INVRS

interactive networked virtual reality system

Tutorial I
-
Medieval Town

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Overview

interactive networked virtual reality system

Introduction and Architecture Overview

Introduction

- ***inVRs*** (**i**nteractive **n**etworked **V**irtual **R**eality **s**ystem)
  - Pronounced ɪnˈvɜːs
  - C++ Application Framework for Networked Virtual Environments (NVEs)

- Publicly available under www.invrs.org (under LGPL)
  - Uses Trac system for distribution
    - Alternatively latest stable release as zip
  - Available for Linux, Windows, Mac OS X and maybe IRIX

- Variety of out-of-the-box Features
  - Network communication supporting close coupled collaboration
  - Clear definition for navigation and interaction (with many techniques provided)
  - Designed for reusability of developed components
  - Easy-to-use configuration for immersive devices

Introduction

- Documentation available on Trac System
  - Several publications (BiBTex files)
  - Tutorial examples
  - Medieval Town Tutorial (on which these slides are based on)
  - Programmers' Guide (coming soon)
  - Doxygen (http://doxygen.invrs.org/)
- Libraries
  - Required
    - OpenSG v1.8 (http://www.opensg.org/)
    - GMTL distributed with source (http://ggt.sourceforge.net)
    - IrrXML distributed with source (http://www.ambiera.com/irrxml/)
    - CMake (http://www.cmake.org/)
  - Optional
    - OpenAL and ALUT (http://www.openal.org/)
    - ODE (http://www.ode.org/)
    - trackD (comes with CAVELib)

Introduction

- Where to position *inVRs* in the development approaches for VR applications
  - Graphical Editors (using software components)
    - (e.g. EON, VirTools, Quest3D)
  - VR systems incorporating scripting languages
    - (e.g. DIVE, ALICE, AVOCADO)
  - Application Frameworks
    - (e.g. VRJuggler)
  - Scene Graphs
    - (e.g. OpenSG, OpenSceneGraph)
  - Full development from scratch via C or C++
    - OpenGL presents comparably high effort for new development of VR applications

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Introduction

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- Application Areas

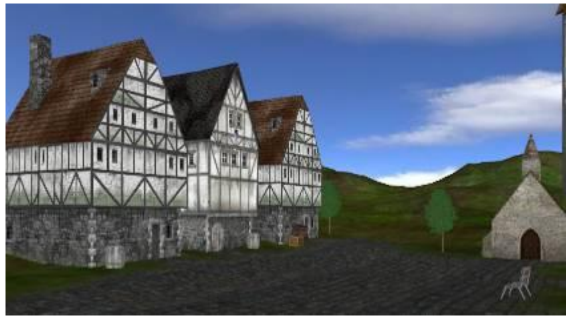
Safety Training

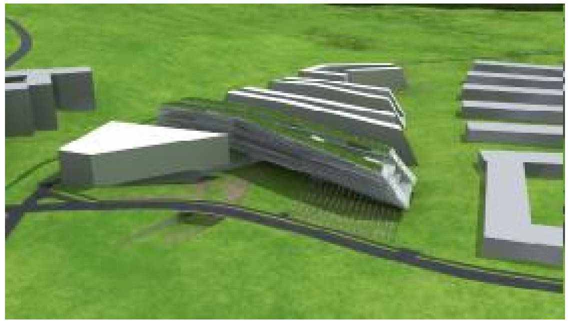
Collaborative Work

Entertainment

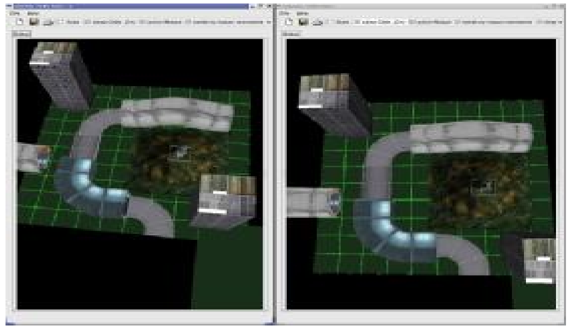
Art

Scientific Visualization


Education

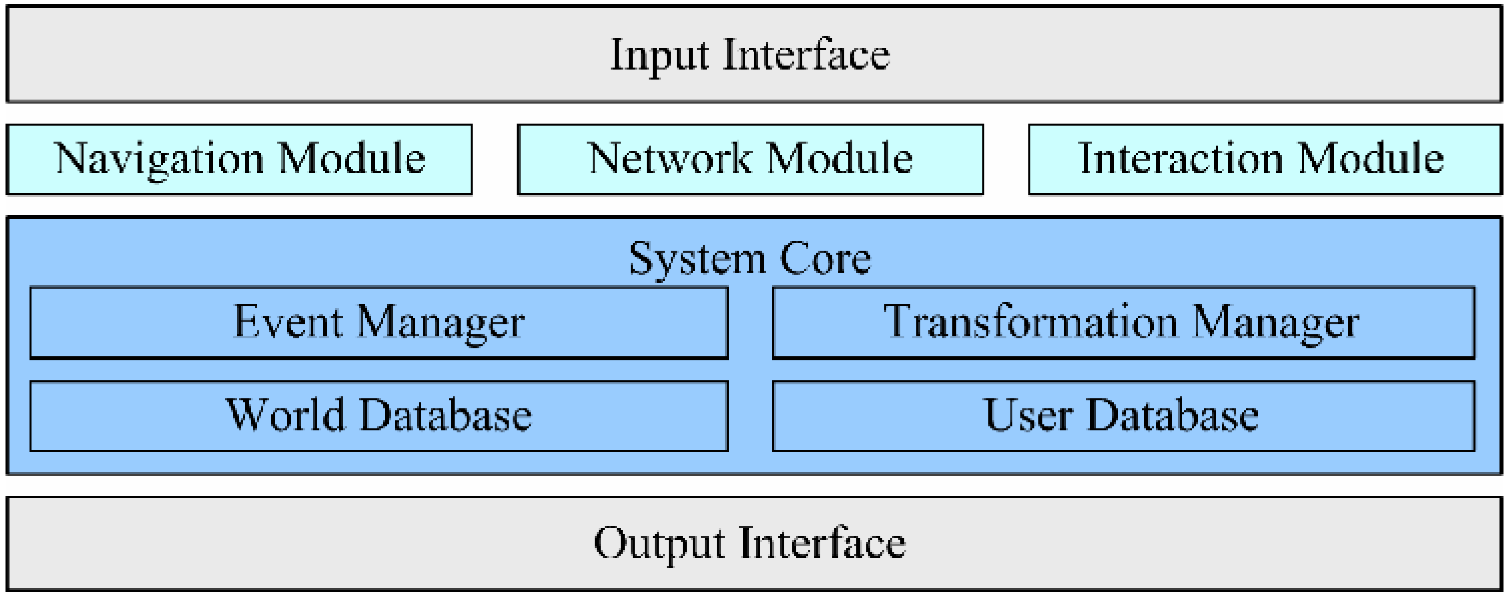

Architecture Visualization

Product Presentation


World Layout

Architecture Overview

- Overview – 3 different types of *inVRs* components
  - System Core (blue)
  - Modules (cyan)
  - Interfaces (grey)



  - Communication typically happening top down in the diagram
  - Strong dependencies between Interfaces and System Core
  - Weak dependencies between Modules and other components

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Architecture Overview

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- System Core
  - System Core contains databases and communication mechanisms
  - Offers interface between external modules and databases
  - Core functionality (data types, configuration handling, logging, timer, etc.)
- Modules
  - Implemented as plugins
  - Follow a structured approach (init, loadConfig, cleanup, etc.)
  - Standard package contains modules for interaction, navigation, and network communication
  - Physics simulation and animation are available as additional modules
- Interfaces
  - Abstraction of input devices
  - Abstraction of graphical and audio output
  - On the graphics side only OpenSG is supported so far, plans to support OpenSceneGraph exist as well

Tutorial Structure

- The tutorial is based on many copy and paste operations in order to safe time
- Four basic file classes are needed for this tutorial
  - MedievalTown.cpp
    - Contains the application parts from where the development can start
  - Configuration Files
    - Stored in the config subdirectorys
    - Have to be altered through snippets (only in offline version with manual)
  - CodeFile - Snippets
    - Contain code snippets which should be copied into the MedievalTown.cpp source file
    - Can be found under the subdirectory snipptes
  - ConfigFile - Snippets
    - Contain XML configuration which has to be copied in the actual configuration files (only in offline version with manual)
    - Can be found under the subdirectory snipptes
- Open the file **`MedievalTown.cpp`** with the editor of your choice

Chapter 1
Basic Application Development

Where a simple OpenSG application makes use of the WorldDatabase in order to load the scene graph of a Medieval Town.

Basic Application Development

- Predefined Functions
  - **`void cleanup()`**
    - System cleanup for OpenSG and later for inVRs
  - **`void display(void)`**
    - Main display loop which is invoked by a GLUT callback.
  - **`void reshape(int w, int h)`**
    - The method is used for reaction on changing of the window size.
  - **`void mouse(int button, int state, int x, int y)`**
    - This method reacts to button presses of the mouse.
  - **`void motion(int x, int y)`**
    - Forwards the coordinates of the mouse during mouse motion.
  - **`void keyboard(unsigned char k, int x, int y)`**
    - This method reacts to keyboard input.
  - **`void keyboardUp(unsigned char k, int x, int y)`**
    - Reacts on keyboard input. It is invoked when a key is released.
  - **`int setupGLUT(int *argc, char *argv[])`**
    - Sets up the GLUT system and registers required callback functions.

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Basic Application Development

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- Writing a simple *inVRs* application using OpenSG and GLUT
  - OpenSG and a GLUT Window have to be initialized first

```
int main(int argc, char **argv) {
  osgInit(argc, argv);                    // initialize OpenSG
  int winid = setupGLUT(&argc, argv);     // initialize GLUT

  // the connection between GLUT and OpenSG is established
  GLUTWindowPtr gwin = GLUTWindow::create();
  gwin->setId(winid);
  gwin->init();
```

MedievalTown.cpp

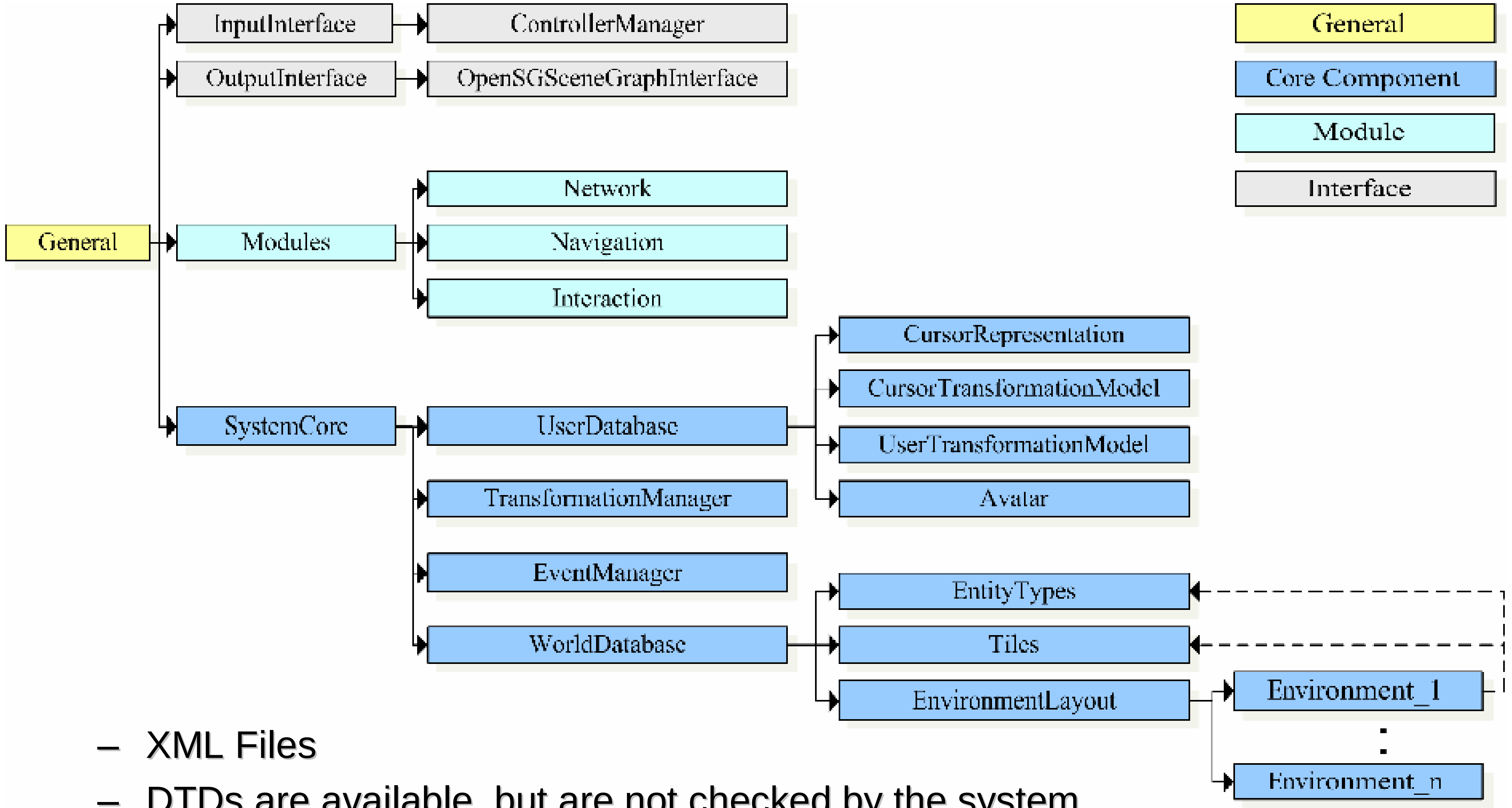
  - Create a simple OpenSG Node and set a Group Core. Attach it to the scene.

```
  NodePtr root = Node::create();
  beginEditCP(root);
    root->setCore(Group::create());
  endEditCP(root);

  mgr = new SimpleSceneManager;  // create the SimpleSceneManager
  mgr->setWindow(gwin);          // tell the manager what to manage
  mgr->setRoot(root);            // attach the scenegraph to the  root node
  mgr->showAll();                // show the whole scene
  mgr->getCamera()->setNear(0.1);

  glutMainLoop(); // GLUT main loop
  return 0;
}
```

MedievalTown.cpp

Basic Application Development

- Configuring *inVRs*



  - XML Files
  - DTDs are available, but are not checked by the system

Basic Application Development

- Configuring *inVRs*
  - **`general.xml`** sets up *inVRs* components (in <general>) and all system paths (in <paths>), you have to update your own plugin path here.
  - Paths refer to other configurations, models and tools

```
<?xml version="1.0"?>
<!DOCTYPE generalConfig SYSTEM "http://dtd.inVRs.org/generalConfig_v1.0a4.dtd">
<generalConfig version="1.0a4">
  <!-- This is the configuration for the inVRs Framework -->
  <general>

<!-- **************************** Snippet-2-1 **************************** -->

    <Interfaces>
      <option key="outputInterfaceConfiguration" value="outputInterface.xml"/>
    </Interfaces>
    <SystemCore>
      <option key="systemCoreConfiguration" value="systemCore.xml"/>
    </SystemCore>
  </general>
  <paths>
    <root directory="./"/>
    <path name="Plugins"
        directory="/please/insert/your/inVRs/libs/path/here/"/>
    <path name="SystemCoreConfiguration" directory="config/systemcore/"/>
    <path name="OutputInterfaceConfiguration"
```

general.xml

Basic Application Development

- Loading *inVRs* Configuration Data
  - Load the general configuration of the *inVRs* framework
  - Call the loadConfig method with the configuration setup at which we had a look at on the previous slide

```
// very first step: load the configuration of the file structures, basically
// paths are set. The Configuration always has to be loaded first since each
// module uses the paths set in the configuration-file
if (!Configuration::loadConfig("config/general.xml")) {
  printf("Error: could not load config-file!\n");
  return -1;
}
```

Snippet 1-1

  - After having set the paths of the needed components the core configuration is to be triggered
  - Triggering this configuration in general results in subsequent internal configure calls, for example for the individual core components, the components of the interfaces or the registered modules

Basic Application Development

- Triggering the Configuration and Adding a Scene
  - This call causes the *inVRs* system to fill the WorldDatabase with its data
  - The medieval town is loaded at this stage
  - The interface to the OpenSG scene graph is established in this step as well

```
std::string systemCoreConfigFile = Configuration::getString(
    "SystemCore.systemCoreConfiguration");
std::string outputInterfaceConfigFile = Configuration::getString(
    "Interfaces.outputInterfaceConfiguration");

// !!!!!! Remove in tutorial part 2, Snippet-2-1 - BEGIN
if (!SystemCore::configure(systemCoreConfigFile, outputInterfaceConfigFile)) {
  printf("Error: failed to setup SystemCore!\n");
  return -1;
}
// !!!!!! Remove - END
```

Snippet 1-2

- Interconnecting OpenSG and *inVRs*
  - Request the SceneGraphInterface from the OutputInterface
  - Retrieve the root node of the scene graph interface
  - Attach it to the to the root node of our so far empty OpenSG scene

Basic Application Development

```
OpenSGSceneGraphInterface* sgIF =
  dynamic_cast<OpenSGSceneGraphInterface*>(OutputInterface::
      getSceneGraphInterface());
if (!sgIF) {
  printf("Error: Failed to get OpenSGSceneGraphInterface!\n");
  printf("Please check if the OutputInterface configuration is correct!\n");
  return -1;
}
// retrieve root node of the SceneGraphInterface (method is OpenSG specific)
NodePtr scene = sgIF->getNodePtr();

root->addChild(scene);
```

Snippet 1-3

- Cleaning Up
  - Since we have instantiated the *inVRs* SystemCore, including its sub-components we have to clean up at exit
  - Insert the following snippet in the cleanup method

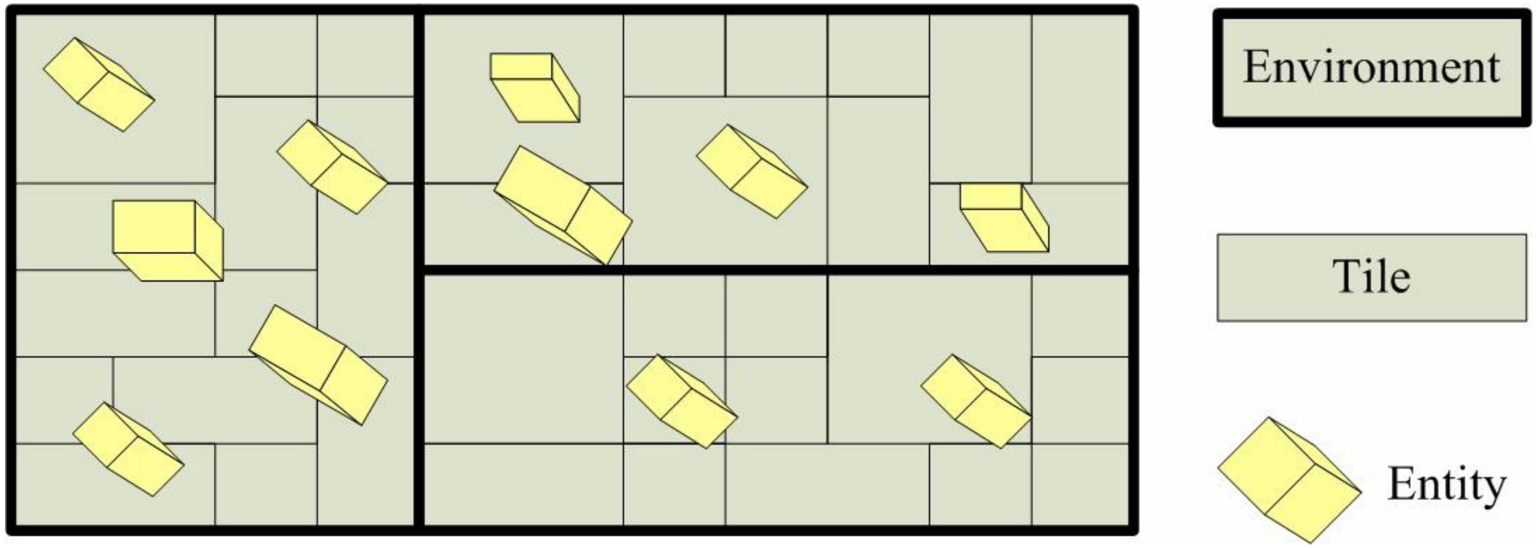
```
SystemCore::cleanup(); // clean up SystemCore and registered components
```

Snippet 1-4

- Recompile and Run
  - You should now see a medieval town behind a black background
  - A basic navigation is provided by the OpenSG SimpleSceneManager

Basic Application Development

- Working with the World Database
  - An *inVRs* VE consists of Environments, Entities and Tiles



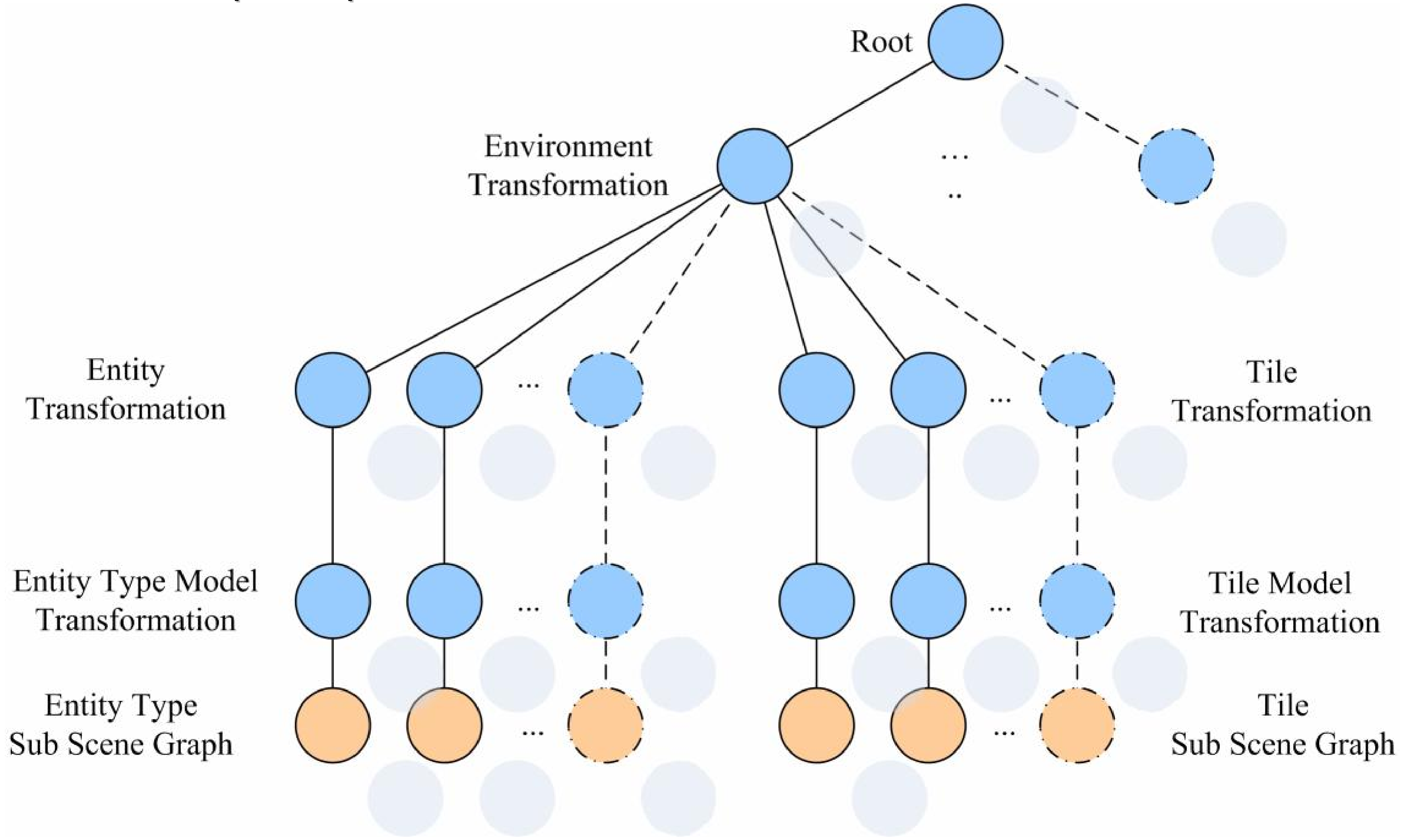
  - They are typically used for partitioning and functionality (Entities) in the VE
  - Configurations for these types are stored in **`worldDatabase.xml`**

```
<?xml version="1.0"?>
<!DOCTYPE worldDatabase SYSTEM "http://dtd.inVRs.org/worldDatabase_v1.0a4.dtd">
<worldDatabase version="1.0a4">
  <entityTypes configFile="entities.xml"/>
  <tiles configFile="tiles.xml"/>
  <environmentLayout configFile="environmentLayout.xml"/>
</worldDatabase>
```

worldDatabase.xml

Basic Application Development

- Scene Graph Representation


Root
Environment Transformation
…
..
Entity Transformation
Tile Transformation
Entity Type Model Transformation
Tile Model Transformation
Entity Type Sub Scene Graph
Tile Sub Scene Graph
...

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Basic Application Development

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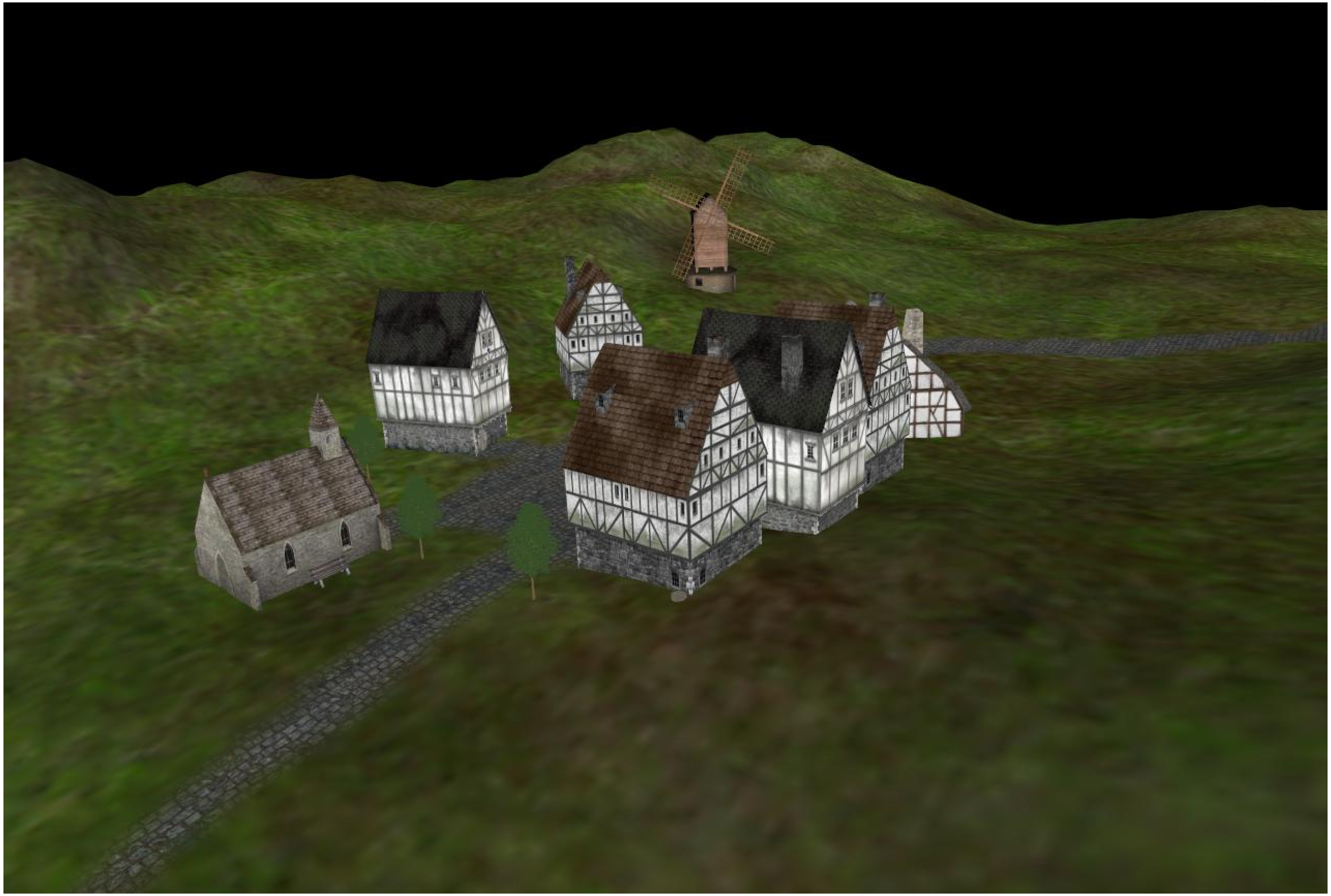

Chapter 2
Navigation and Skybox

Where new *inVRs* components will be added, the user is able to travel through the scene and the environment is lightened up.

Navigation and Skybox

- Adding *inVRs* Components
  - In order to use the navigation several components are needed
    - The Navigation module – to provide new user or camera coordinates
    - The InputInterface – to gather input from devices and expose it to the Navigation module
    - The UserDatabase – to set camera and user transformations
    - The TransformationManager – to pass the transformations generated by the Navigation module to the UserDatabase
  - This requires
    - Setting up the configurations of these components if they are not already provided
    - Registering these components unless they are core components
    - Implementing callbacks to access these components during the initialization

Navigation and Skybox

- Adding *inVRs* Components
  - The configuration-files for the two component types, the InputInterface and the modules, have to be set as well at the top of general.xml

```
<Modules>
  <option key="modulesConfiguration" value="modules.xml" />
</Modules>
<Interfaces>
  <option key="inputInterfaceConfiguration" value="inputInterface.xml" />
</Interfaces>
```

general.xml

  - Interfaces and modules are available as individual libraries
  - They can be loaded as plugins
  - The paths provided in this snippet define the location where the configuration files for these component types are located

```
<path name="InputInterfaceConfiguration" directory="config/inputinterface/" />
<path name="ModulesConfiguration" directory="config/modules/" />
```

general.xml

Navigation and Skybox

- Adding *inVRs* Components
  - The paths for the configurations of the individual components, not to be mixed up with the component types, have to be provided in general.xml

```
<!-- Path for Interfaces Datastructure -->
<path name="ControllerManagerConfiguration"
  directory="config/inputinterface/controllermanager/" />

<!-- Paths for Module Datastructure -->
<path name="NavigationModuleConfiguration"
    directory="config/modules/navigation/" />
```

general.xml

  - More configuration paths have to be set, since we are working in this chapter with the UserDatabase and later on with the representation of the user too

```
<avatar configFile="avatar.xml"/>
```

userDatabase.xml

  - In the module configuration file the Navigation modules configuration file has to be provided

```
<module name="Navigation" configFile="navigation.xml" />
```

modules.xml

  - The configuration of the system might seem cumbersome so far, typically standard configurations are used and only single parts for components are to be exchanged

Navigation and Skybox

- Adding *inVRs* Components
  - Initialization process has to be changed
    - Paths for modules and interfaces are requested
    - The interfaces and the modules have to be configured as well
    - Thus the overloaded configure function is used

```
// !!!!!! Remove part of Snippet-1-2 (right above)
// in addition to the SystemCore config file, modules and interfaces config
// files have to be loaded.
std::string modulesConfigFile = Configuration::getString(
      "Modules.modulesConfiguration");
std::string inputInterfaceConfigFile = Configuration::getString(
    "Interfaces.inputInterfaceConfiguration");

if (!SystemCore::configure(systemCoreConfigFile, outputInterfaceConfigFile,
    inputInterfaceConfigFile, modulesConfigFile)) {
  printf("Error: failed to setup SystemCore!\n");
  printf("Please check if the Plugins-path is correctly set to the inVRs-lib
      directory in the ");
  printf("'final/config/general.xml' config file, e.g.:\n");
  printf("<path name=\"Plugins\" path=\"/home/guest/inVRs/lib\"/>\n");
  return -1;
}
```

Snippet 2-1

- Watch out with inserting this snippet code, parts above have to be removed

Navigation and Skybox

- Adding *inVRs* Components
  - Both callbacks request pointers to the components at the initialization

```
void initInputInterface(ModuleInterface* moduleInterface) {
  // store ControllerManger and the Controller as soon as the ControllerManager
  // is initialized
  if (moduleInterface->getName() == "ControllerManager") {
    controllerManager = (ControllerManager*)moduleInterface;
    controller = (Controller*)controllerManager->getController();
  }
}
```

Snippet 2-2

  - Watch out when inserting this snippet, it contains cross references to others

```
void initModules(ModuleInterface* module) {
  // store the Navigation as soon as it is initialized
  if (module->getName() == "Navigation") {
    navigation = (Navigation*)module;
  }
  //----------------------------------------------------------------------//
  // Snippet-4-1                                                          //
  //----------------------------------------------------------------------//

  //----------------------------------------------------------------------//
  // Snippet-5-1                                                          //
  //----------------------------------------------------------------------//
}
```

Snippet 2-3

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Navigation and Skybox

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- Adding *inVRs* Components
  - Finally the callback functions for the interfaces and the modules have to be registered

```
// register callbacks
InputInterface::registerModuleInitCallback(initInputInterface);
SystemCore::registerModuleInitCallback(initModules);
```

Snippet 2-4

  - As with the XML configuration this approach might seem cumbersome, but is very generic and can be avoided by using an additional helper class
  - This helper class is introduced in the following tutorial the *Going Immersive Tutorial*

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Navigation and Skybox

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- Navigation Concepts
  - Navigation or travel consists of three independent models
    - Speed
    - Orientation
    - Translation
  - Are composed by the Navigation module in order to create a resulting transformation
  - This transformation is to be passed on an object (e.g. camera, avatar)
  - Typically the camera is used, but effects like dangling camera as known from third-person VEs can be implemented easily
  - Each model takes data from an abstract controller which is part of the input interface
    - The controller takes input from devices and exposes it as
      - Buttons (boolean values)
      - Axes (linear values)
      - Sensors (6DOF position and orientation values)

Navigation and Skybox

- Implementing Navigation
  - At first gather pointers to the relevant objects
    - User
    - Camera
    - Avatar
  - The camera and the avatar object are retrieved from the user object
  - In our case we are working with the local user
    - These objects can be retrieved as well from remote users once they are connect and the data is stored in the UserDatabase
  - The display of the avatar is set to false
  - The initial transformation of the user is retrieved from the environment
    - The entryPoint as described in the previous chapter is taken into account
  - This transformation is then set on the navigated transformation of the user object

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Navigation and Skybox

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- Implementing Navigation

```
// fetch users camera, it is used to tell the Navigator where we are
localUser = UserDatabase::getLocalUser();
if (!localUser) {
  printd(ERROR, "Error: Could not find localUser!\n");
  return -1;
}

camera = localUser->getCamera();
if (!camera) {
  printd(ERROR, "Error: Could not find camera!\n");
  return -1;
}

avatar = localUser->getAvatar();
if (!avatar) {
  printd(ERROR, "Error: Could not find avatar!\n");
  return -1;
}
avatar->showAvatar(false);

// set our transformation to the start transformation
TransformationData startTrans =
  WorldDatabase::getEnvironmentWithId(1)->getStartTransformation(0);
localUser->setNavigatedTransformation(startTrans);
```

Snippet 2-5

Navigation and Skybox

- Implementing Navigation
  - The OpenSG SimpleSceneManger functionality has to be decoupled
  - Pointer to the Navigator is retrieved from the manager and disabled
  - A Timer is initialized
  - The camera matrix is initialized

```
// Navigator is part of SimpleSceneManager and not of the inVRs framework
Navigator *nav = mgr->getNavigator();
nav->setMode(Navigator::NONE);      // turn off the navigator
lastTimeStamp = timer.getTime();    // initialize timestamp;
camMatrix = gmtl::MAT_IDENTITY44F; // initial setting of the camera matrix
```

Snippet 2-6

  - Navigation and input processing, as well as timer updates and transformation management has to take place on a per-frame basis
  - The display() - method which was registered as GLUT callback has to be altered

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Navigation and Skybox

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- Implementing Navigation
  - The timestamp is updated and a delta value describing the time difference from the last update is set
  - The abstract controller is updated
    - Devices are polled and their values are exposed
  - Navigation is updated based on these values
  - The TransformationManager processes the navigation
  - The transformation matrix of the *inVRs* camera is requested

```
float currentTimeStamp;
Matrix osgCamMatrix;
float dt; // time difference between currentTimestamp and lastTimestamp

currentTimeStamp = timer.getTime(); //get current time
dt = currentTimeStamp - lastTimeStamp;

controller->update();    // poll/update associated devices
navigation->update(dt);  // update navigation

// process transformations which belong to the pipes with priority 0x0E000000
TransformationManager::step(dt, 0x0E000000);

camera->getCameraTransformation(camMatrix); // get camera transformation
```

Snippet 2-7

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Navigation and Skybox

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- Implementing Navigation
  - The *inVRs* camera matrix is converted in to a OpenSG camera matrix
  - The navigator of the SimpleSceneManager is requested
  - The converted matrix is set in the navigator
  - The TransformationManager is invoked to process the remaining transformations (more detail on this in the next chapter)
  - The timeStamp is kept as the previous timeStamp

```
set(osgCamMatrix, camMatrix);        // convert gmtl matrix into OpenSG matrix

Navigator* nav = mgr->getNavigator();
nav->set(osgCamMatrix);              // plug new camera matrix into navigator

TransformationManager::step(dt);    // process the remaining pipes

lastTimeStamp = currentTimeStamp;
```

Snippet 2-8

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Navigation and Skybox

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- Decoupling the OpenSG Input – Integrating *inVRs* Input Handling
  - Alter the predefined GLUT – callback functions
  - Data is now passed to *inVRs* (GlutMouseDevice and GlutKeyboardDevice) instead of the SimpleSceneManager
  - Gather knowledge on current window size for calculation of the cursor position

```
// the mouse device must be aware of the window size in pixel
GlutMouseDevice::setWindowSize(w, h);
```

Snippet 2-9

  - Poll the mouse button state

```
// (replace the lines above in this function) instead of calling the
// SimpleSceneManager we delegate the message to our mouse device
GlutMouseDevice::cbGlutMouse(button, state, x, y);
```

Snippet 2-10

  - Gather input on the mouse movement

```
// (replace the lines above in this function) instead of calling the
// SimpleSceneManager we delegate the message to our mouse device
GlutMouseDevice::cbGlutMouseMove(x, y);
```

Snippet 2-11

  - Gather input on pressed keyboard keys

```
// notify keyboard device about GLUT message
GlutCharKeyboardDevice::cbGlutKeyboard(k, x, y);
```

Snippet 2-12

Navigation and Skybox

- Decoupling the OpenSG Input – Integrating *inVRs* Input Handling
  - Additional keys should be checked to trap the mouse cursor in the active window

```
// grab the mouse
case 'm':
case 'M': {
  grabMouse = !grabMouse;
  GlutMouseDevice::setMouseGrabbing(grabMouse);
} break;
```

Snippet 2-13

  - Gather input on released keyboard keys

```
GlutCharKeyboardDevice::cbGlutKeyboardUp(k, x, y);
```

Snippet 2-14

- Configuring the Navigation
  - Each model has its specific configuration
  - Typically the arguments passed to the models perform a mapping from the abstract input into model specific parameters
  - Setup in navigation.xml
  - Many predefined models exist

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Navigation and Skybox

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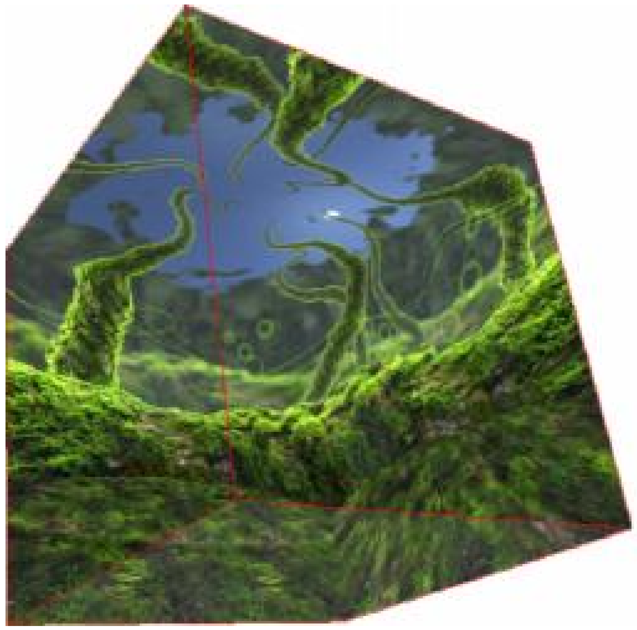
- Configuring the Navigation

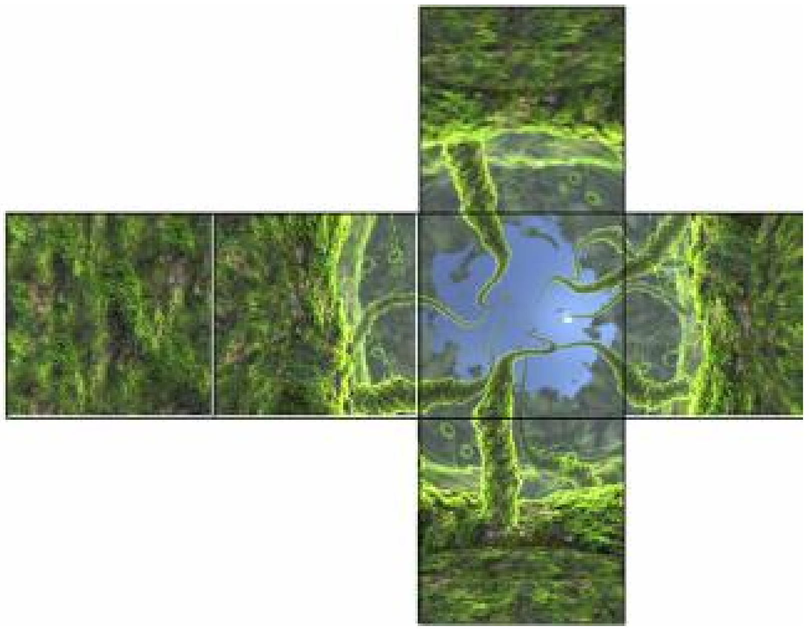
```
<?xml version="1.0"?>
<!DOCTYPE navigation SYSTEM "http://dtd.inVRs.org/navigation_v1.0a4.dtd">
<navigation version="1.0a4">
  <translationModel type="TranslationViewDirectionButtonStrafeModel">
    <arguments>
      <arg key="frontIndex" type="uint" value="3"/>
      <arg key="backIndex" type="uint" value="4"/>
      <arg key="leftIndex" type="uint" value="5"/>
      <arg key="rightIndex" type="uint" value="6"/>
    </arguments>
  </translationModel>
  <orientationModel type="OrientationDualAxisModel" angle="20">
    <arguments>
      <arg key="xAxisIndex" type="int" value="0"/>
      <arg key="yAxisIndex" type="int" value="1"/>
      <arg key="buttonIndex" type="int" value="1"/>
    </arguments>
  </orientationModel>
  <speedModel type="SpeedMultiButtonModel" speed="10">
    <arguments>
      <arg key="accelButtonIndices" type="string" value="3 4 5 6"/>
    </arguments>
  </speedModel>
</navigation>
```

navigation.xml

Navigation and Skybox

- Skybox Tool
  - Skyboxes are used to represent scene surroundings
  - Skyboxes move with the camera
  - The Skybox orientation is always fixed to the scene
  - Typically 6 textures mapped on cubes, *inVRs* offers different box shapes





Navigation and Skybox

- Adding a Skybox
  - The path is retrieved from the configuration and a skybox is set up with 6 image files
  - Dimensions and far clipping plane have to be set as well

```
// generate and configure the SkyBox
std::string skyPath = Configuration::getPath("Skybox");
skybox.init(5,5,5, 1000, (skyPath+"lostatseaday/lostatseaday_dn.jpg").c_str(),
  (skyPath+"lostatseaday/lostatseaday_up.jpg").c_str(),
  (skyPath+"lostatseaday/lostatseaday_ft.jpg").c_str(),
  (skyPath+"lostatseaday/lostatseaday_bk.jpg").c_str(),
  (skyPath+"lostatseaday/lostatseaday_rt.jpg").c_str(),
  (skyPath+"lostatseaday/lostatseaday_lf.jpg").c_str());
```

Snippet 2-15

  - The Skybox is internally generated and a node pointer containing the Skybox scene graph is requested
  - This node is attached to the top node of the scene

```
root->addChild(skybox.getNodePtr());
```

Snippet 2-16

  - The box position is set to the camera position

```
skybox.setupRender(camera->getPosition());
```

Snippet 2-17

  - Compile and run

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Navigation and Skybox

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Chapter 3
Transformation Management

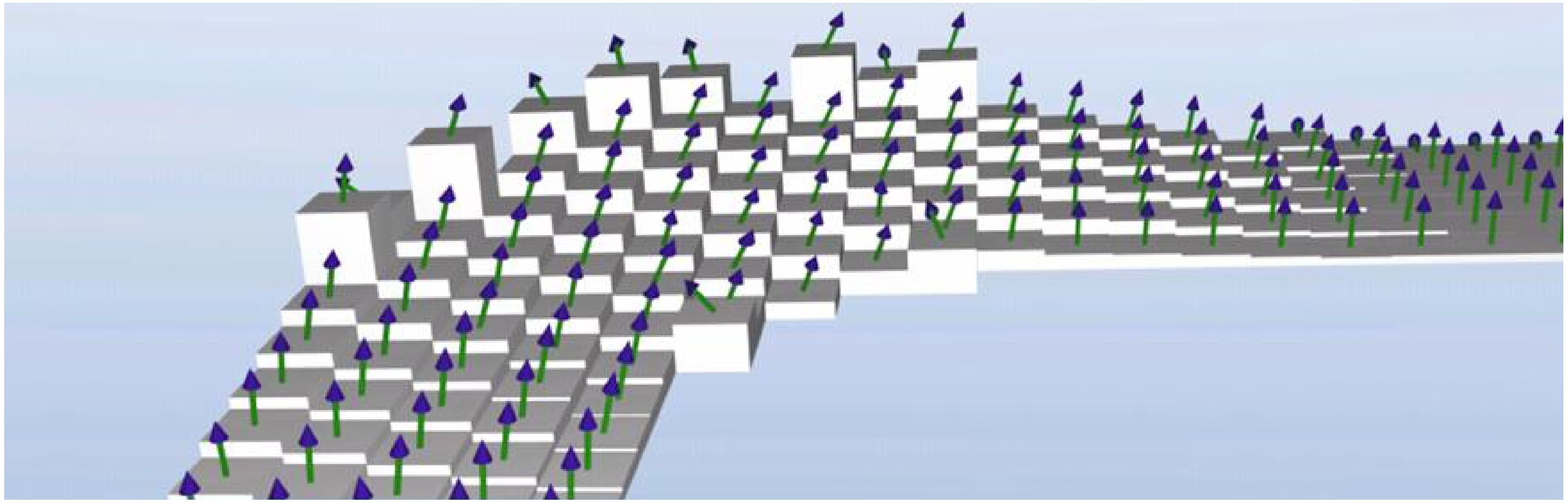
Where the navigation results are altered that the terrain can be followed and collisions with the buildings can be detected and resolved.

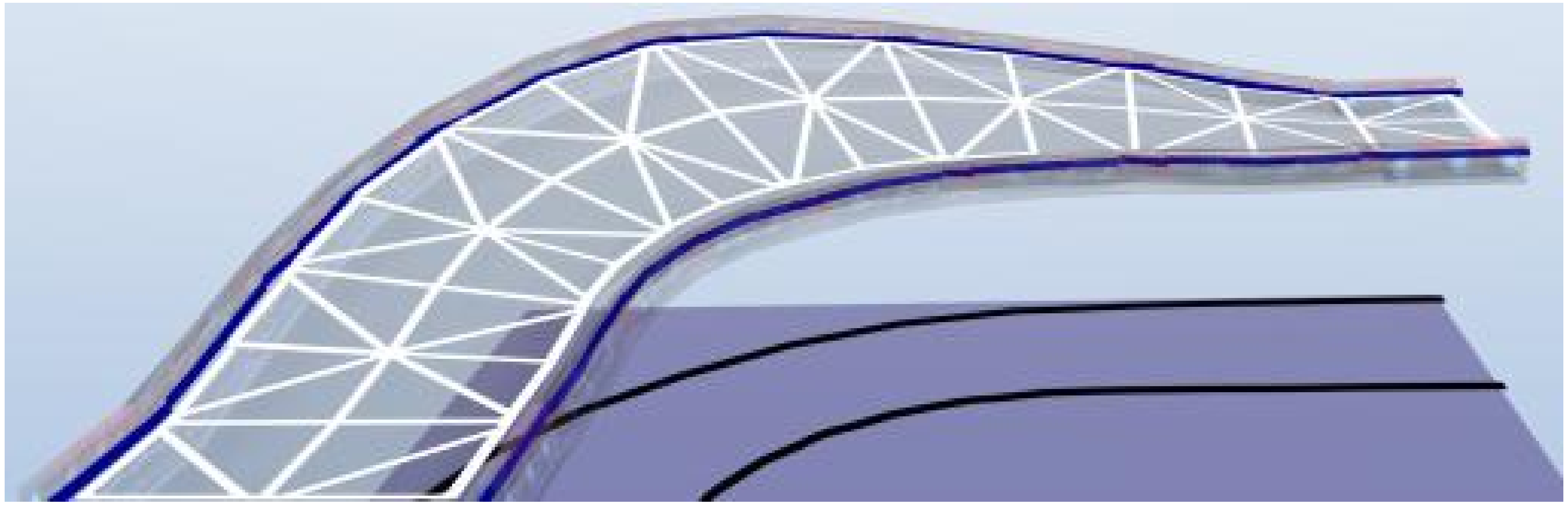
Transformation Management

- Height Maps and Collision Maps
  - Height maps
    - 2D Grid structure defining the height value underneath a 3D geometry
    - Additional normal vectors are provided which describe the orientation of the triangles at given grid location
  - Collision Maps
    - Line sets defining non-passable areas in a VE
    - Mapping from 3D objects on a plane
    - Plane is placed in the scene
    - Lines are drawn where geometries at a defined height are cut
  - Both are implemented as modifiers and can alter the generated transformation matrix

Transformation Management

- Height Maps and Collision Maps





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Transformation Management

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- Generating Height Maps
  - Either offline or online
  - Take tiles as input
  - If height maps have to be generated during runtime this can take a significant amount of time
  - In case no pre-defined height map is available for a tile and the method generate is called a height map will be automatically created
  - The geometry of a tile sampled and the grid is generated

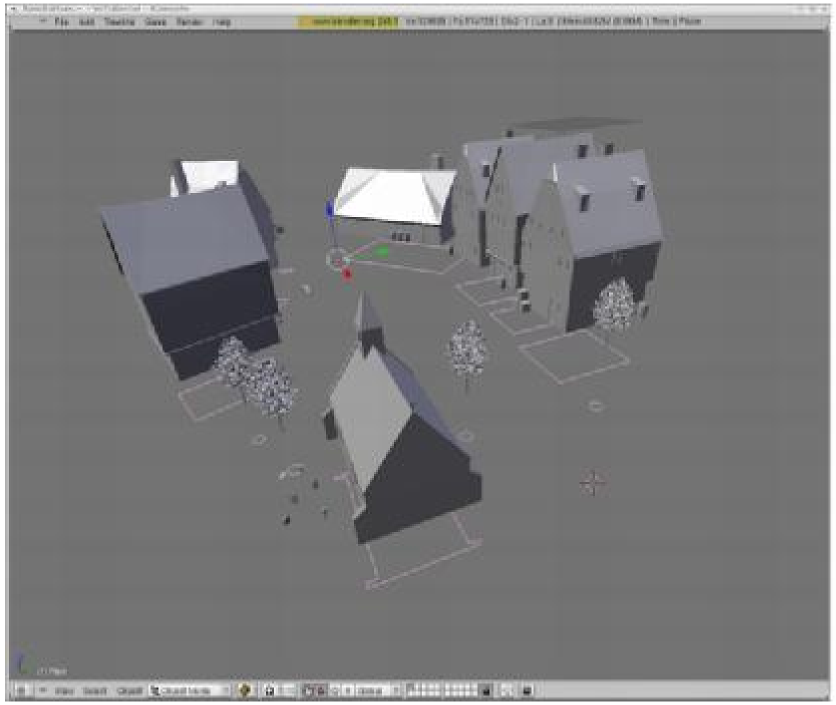
```
HeightMapManager::generateTileHeightMaps();
```

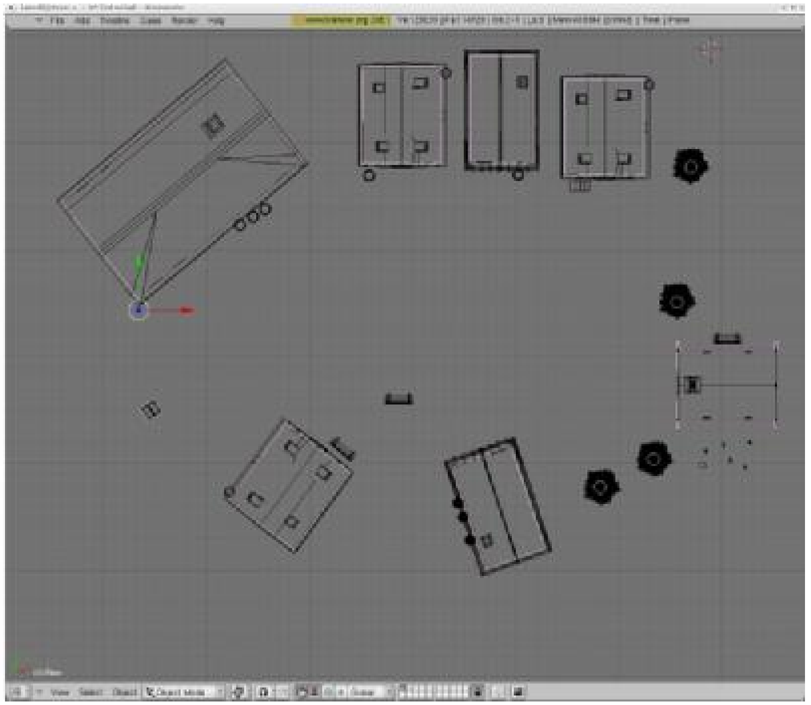
Snippet 3-1

- Generating Collision Maps
  - Always have to be created offline
  - Can be generated automatically by an external tool
  - Modeling tools (e.g. Blender, MAYA, 3D Max) are often used to manually draw collision lines

Transformation Management

- Generating Collision Maps
  - Typically the final scene is dumped to disk from the application
  - It is loaded into the modeling tool
  - The lines are drawn from top view
  - The line sets are again written to disc in a VRML file format





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Transformation Management

interactive networked virtual reality system

- Transformation Manager Architecture
  - Consists of Pipes and Modifiers
  - TransformationData is sent from a source component to a destination component via the TransformationManager
  - At the destination component the transformation is to be applied on a target
- Pipes
  - Transformations are routed through pipes inside the transformation manager
  - Have a key consisting of source and destination component, target, received from network, etc.
  - Have several stages where the transformation can be modified
- Modifiers
  - Pipe stage
  - Different types e.g. for reading and writing data from and to external components exist

Transformation Management

- Setting up the Transformation Manager
  - Pipe is identified by a key
  - Contains list of modifiers

```xml
<?xml version="1.0"?>
<!DOCTYPE transformationManager SYSTEM "http://dtd.inVRs.org/
    transformationManager_v1.0a4.dtd">
<transformationManager version="1.0a4">
  <mergerList/>
  <pipeList>
    <pipe srcComponentName="NavigationModule"
        dstComponentName="TransformationManager" pipeType="Any"
        objectClass="Any" objectType="Any" objectId="Any"
        fromNetwork="0">
      <modifier type="ApplyNavigationModifier"/>

<!-- *************************** Snippet-3-1 ****************************** -->

<!-- *************************** Snippet-3-2 ****************************** -->

<!-- *************************** Snippet-5-3 ****************************** -->

      <modifier type="UserTransformationWriter"/>
      <modifier type="CameraTransformationWriter">

<!-- *************************** Snippet-3-3 ****************************** -->
```

modifiers.xml

Transformation Management

- Integrating the Height Maps and Collision Maps
  - Height map modifier has to be integrated after the navigated transformation is put in the pipe

```
<modifier type="HeightMapModifier" />
```

modifiers.xml

  - CheckCollisionModifier is applied afterwards
  - Radius for collision detection is to be set
  - Filename of the collision map has to be provided

```
<modifier type="CheckCollisionModifier">
  <arguments>
    <arg key="radius" type="float" value="1" />
    <arg key="fileName" type="string" value="MedievalTownCollisionMap.wrl"/>
  </arguments>
</modifier>
```

modifiers.xml

  - The height of the camera has to be modified

```
<arguments>
  <arg key="cameraHeight" type="float" value="1.8"/>
  <arg key="useGlobalYAxis" type="bool" value="true"/>
</arguments>
```

modifiers.xml

Transformation Management

- Adding the Transformation Managers' Setup
  - The factories for generating the used modifiers have to be registered since the modifiers are not provided as core features
  - All additional modifiers which are not provided by the SystemCore have to register their factories at the initialization callback

```
void initCoreComponents(CoreComponents comp) {
  // register factory for HeightMapModifier as soon as the
  // TransformationManager is initialized
  if (comp == TRANSFORMATIONMANAGER) {
    TransformationManager::registerModifierFactory
      (new HeightMapModifierFactory());
  // register factory for CheckCollisionModifier
    TransformationManager::registerModifierFactory
      (new CheckCollisionModifierFactory);
  }
}
```

Snippet 3-2

  - The TransformationManager has to be registered for a callback

```
  SystemCore::registerCoreComponentInitCallback(initCoreComponents);
```

Snippet 3-3

  - Compile and run

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Transformation Management

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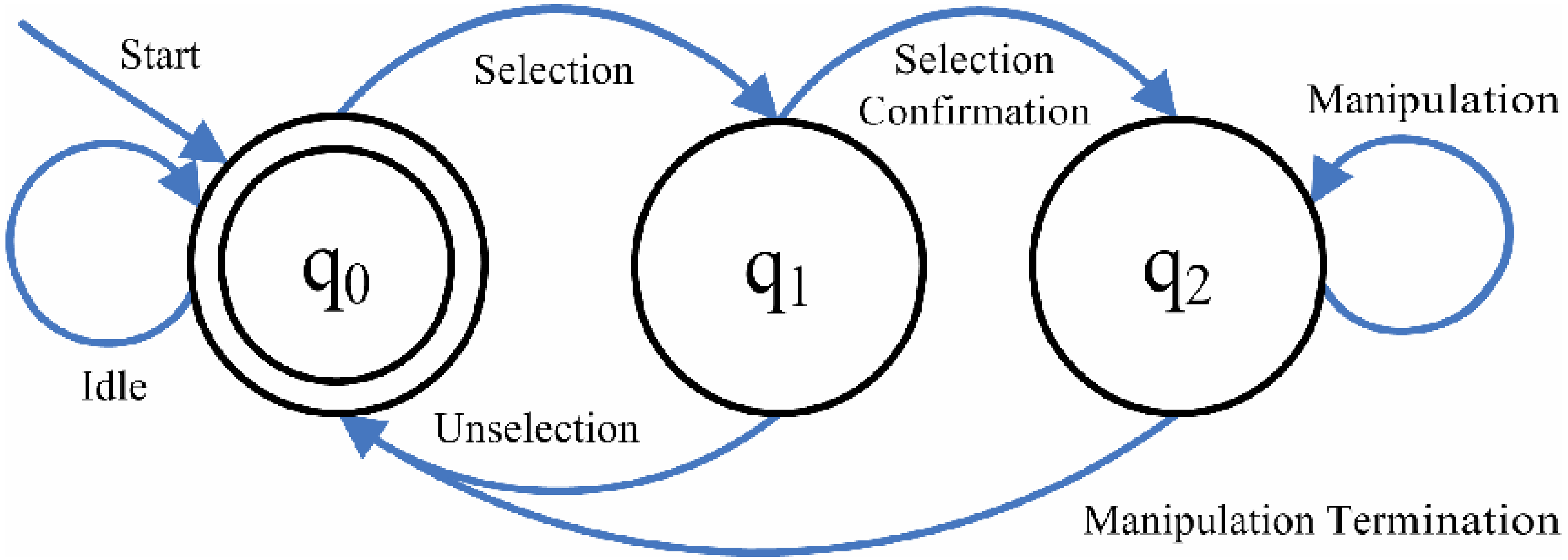
Chapter 4
Interaction

Where the user is able to pick up and drop boxes and benches in the town.

Interaction

- Implemented as a deterministic finite automaton (DFA)
  - Input alphabet Σ defined through components of the abstract input device and system states
  - $q = \{q_0$ (Idle), q_1, (Selection) q_2, (Manipulation)$\}$
  - Transition function δ defined through interaction techniques
  - Start- and end state = q_0



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Interaction

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- Configuring the State Machine

```
<?xml version="1.0"?>
<!DOCTYPE interaction SYSTEM "http://dtd.inVRs.org/interaction_v1.0a4.dtd">
<interaction version="1.0a4">

  <stateActionModels>
    <selectionActionModel type="HighlightSelectionActionModel">
      <arguments>
        <arg key="modelType" type="string" value="OSG"/>
        <arg key="modelPath" type="string" value="box.osg"/>
      </arguments>
    </selectionActionModel>
    <manipulationActionModel type="HomerManipulationActionModel">
      <arguments>
        <arg key="usePickingOffset" type="bool" value="true"/>
      </arguments>
    </manipulationActionModel>
  </stateActionModels>

  <stateTransitionModels>
    <selectionChangeModel type="LimitRayCastSelectionChangeModel">
      <arguments>
        <arg key="rayDistanceThreshold" type="float" value="5"/>
      </arguments>
    </selectionChangeModel>
    <unselectionChangeModel type="LimitRayCastSelectionChangeModel">
      <arguments>
```

interaction.xml

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Interaction

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- Adding the Interaction Module to our Application
  - Set the path for the interaction configuration first

```
<path name="InteractionModuleConfiguration"
      directory="config/modules/interaction/" />
```
general.xml

  - Provide a configuration file for the Interaction module

```
<module name="Interaction" configFile="interaction.xml" />
```
modules.xml

  - Retrieve the module in callback function

```
// store the Interaction as soon as it is initialized
else if (module->getName() == "Interaction") {
  interaction = (Interaction*)module;
}
```
Snippet 4-1

Interaction

- Setting up the Transformation Management
  - For interaction the transformation pipe has to be altered again
  - In the navigation pipe the updated position has to write out the cursor position, which is always relative to the user

```
<modifier type="ApplyCursorTransformationModifier" />
<modifier type="CursorTransformationWriter" />
```

modifiers.xml

  - An additional pipe has to be configured, which takes as a source the Interaction module and as destination the WorldDatabase
  - The pipe is opened by the modules when needed
  - This pipe is the interaction pipe using modifiers for
    - Adding manipulation offset
    - Writing out the transformation

```
<pipe srcModuleName="InteractionModule" dstModuleName="WorldDatabase"
  pipeType="Any" objectClass="Any" objectType="Any" objectId="Any"
  fromNetwork="0">
  <modifier type="ManipulationOffsetModifier"/>
  <modifier type="TransformationDistributionModifier"/>
  <modifier type="EntityTransformationWriter" />
</pipe>
```

modifiers.xml

Interaction

- Adding a Cursor Representation
  - Helpful to have a visual representation of the cursor for selection and manipulation
  - Paths for model and representation have to be set as well

```
<path name="CursorConfig"
  path="config/systemcore/userdatabase/cursorRepresentation/" />
<path name="CursorModelConfiguration"
  path="config/systemcore/userdatabase/cursorModel/" />
```

general.xml

  - Additionally the configuration files have to be set in the UserDatabase

```
<cursorRepresentation configFile="handRepresentation.xml" />
<cursorTransformationModel configFile="homerCursorModel.xml" />
```

userDatabase.xml

- Invoking Interaction and Changing the Cursor Appearance
  - In the display loop the interaction has to be invoked for checking the transition functions, changing the state, writing transformations and event processing
  - The cursor is updated based on information of the state machine

```
interaction->step(dt);

UserDatabase::updateCursors(dt);
```

Snippet 4-2

  - Compile and execute

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Interaction

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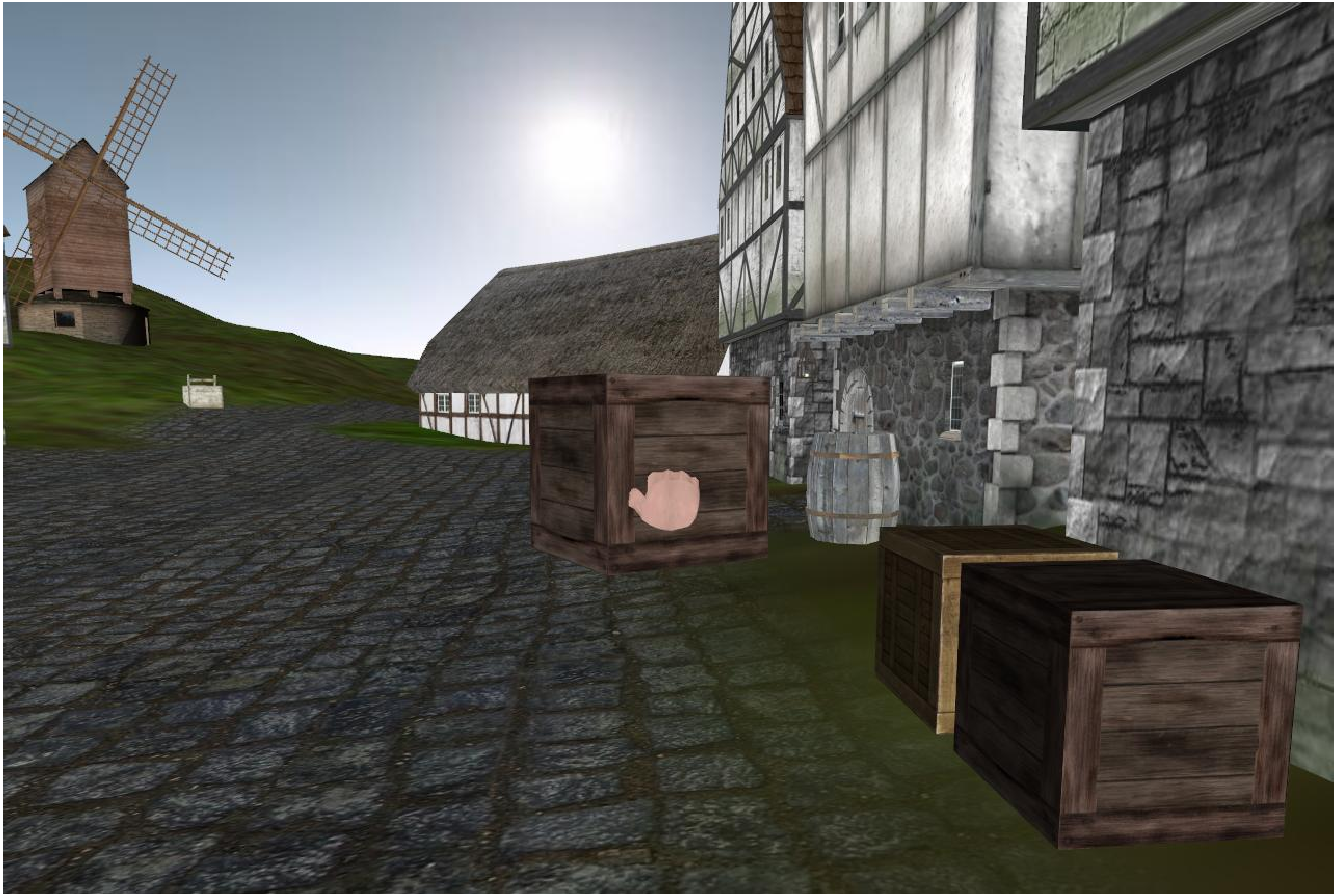

Chapter 5
Using Network Communication

Where the virtual world is shared with other participants and remote interaction and navigation can be perceived.

Using Network Communication

- Network Concepts
  - Module designed for exchangeability
    - Many implementations exist already
  - Standard module
    - Communication topology represents a complete graph
    - Databases fully replicated
  - Communication between components and network uses a high level interface
    - Sending and receiving of TransformationData and Events
    - Sending and receiving of user defined messages
    - Connection establishment and disconnecting

Using Network Communication

- Adding the Network Module to our Application
  - As usual set the path for the network configuration first

```
<path name="NetworkModuleConfiguration"
    directory="config/modules/network/" />
```

general.xml

  - Provide a configuration file for the Network module

```
<module name="Network" configFile="network.xml" />
```

modules.xml

  - Retrieve the module in callback function

```
// store the NetworkInterface as soon as it is initialized
else if (module->getName() == "Network") {
  network = (NetworkInterface*)module;
}
```

Snippet 5-1

  - Connection establishment using the first command line argument
  - Synchronization between the different instances (e.g. updates on the WorldDatabase)

```
// try to connect to network first command line argument is {hostname|IP}:port
if (argc > 1) {
  printf("Trying to connect to %s\n", argv[1]);
  network->connect(argv[1]);
}
SystemCore::synchronize();   // synchronize both VEs
```

Snippet 5-2

Using Network Communication

- Using the Network Module
  - An update on the SystemCore has to be triggered at the beginning of the display loop
  - Internal events like updating the UserDatabase and synchronizing the VEs can be subsequently trigged in in the core

```
SystemCore::step();  //update the system core, needed for event handling
```
Snippet 5-3

  - The ports which are used for communication are defined in network.xml
    - TCP is typically used for Events
    - UDP is typically used for TransformationData

```
<?xml version="1.0"?>
<!DOCTYPE network SYSTEM "http://dtd.inVRs.org/network_v1.0a4.dtd">
<network version="1.0a4">
  <ports TCP="8081" UDP="8082"/>
</network>
```
network.xml

- Altering the Transformation Management
  - In the interaction and navigation pipe a distributor has to be included
  - The current value at this stage is distributed to remote users and passed inside a similar pipe

Using Network Communication

```
    <modifier type="TransformationDistributionModifier" />
```
modifiers.xml

– An additional pipe for remote interaction input has to be set up
  - The attribute fromNetwork is in that case set to true

```
<pipe srcComponentName="InteractionModule" dstComponentName="WorldDatabase"
  pipeType="Any" objectClass="Any" objectType="Any" objectId="Any"
  fromNetwork="1">
  <modifier type="EntityTransformationWriter" />
</pipe>
```
modifiers.xml

– An additional pipe for remote navigation input has to be set up
  - The attribute fromNetwork is in that case set to true

```
<pipe srcComponentName="NavigationModule" dstComponentName="
    TransformationManager"
  pipeType="Any" objectClass="Any" objectType="Any" objectId="Any"
  fromNetwork="1">
  <modifier type="UserTransformationWriter" />
  <modifier type="AvatarTransformationWriter" >
    <arguments>
      <arg key="clipRotationToYAxis" type="bool" value="true" />
    </arguments>
  </modifier>
</pipe>
```
modifiers.xml

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Using Network Communication

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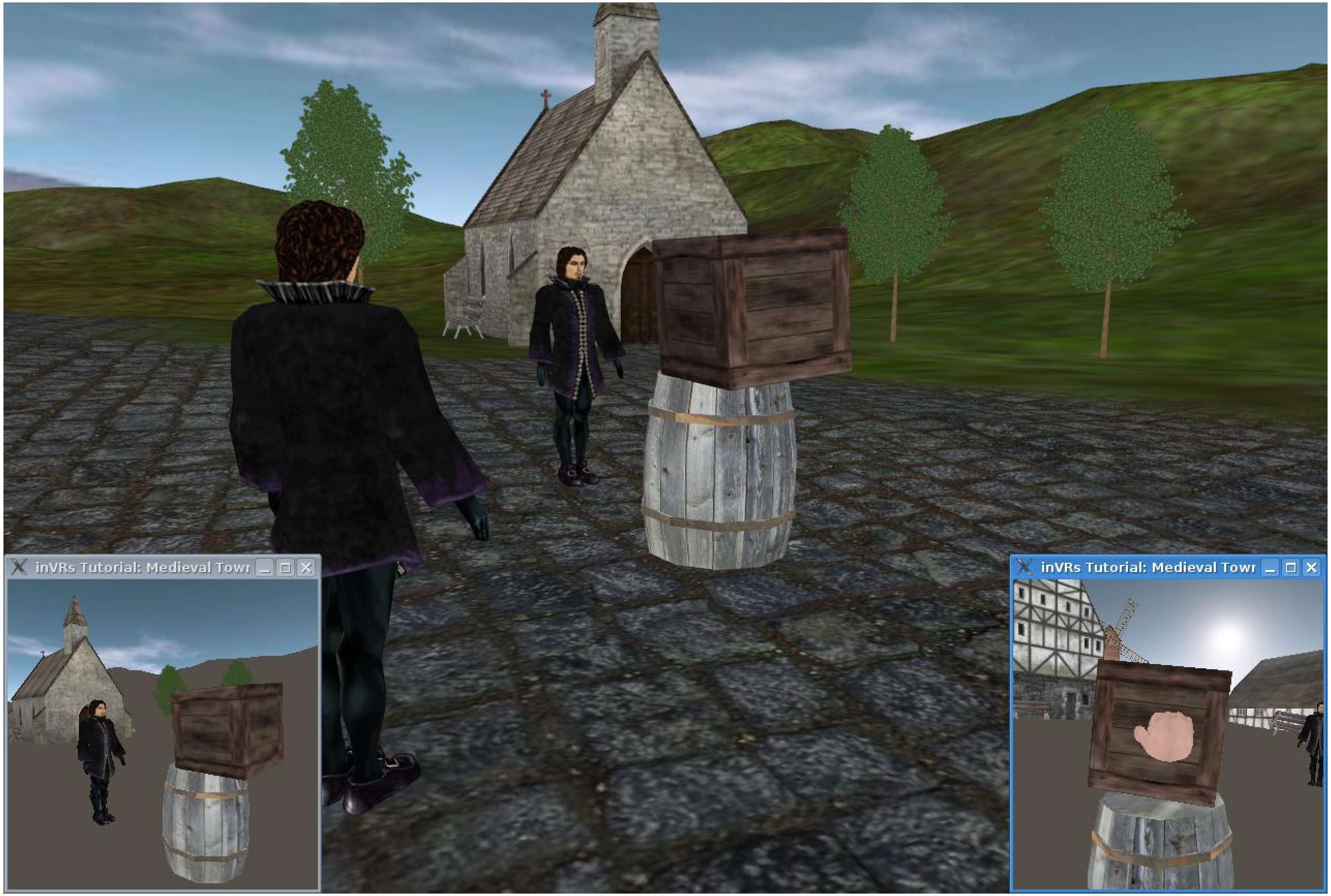

Chapter 6
Developing own Application Logic

Where new code is introduced into the application to make the sails of a windmill turn.

Developing own Application Logic

- Own Application Logic
  - Goal: to manipulate a scene graph of an entity based on user input
  - Gather exposed user input in display loop
  - Variable containing a rotational speed is used
  - In case the defined button is pressed speed is increased up to a threshold
  - If the button is not pressed the speed will be decreased to zero

```
if (controller->getButtonValue(2)) { // the right mouse button is pressed
  windMillSpeed += dt*0.5;           // increase speed of the windmill
  if (windMillSpeed > 2*M_PI) {
    windMillSpeed = 2*M_PI;
  }
} else if (windMillSpeed > 0) {      // pressing mouse button stopped
  windMillSpeed -= dt*0.5;           // decrease speed of windmill
} else if (windMillSpeed < 0) {
  windMillSpeed = 0;
}
```

Snippet-6-1

  - In next step the calculated speed has to be applied on the sails of the windmill model

Developing own Application Logic

- Own Application Logic
  - First get the entity from the WorldDatabase
  - Get the scene graph of the Entity
  - Get the sub scene graph of the previously retrieved scene graph with the name “Sails” (this name is stored in the loaded model)
  - Make sure it is a transformation node
  - Cast the *inVRs* scene graph node into an *inVRs* transformation node
  - Request the transformation from the node
  - Apply the rotational change to the transformation
  - Apply the final transformation on the transformation node

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Developing own Application Logic

INVRS
interactive networked virtual reality system

- Own application logic

```
if (windMillSpeed > 0) {                // rotate sails
  // retrieve the windmill entity
  Entity* windMill = WorldDatabase::getEntityWithEnvironmentId(1, 27);
  ModelInterface* windMillModel = windMill->getVisualRepresentation();

  // retrieve the windmill's sails
  SceneGraphNodeInterface* sceneGraphNode =
    windMillModel->getSubNodeByName("Sails");

  // make sure this node is a transformation node
  assert(sceneGraphNode->getNodeType() ==
    SceneGraphNodeInterface::TRANSFORMATION_NODE);
  TransformationSceneGraphNodeInterface* transNode =
    dynamic_cast<TransformationSceneGraphNodeInterface*>(sceneGraphNode);
  assert(transNode);

  // rotate the sails
  TransformationData trans = transNode->getTransformation();
  gmtl::AxisAnglef axisAngle(windMillSpeed*dt, 0, 0, 1);
  gmtl::Quatf rotation;
  gmtl::set(rotation, axisAngle);
  trans.orientation *= rotation;
  transNode->setTransformation(trans);
}
```

Snippet-6-1

- Recompile and execute

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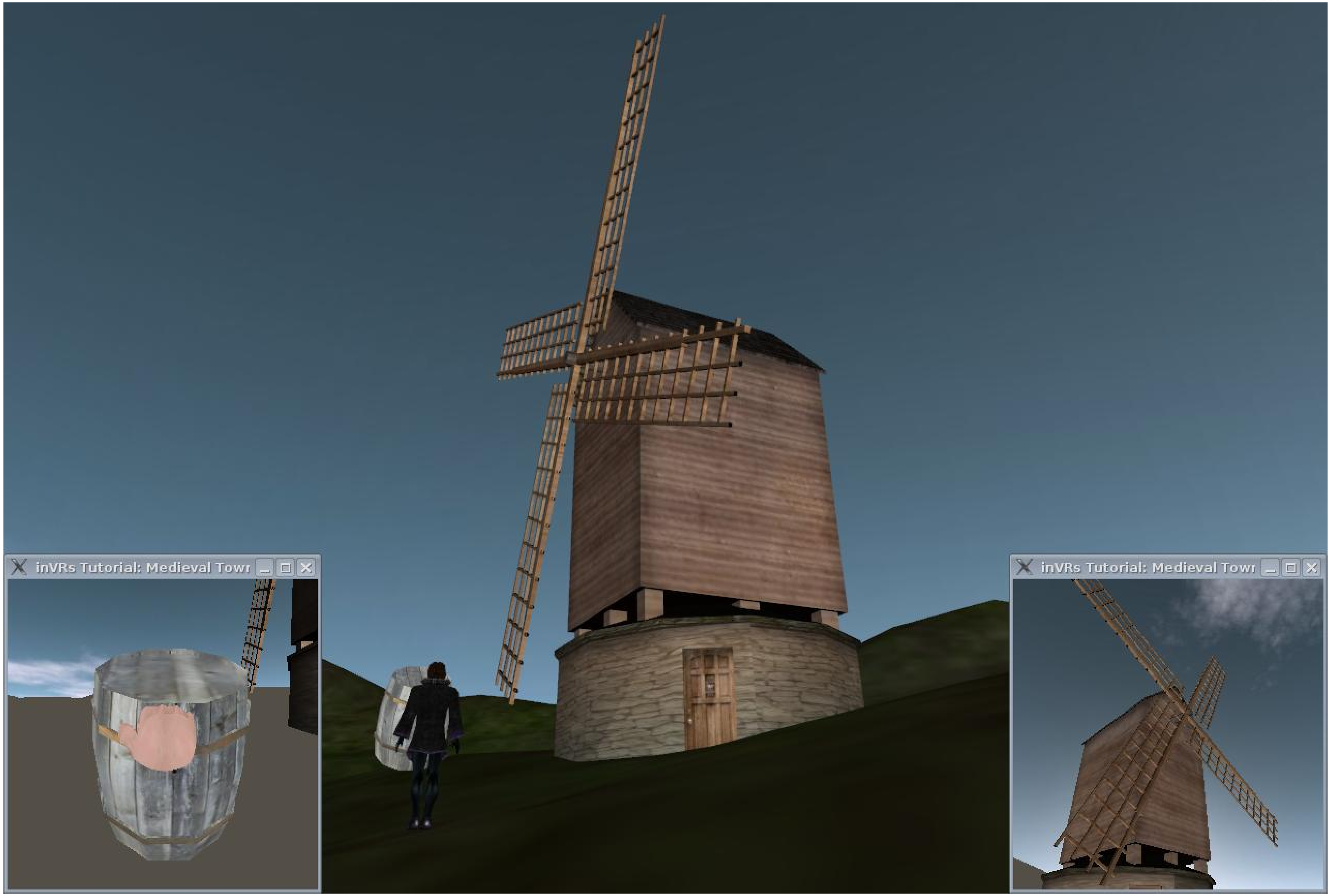
Developing own Application Logic

interactive networked virtual reality system



Outlook

Outlook

- Variety of additional tools are available
  - Modules
    - Physics Support (2D and 3D Physics)
    - Animation and Camera path
  - External Tools
    - Collaborative Editor
  - Scene Graph Specific Enhancements (OpenSG)
    - Avatars (with export from 3D Max, MAYA and Blender)
    - CAVESceneManager
    - Particle Wrapper
    - Skybox
    - 3D Menu System

Outlook

- Novel concepts
  - Clear distinction in the area of communication patterns
  - Events and transformations are handled independently
  - Transformation management allows for concurrent object manipulation
  - Composeable and clearly defined interaction and navigation
  - Automatic data distribution mechanism
  - Full abstraction from graphics, input, network, etc.; the developer should be able to focus on the application logic
  - Development and integration of networked physics module (Roland Landertshamer)

- Does not provide
  - Scripting support
  - Logic support

Acknowledgements

- Contributors
  - Architecture and Main Development

    Christoph Anthes, Helmut Bressler, Roland Landertshamer, Marina Lenger

  - Tools

    Helmut Garstenauer, Martin Garstenauer, Adrian Haffegee, Marlene Hochrieser, Roland Hopferwieser, Robert Owen, Stephan Reiter, Thomas Weberndorfer, Christian Wressnegger, Johannes Zarl

Bibliography

- Christoph Anthes; Paul Heinzlreiter; Gerhard Kurka & Jens Volkert, “Navigation Models for a Flexible, Multi-Mode VR Navigation Framework“, *ACM SIGGRAPH on Virtual Reality Continuum and Its Applications in Industry (VRCAI '04), ACM Press,* 2004, pages 476-479

- Christoph Anthes; Roland Landertshamer; Helmut Bressler & Jens Volkert, “Managing Transformations and Events in Networked Virtual Environments“ *ACM International MultiMedia Modeling Conference (MMM '07), Springer,* 2007*, 4352*, pages 722-729

- Christoph Anthes; Roland Landertshamer & Jens Volkert, “Physically-Based Interaction for Networked Virtual Environments.“, *International Conference on Computational Science (ICCS '07), Springer,* 2007*, 4488*, pages 776-783

- Christoph Anthes & Jens Volkert, “inVRs - A Framework for Building Interactive Networked Virtual Reality Systems“, *International Conference on High Performance Computing and Communications (HPCC '06), Springer,* 2006*, 4208*, pages 894-904

Bibliography

- Christoph Anthes; Alexander Wilhelm; Roland Landertshamer; Helmut Bressler & Jens Volkert, “Net’’O’’Drom -- An Example for the Development of Networked Immersive VR Applications“, *International Conference on Computational Science (ICCS '07), Springer,* 2007*, 4488*, pages 752-759

- Helmut Bressler; Roland Landertshamer; Christoph Anthes & Jens Volkert, “An Efficient Physics Engine for Virtual Worlds“, *medi@terra '06,* 2006, pages 152-158

- Adrian Haffegee; Ronan Jamieson; Christoph Anthes & Vassil N. Alexandrov, “Tools For Collaborative VR Application Development“, *International Conference on Computational Science (ICCS '05), Springer,* 2005*, 3516*, pages 350-358