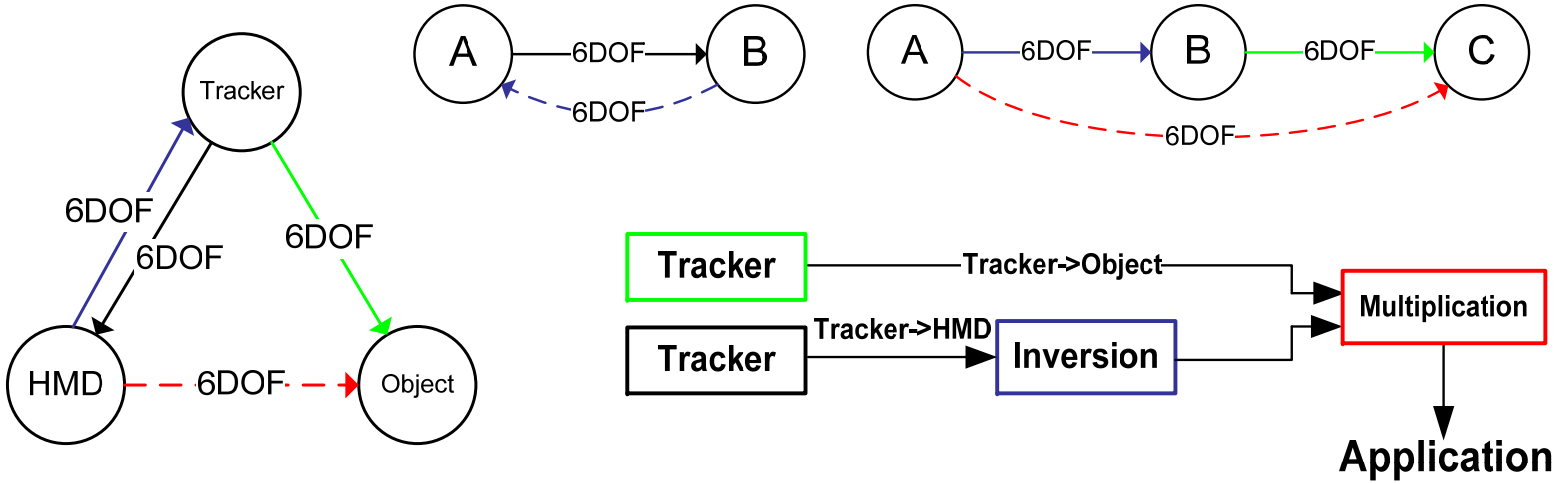
- Patterns describe structural properties of tracking algorithms
- Input edges are necessary preconditions
- Output edges describe the result of the algorithm
- A pattern describes how new relationships can be inferred

- Example: Pose concatenation or multiplication



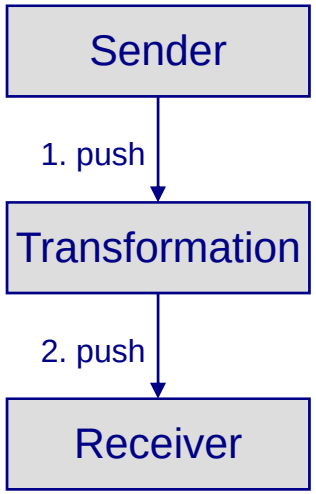
Basics: Patterns and Data Flow Networks

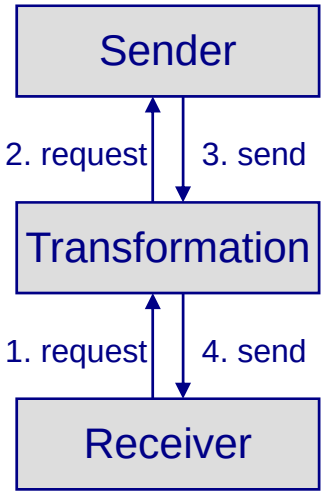
- Data flow networks (DFNs) are formed by connected components that compute new relationships at runtime
- DFNs only needs to change when the topology of the underlying SRG changes
- DFNs can be constructed by applying patterns



Basics: Push- and Pull-Style Communication

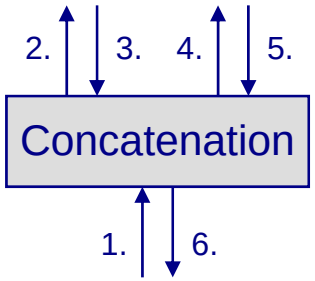
- Push-Style Interface
  - asynchronous
  - all tracking hardware
- Pull-Style Interface
  - synchronous
  - request by timestamp
    - senders are continuous



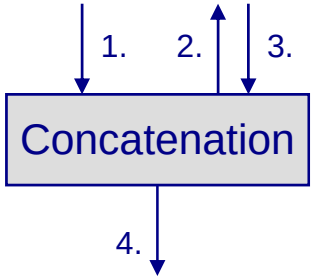


Basics: Combining Multiple Measurements

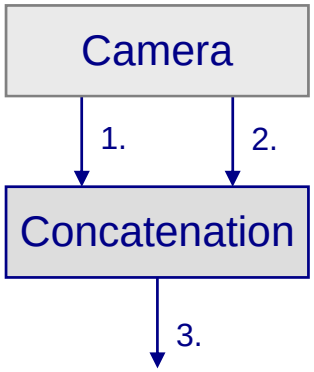
- Pull-Pull



- Push-Pull

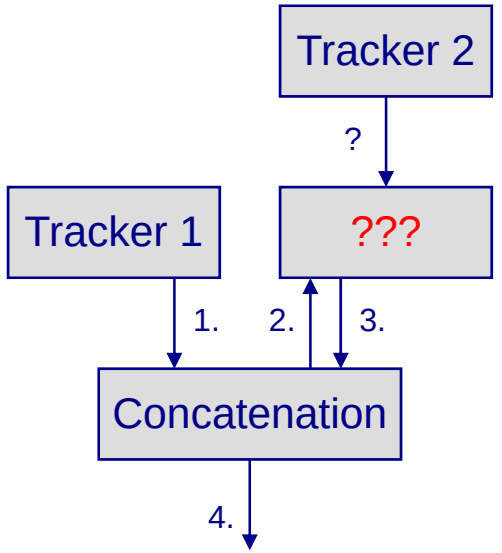


- Push-Push
  - not possible in general
- Special case: Synchronized push
  - If incoming measurements are synchronous

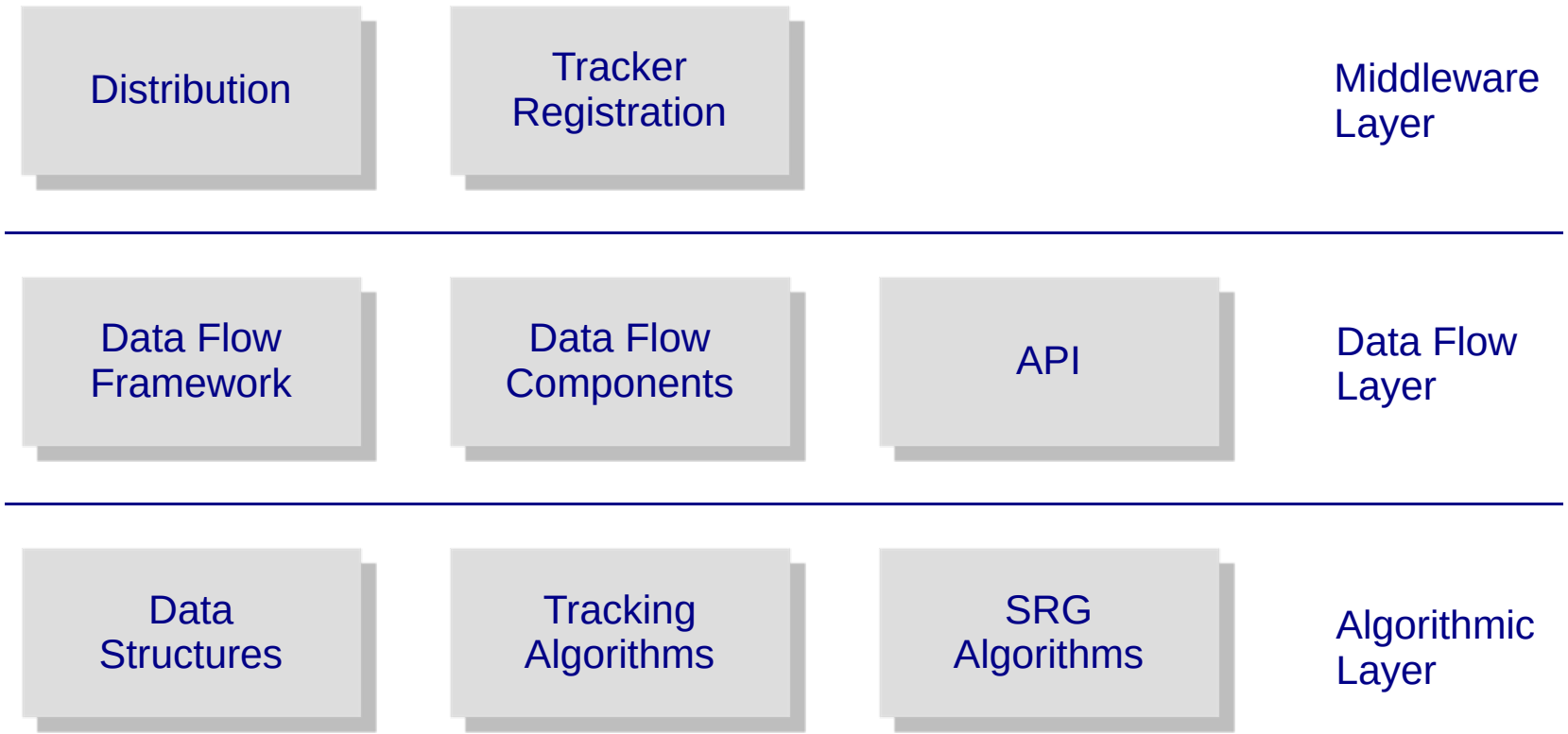


Push-To-Pull Conversion

- Buffering
  - Only valid for quasi-static relationships
- Averaging
  - Improves error characteristics
  - Only valid for static relationships
- Interpolation/Extrapolation
  - Linear, quadratic, SLERP
- Kalman Filter
  - Different motion models
  - Improves error characteristics
  - Provides accuracy estimates



Ubitrack: A Layered Approach



Outline

- General Introduction
  - Spatial Relationship Graphs and Patterns
  - Library Overview
- **Download and compile session**
- Writing and running data flow descriptions in UTQL
- Using the API in C++ and Java
- Outlook
  - Ubitrack Server

Where to get Ubitrack

- The Ubitrack library is currently available using Subversion only
- If you have a login at the chair:
  - svn+ssh://<username>@svnnavab.informatik.tu-muenchen.de/svn/ubitrack/trunk
- Anonymous read-only access
  - https://svnnavab.informatik.tu-muenchen.de/ubitrack/trunk
- Checkout either using TortoiseSVN or

```
svn co <repositoryname> ubitrack
```

Ubitrack Dependencies

- To build Ubitrack, the following is minimally required
  - A recent C++ compiler (GCC>=3.3 or VC>=7.1)
  - Python (required by the build system)
  - SCons (the build system)
  - Boost (indispensable for modern C++ programming)
- Today's examples also require
  - OpenCV (for marker tracking, must have HighGui)
  - LAPACK (included for Win32)
  - Glut (for rendering)
- For the Java interface
  - SWIG (interface generator)
  - JDK

Building Ubitrack

- Ubitrack uses the SCons build system
  - platform-independent make replacement
  - provides configure functionality
  - written in python
  - “Makefiles” are python scripts ☺
- To build, simply go to the ubitrack directory and enter

  `scons all`
- Build options can be set using e.g.

  `scons OPENCV_PATH=C:\Code\OpenCV all`
  - options are remembered and need to be specified only once
  - print a list of all options: **`scons --help`**

Building Ubitrack: Checking the result

- Running **scons** should give the following lines with “yes”

```
Checking for C++ header file boost/shared_ptr.hpp... yes
Checking for dgesvd_() in C library lapack... yes
Checking for cvGetQuadrangleSubPix( NULL, NULL, NULL ) in C++ library cv... yes
Checking for cvNamedWindow( "xxx", 0 ) in C++ library highgui... yes
Checking for glutInitWindowSize( 800, 600 ) in C++ library glut... yes
```

- If you get a “no” in the lines above, check dependencies and if necessary add build options

Running Unit Tests and Installing

- To check that everything works, enter
  `scons test`
- Finally install the libraries and components using
  `scons install-all`
- Now everything should reside in the **`bin`** and **`lib`** directories

Outline

- General Introduction
  - Spatial Relationship Graphs and Patterns
  - Library Overview
- Download and compile session
- **Writing and running data flow descriptions in UTQL**
- Using the API in C++ and Java
- Outlook
  - Ubitrack Server

The Ubiquitous Tracking Query Language

- Purposes of UTQL
  - Specifying the tracking environment: Spatial Relationship Graphs
  - Specifying capabilities of clients: Spatial Relationship Patterns
  - Specifying application queries
- **Today's focus: Specifying Dataflow Networks**
  - normally automatically created by a Ubitrack server
    - →still many problems to solve (by us)
  - manual creation is currently more reliable

UTQL Dataflow Specification: Outline

- A UTQL dataflow specifications in XML is enclosed in

```
<UTQLResponse>
   …
</UTQLResponse>
```

- Each single data flow operation is represented as a pattern

```
<Pattern>
   <Input>
     <Node …/> … <Edge …/> …
   </Input>
   <Output>
     <Node …/> … <Edge …/> …
   </Output>
   <DataflowConfiguration> … </DataflowConfiguration>
</Pattern>
```

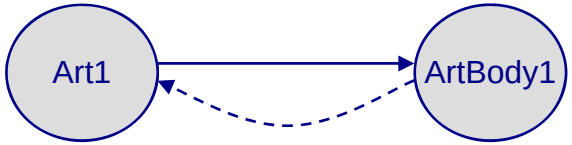
Example 1: Specifying a Tracker

```
<Pattern name="Art" id="Art1">
  <Output>
    <Node name="Art" id="Art1">
      <Attribute name="artPort" value="5000"/>
    </Node>

    <Node name="Body" id="ArtBody1"/>

    <Edge name="ArtToTarget" source="Art"
     destination="Body">
      <Attribute name="artBodyId" value="3"/>
    </Edge>
  </Output>

  <DataflowConfiguration>
    <UbitrackLib class="ArtTracker"/>
  </DataflowConfiguration>
</Pattern>
```

- A tracker only has **<Output>** elements
- Patterns and nodes:
  - **name**s are used locally
  - **id**s are globally unique
- Edges
  - refer to node **name**s
- Nodes and edges have **<Attribute>**s:
  - used for configuration
- **<DataflowConfiguration>** tells the library how to instantiate the component

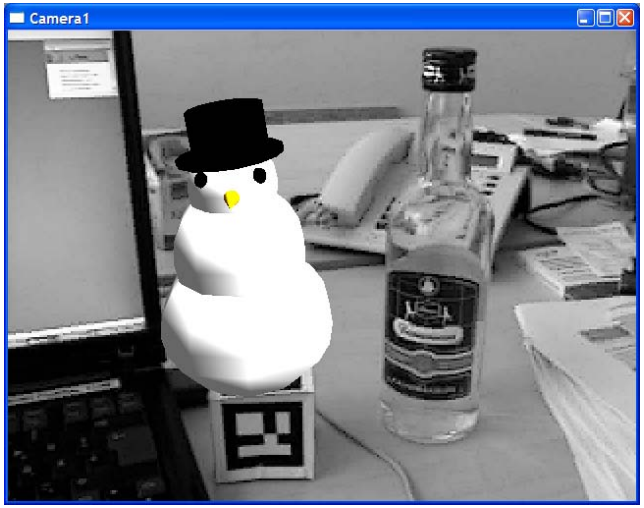
Example 2: Inverting the Transformation

```
<Pattern name="Inversion" id="Inv1">
  <Input>
    <Node name="A" id="Art1"/>
    <Node name="B" id="ArtBody1"/>
    <Edge name="AB" source="A"
     destination="B" graph-ref="Art1"
     edge-ref="ArtToTarget"/>
  </Input>

  <Output>
    <Edge name="BA" source="B"
     destination="A"/>
  </Output>

  <DataflowConfiguration>
    <UbitrackLib
     class="PosePushInversion"/>
  </DataflowConfiguration>
</Pattern>
```



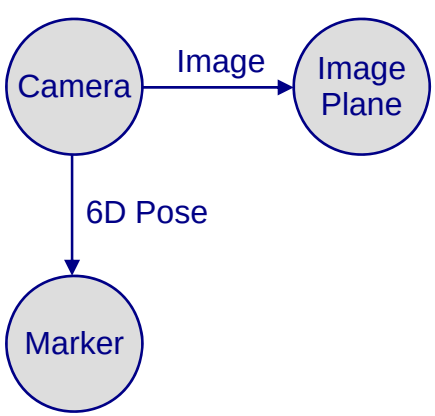
- Input edges refer to an output edge of another pattern using
  - **id** of the pattern: **`graph-ref`**
  - **name** of the edge: **`edge-ref`**
- **Note:** Node and edge **name**s are specified by the implementation of a pattern and cannot be exchanged!

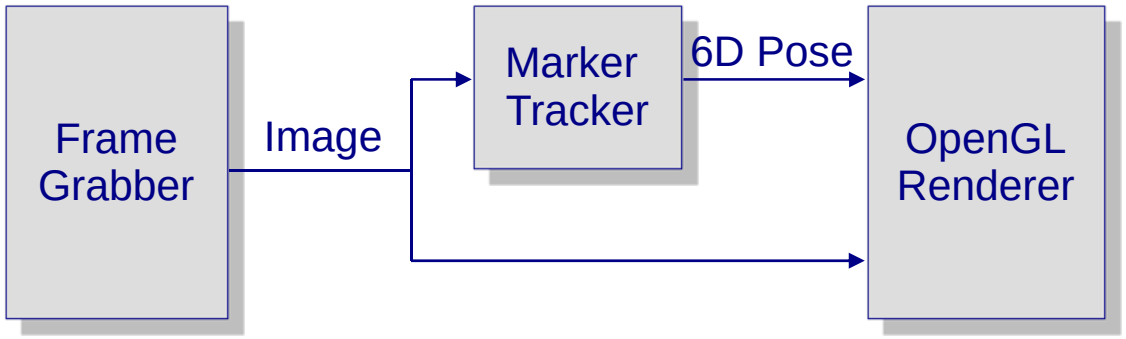
Assignment 1



- Display a snowman on a flat marker
- Make a UTQL file that connects the required components
- Run it using the **`utConsole`**

- Requires the following “SRG” and dataflow:





Hint: Frame Grabber Pattern

```
<Pattern name="FrameGrabber" id="FrameGrabber1">
    <Output>
          <Node name="Camera" id="Camera"/>
          <Node name="ImagePlane" id="ImagePlane"/>
          <Edge name="Output" source="Camera" destination="ImagePlane“/>
    </Output>

    <DataflowConfiguration>
          <UbitrackLib class="HighguiFrameGrabber"/>
    </DataflowConfiguration>
</Pattern>
```

Hint: Marker Tracker Pattern

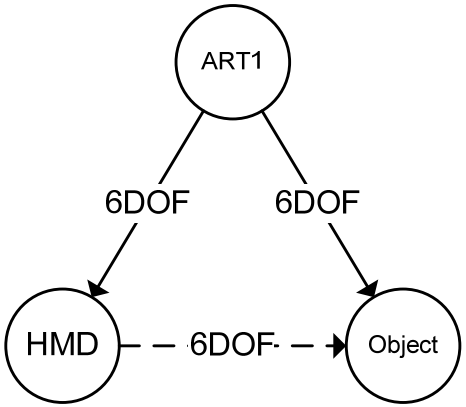
```
<Pattern name="MarkerTracker" id="MarkerTracker1">
    <Input>
          <Node name="Camera" id="Camera"/>
          <Node name="ImagePlane" id="ImagePlane"/>
          <Edge name="Image" source="Camera" destination="ImagePlane“/>
    </Input>
    <Output>
          <Node name="Marker" id="Marker">
             <Attribute name="markerId" value="0x0272"/>
          </Node>
          <Edge name="Output" source="Camera" destination="Marker“/>
    </Output>
    <DataflowConfiguration>
          <UbitrackLib class="MarkerTracker"/>
    </DataflowConfiguration>
</Pattern>
```

Hint: Renderer Pattern

```
<Pattern name="Renderer" id="Renderer1">
    <Input>
        <Node name="Camera" id="Camera">
            <Attribute name="virtualCameraFov" value="30"/>
            <Attribute name="virtualCameraNear" value="0.01"/>
            <Attribute name="virtualCameraFar" value="40"/>
            <Attribute name="virtualCameraWidth" value="640"/>
            <Attribute name="virtualCameraHeight" value="480"/>
        </Node>
        <Node name="Object" id="Marker">
            <Attribute name="virtualObjectX3DPath" value="snowman.x3d"/>
        </Node>
        <Edge name="PushInput" source="Camera" destination="Object"/>
        <Node name="ImagePlane" id="ImagePlane"/>
        <Edge name="Image" source="Camera" destination="ImagePlane"/>
    </Input>
    <DataflowConfiguration>
        <UbitrackLib class="RenderModule"/>
    </DataflowConfiguration>
</Pattern>
```

Assignment 2

- Create and run a dataflow that renders an ART-tracked object inside an ART-tracked HMD



Hint: Synchronized Push Multiplication Pattern

```
<Pattern name="Multiplication">
  <Input>
    <Node name="A"/>
    <Node name="B"/>
    <Node name="C"/>
    <Edge name="AB" source="A" destination="B" />
    <Edge name="BC" source="B" destination="C" />
  </Input>

  <Output>
    <Edge name="AC" source="A" destination="C"/>
  </Output>

  <DataflowConfiguration>
    <UbitrackLib class="PoseSynchronizedPushMultiplication"/>
  </DataflowConfiguration>
</Pattern>
```

Outlook: Other Existing Components

- Push-Pull conversion: **`Buffer`**, **`LinearInterpolation`**
- Pull-Push conversion: **`Sampler`**
- Data type conversion: **`PoseSplit`**, **`FunctionalFusion`**
- Fixed transformations: **`StaticMeasurement`**
- Calibration: **`AbsoluteOrientation`**, **`SPAAM`**, **`RotHecKalmanFilter`**
- Sensor fusion: **`TimeComplementaryFusion`**, **`RotOnlyKalmanFilter`**
- Debugging: **`PrintSink`**, **`Recorder`**, **`Player`**
- Network transport: **`NetworkSource/Sink`**
- Trackers: **`ART`**, **`XSens`**, **`MarkerTracker`**

Outline

- General Introduction
  - Spatial Relationship Graphs and Patterns
  - Library Overview
- Download and compile session
- Writing and running data flow descriptions in UTQL
- **Using the API in C++ and Java**
- Outlook
  - Ubitrack Server

Getting API Documentation

- The Ubitrack library API documentation can be built using Doxygen and the supplied Doxyfile
- The documentation is also available online (built nightly)
  http://campar.in.tum.de/personal/fardemo/ubidoc/
  - Username: ubitrack
  - Password: (empty)
- Some information can also be found in the Ubitrack Web
  http://campar.in.tum.de/UbiTrack/WebHome

Instantiating a Ubitrack Data Flow Network

C++

- Get access to the SimpleFacade

```
#include
   <Ubitrack/Facade/SimpleFacade.h>
using namespace Ubitrack::Facade;
```

- Instantiate a SimpleFacade

```
SimpleFacade f();
```

- Load a UTQL dataflow description

```
f.loadDataflow( “test.utql” );
```

- Start the dataflow network

```
f.startDataflow();
```

- At the end, stop it again

```
f.stopDataflow();
```

Java

```
import ubitrack.*;
System.loadLibrary("ubitrack_java");
```

```
SimpleFacade f = new SimpleFacade();
```

```
f.loadDataflow( “test.utql” );
```

```
f.startDataflow();
```

```
f.stopDataflow();
```

Sending Tracking Data to the Application

- To receive tracking data in an application, the data flow network needs to end in an **`ApplicationPushSinkPose`** component

```
<Pattern name="ApplicationPushSink" id="PushSink1">
    <Input>
          <Node name="A"/>
          <Node name="B"/>
          <Edge name="Input" source="A" destination="B"/>
    </Input>
    <DataflowConfiguration>
          <UbitrackLib class="ApplicationPushSinkPose"/>
    </DataflowConfiguration>
</Pattern>
```

Getting the Tracking Data

C++

- Derive from SimplePoseReceiver

```
class MyReceiver :
   public SimplePoseReceiver {
public:
   void receivePose( const
      SimplePose& pose )
   { double tx = pose.trans[0];
     double rw = pose.rot[3]; }
};
```

- Register callback at the facade

```
f.setPoseCallback( “PushSink1”,
   &myReceiver );
```

Java

```
class MyReceiver
   extends SimplePoseReceiver {

   public void receivePose(
      SimplePose pose )
   { double tx = pose.getTrans()[0];
     double rw = pose.getRot()[3]; }
};
```

```
f.setPoseCallback( “PushSink1”,
   myReceiver );
```

- The first parameter to **`setPoseCallback`** corresponds to the **`id`** of the **`ApplicationPushSinkPose`** component in the data flow network.

Notes

- Most **`SimpleFacade`** methods return **`false`** when an error occurred. In this case, **`f.getLastError()`** returns a description.
- If you want the Ubitrack library to print what is going on, enable logging using
  - C++:
    ```
    #include <Ubitrack/Util/Logging.h>
    Ubitrack::Util::initLogging();
    ```
  - Java:
    ```
    ubitrack.initLogging();
    ```
- For C++ clients, an **`AdvancedFacade`** is also provided, which provides more flexible access to the data flow network.
- The SimpleFacade can also be used from Python ☺

Assignment 3

- Create a C++ or Java application that receives tracking data from the marker tracking.
- Don’t forget to write an appropriate UTQL file

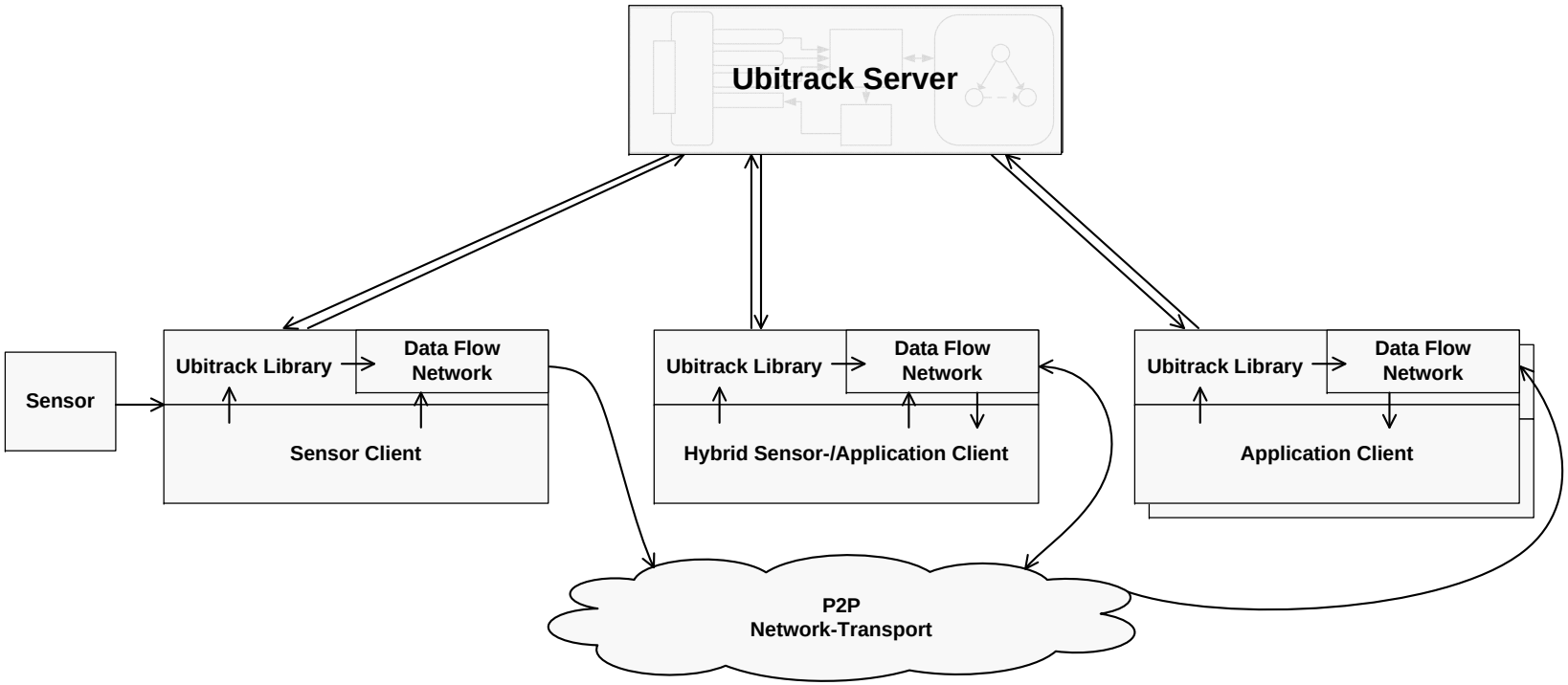
Outline

- General Introduction
  - Spatial Relationship Graphs and Patterns
  - Library Overview
- Download and compile session
- Writing and running data flow descriptions in UTQL
- Using the API in C++ and Java
- **Outlook**
  - Ubitrack Server

The Ubitrack Server

- Goal: Automatic data flow creation
- Automatically share tracking between different clients
- Queries for (unknown) objects with certain attributes
- Automatic reconfiguration of data flow at runtime, when new trackers and/or objects become available or disappear

The Ubitrack Architecture



Server SRG Specification Example

```
<UTQLRequest>
<Pattern name="Art" id="Tracker001">
<Output>
  <Node name="Art" id="Art">
    <Attribute name="ArtPort" value="5000"/>
  </Node>
</Output>
</Pattern>

<Pattern name="ArtSheep" id="Tracker002">
<Output>
  <Node name="Art" id="Art"/>
  <Node name="ArtTarget" id="ArtSheep">
    <Attribute name="renderable" value="true"/>
  </Node>
  <Edge name="ArtToTarget" source="Art"
        destination="ArtTarget">
    <Attribute name="type" value="6D"/>
    <Attribute name="mode" value="push"/>
    <Attribute name="artBodyId" value="1"/>
  </Edge>
</Output>
<DataflowConfiguration>
  <UbitrackLib class="ArtTracker"/>
</DataflowConfiguration>
</Pattern>

<Pattern name="ArtSheep" id="Tracker003">
<Output>
  <Node name="Art" id="Art"/>
  <Node name="ArtTarget" id="ArtHMD">
    <Attribute name="renderable" value="true"/>
  </Node>
  <Edge name="ArtToTarget" source="Art"
        destination="ArtTarget">
    <Attribute name="type" value="6D"/>
    <Attribute name="mode" value="push"/>
    <Attribute name="artBodyId" value="3"/>
  </Edge>
</Output>
<DataflowConfiguration>
  <UbitrackLib class="ArtTracker"/>
</DataflowConfiguration>
</Pattern>
```

Server Query Example

```
<Pattern name="Query">
  <Input>
    <Node name="Camera">
      <Predicate>id=="ArtHMD"</Predicate>
    </Node>
    <Node name="Object">
      <Predicate>renderable=="true"</Predicate>
    </Node>
    <Edge name="Input" source="Camera" destination="Object">
      <Predicate>type=="6D“&amp;amp;&amp;amp;mode=="push"</Predicate>
    </Edge>
  </Input>
  <DataflowConfiguration>
    <UbitrackLib class="PosePrintSink"/>
  </DataflowConfiguration>
</Pattern>
</UTQLRequest>
```

Thank you for your attention

- Please use Ubitrack in all your projects!

Replacement for the MarkerTracker

- If OpenCV does not work, use the following:

```
<Pattern name="TestSource" id="TestSource1">
    <Output>
          <Node name="A" id="Camera"/>
          <Node name="B" id="Marker0272"/>
          <Edge name="Output" source="A" destination="B"/>
    </Output>

    <DataflowConfiguration>
          <UbitrackLib class="TestSourcePose"/>
          <Attribute name="position" value="0 0 -0.6"/>
          <Attribute name="posnoise" value="0.3"/>
          <Attribute name="rotnoise" value="0.5"/>
    </DataflowConfiguration>
</Pattern>
```