OpenDaVINCI Documentation

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OpenDaVINCI is a compact middleware OpenDaVINCI written entirely in standard C++. It runs on a variety of POSIX-compatible OS. And Windows.

CHAPTER 1

How to install pre-compiled OpenDaVINCI libraries

To explore the features of OpenDaVINCI and to use it in your own projects, you can find pre-compiled packages in .deb and .rpm format for x86, x86_64, and armfh.

1.1 Adding OpenDaVINCI to your Ubuntu 14.04 Linux distribution

1. Add the public key from our repository:

```
$ wget -O - -q http://opendavinci.cse.chalmers.se/opendavinci.cse.chalmers.se.gpg.
↪key | sudo apt-key add -
```

2. Add our repository itself to your sources.list:

```
$ sudo sh -c 'echo "deb http://opendavinci.cse.chalmers.se/deb/ trusty main" >> /
↪etc/apt/sources.list'
```

3. Update your package database:

```
$ sudo apt-get update
```

4. Install OpenDaVINCI:

```
$ sudo apt-get install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

1.2 Adding OpenDaVINCI to your Ubuntu 15.04 Linux distribution

1. Add the public key from our repository:

```
$ wget -O - -q http://opendavinci.cse.chalmers.se/opendavinci.cse.chalmers.se.gpg.
↪key | sudo apt-key add -
```

2. Add our repository itself to your sources.list:

```
$ sudo sh -c 'echo "deb http://opendavinci.cse.chalmers.se/deb/ vivid main" >> /
↪etc/apt/sources.list'
```

3. Update your package database:

```
$ sudo apt-get update
```

4. Install OpenDaVINCI:

```
$ sudo apt-get install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

1.3 Adding OpenDaVINCI to your Ubuntu 15.10 Linux distribution

1. Add the public key from our repository:

```
$ wget -O - -q http://opendavinci.cse.chalmers.se/opendavinci.cse.chalmers.se.gpg.
↪key | sudo apt-key add -
```

2. Add our repository itself to your sources.list:

```
$ sudo sh -c 'echo "deb http://opendavinci.cse.chalmers.se/ubuntu-wily/ wily main
↪" >> /etc/apt/sources.list'
```

3. Update your package database:

```
$ sudo apt-get update
```

4. Install OpenDaVINCI:

```
$ sudo apt-get install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

1.4 Adding OpenDaVINCI to your Ubuntu 16.04 Linux distribution

1. Add the public key from our repository:

```
$ wget -O - -q http://opendavinci.cse.chalmers.se/opendavinci.cse.chalmers.se.gpg.
↪key | sudo apt-key add -
```

2. Add our repository:

```
$ sudo sh -c 'echo "deb [arch=amd64] http://opendavinci.cse.chalmers.se/ubuntu␣
↪xenial main" > /etc/apt/sources.list.d/opendavinci.list'
```

3. Update your package database:

```
$ sudo apt-get update
```

4. Install OpenDaVINCI:

```
$ sudo apt-get install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

1.5 Adding OpenDaVINCI to your Debian 8 Linux distribution

1. Add the public key from our repository:

```
$ wget -O - -q http://opendavinci.cse.chalmers.se/opendavinci.cse.chalmers.se.gpg.
↪key | sudo apt-key add -
```

2. Add our repository itself to your sources.list:

```
$ sudo echo "deb http://opendavinci.cse.chalmers.se/deb/ jessie main" >> /etc/apt/
↪sources.list
```

3. Update your package database:

```
$ sudo apt-get update
```

4. Install OpenDaVINCI:

```
$ sudo apt-get install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

1.6 Adding OpenDaVINCI to your CentOS 7 Linux distribution

1. Add our repository:

```
$ cd /etc/yum.repos.d && sudo wget http://opendavinci.cse.chalmers.se/OpenDaVINCI-
↪x86_64.repo
```

2. Update your package database:

```
$ sudo yum -y update
```

3. Install OpenDaVINCI:

```
$ sudo yum install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

1.7 Adding OpenDaVINCI to your Fedora 21 Linux distribution

1. Add our repository:

```
$ cd /etc/yum.repos.d && sudo wget http://opendavinci.cse.chalmers.se/OpenDaVINCI-
↪x86_64.repo
```

2. Update your package database:

```
$ sudo yum -y update
```

3. Install OpenDaVINCI:

```
$ sudo yum install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

1.8 Adding OpenDaVINCI to your Fedora 22 Linux distribution

1. Add our repository:

```
$ cd /etc/yum.repos.d && sudo wget http://opendavinci.cse.chalmers.se/OpenDaVINCI-
↪x86_64.repo
```

2. Update your package database:

```
$ sudo dnf -y upgrade
```

3. Install OpenDaVINCI:

```
$ sudo dnf install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

1.9 Adding OpenDaVINCI to your openSuSE 13 Linux distribution

1. Add our repository:

```
$ cd /etc/zypp/repos.d && sudo wget http://opendavinci.cse.chalmers.se/
↪OpenDaVINCI-x86_64.repo
```

2. Update your package database:

```
$ sudo zypper --no-gpg-checks refresh
```

3. Install OpenDaVINCI:

```
$ sudo zypper install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

1.10 Using our Docker images

You also find pre-built Docker images for x86_64 and armhf. These images will be automatically updated whenever new features or patches are released.

For Ubuntu/x86_64 (https://registry.hub.docker.com/u/seresearch/opendavinci-ubuntu-16.04-complete/):

```
$ docker pull seresearch/opendavinci-ubuntu-16.04-complete
```

For Ubuntu/armhf (https://registry.hub.docker.com/u/seresearch/opendavinci-ubuntu-16.04-armhf-complete/):

```
$ docker pull seresearch/opendavinci-ubuntu-armhf
```

CHAPTER 2

OpenDaVINCI Tutorials

2.1 How to use concurrency

2.1.1 How to use concurrency

OpenDaVINCI has a built-in platform-independent concurrency engine. Concurrency is realized on Linux-based and BSD-based operating systems using pthreads and on Windows by using C++11 features. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/service

In order to use concurrency in a user-supplied module, you will find a simple example below.

MyService.hpp:

```
#include <opendavinci/odcore/base/Service.h>

// Concurrency is provided by the class odcore::base::Service.
class MyService : public odcore::base::Service {

    // Your class needs to implement the method void beforeStop().
    virtual void beforeStop();

    // Your class needs to implement the method void run().
    virtual void run();

};
```

MyService.cpp:

```
#include <stdint.h>
#include <iostream>
#include <opendavinci/odcore/base/Thread.h>

#include "MyService.hpp"

using namespace std;
```

```
// Your class needs to implement the method void beforeStop().
void MyService::beforeStop() {
    // This block is executed right before
    // the thread will be stopped.
    cout << "This method is called right before "
         << "isRunning will return false." << endl;
}

// Your class needs to implement the method void run().
void MyService::run() {
    // Here, you can do some initialization of
    // resources (e.g. data structures and the like).
    cout << "Here, I can do some initialization as the "
         << "calling thread, which will start this service, "
         << "will be blocked until serviceReady() has been called." << endl;

    serviceReady();

    // This is the body of the concurrently executed method.
    while (isRunning()) {
        cout << "This message is printed every second." << endl;

        const uint32_t ONE_SECOND = 1000 * 1000;
        odcore::base::Thread::usleepFor(ONE_SECOND);
    }
}

int32_t main(int32_t argc, char **argv) {
    MyService s;

    s.start();
    const uint32_t ONE_SECOND = 1000 * 1000;
    odcore::base::Thread::usleepFor(10 * ONE_SECOND);

    s.stop();
}
```

Your class needs to derive from `odcore::base::Service`, which is provided in `#include <opendavinci/odcore/base/Service.h>` in the include directory `opendavinci`. This class provides two methods that need to be implemented in deriving classes: `void beforeStop()` and `void run()`. The former method is called from an outside thread intending to stop the concurrently executing thread; thus any shared resources can be released properly for example. The latter method will be executed in a new thread running concurrently to the calling thread.

To detach the execution of the newly created thread from the calling one, the method `serviceReady()` needs to be called to signal to the calling thread that the new thread is initialized and will now enter, e.g., its main processing loop; the calling thread is blocked from any further execution until this method is called. This synchronization dependency ensures that both resources that need to be provided by the operating system to run a thread are available and ready, and any shared resources like data structures that are needed from a deriving class are set up and ready.

You can compile and link the example assuming the file is called MyService.cpp:

```
g++ -std=c++11 -I /usr/include -c MyService.cpp -o MyService.o
g++ -o service MyService.o -lopendavinci -lpthread
```

Running the example above will print the following on the console:

```
$ ./service
Here, I can do some initialization as the calling thread, which will start this␣
↪service, will be blocked until serviceReady() has been called.
This message is printed every second.
This message is printed every second.
This message is printed every second.
This message is printed every second.
This message is printed every second.
This message is printed every second.
This message is printed every second.
This message is printed every second.
This message is printed every second.
This message is printed every second.
This method is called right before isRunning will return false.
```

2.1.2 How to use realtime concurrency

OpenDaVINCI has a built-in realtime concurrency engine available only on Linux platforms with rt-preempt kernels. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/realtimeservice

In order to use realtime concurrency in a user-supplied module, you will find a simple example below.

MyRealtimeService.hpp:

```
#include <opendavinci/odcore/base/RealtimeService.h>

// Realtime concurrency is provided by the class odcore::base::RealtimeService.
class MyRealtimeService : public odcore::base::RealtimeService {

    public:
        MyRealtimeService(const enum PERIOD &period);

        // Your class needs to implement the method void nextTimeSlice().
        virtual void nextTimeSlice();

};
```

MyRealtimeService.cpp:

```
#include <stdint.h>
#include <iostream>
#include <opendavinci/odcore/base/Thread.h>

#include "MyRealtimeService.hpp"

using namespace std;

MyRealtimeService::MyRealtimeService(const enum PERIOD &period) :
    odcore::base::RealtimeService(period) {}

void MyRealtimeService::nextTimeSlice() {
    cout << "This message is printed every 100 ms." << endl;
}

int32_t main(int32_t argc, char **argv) {
    MyRealtimeService rts(odcore::base::RealtimeService::ONEHUNDREDMILLISECONDS);
```

```
    rts.start();

    const uint32_t ONE_SECOND = 1000 * 1000;
    odcore::base::Thread::usleepFor(5 * ONE_SECOND);

    rts.stop();
}
```

Your class needs to derive from `odcore::base::RealtimeService`, which is provided in `#include <opendavinci/odcore/base/RealtimeService.h>` in the include directory `opendavinci`. This class provides one method that needs to be implemented in deriving classes: `void nextTimeSlice()`. This method will be called with the specified periodicity.

Furthermore, the deriving class needs to pass the desired periodicity to the superclass `RealtimeService`.

You can compile and link the example:

```
g++ -std=c++11 -I /usr/include -c MyRealtimeService.cpp -o MyRealtimeService.o
g++ -o realtimeservice MyRealtimeService.o -lopendavinci -lpthread -lrt
```

The resulting program can be run as superuser (as the scheduling properties will be adjusted) and will print the following on the console:

```
$ sudo ./realtimeservice
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
This message is printed every 100 ms.
```

2.1.3 Dining Philosophers

This example illustrates the known "Dining Philosophers" problem. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/diningphilosophers

The background for this example is well described here at https://en.wikipedia.org/wiki/Dining_philosophers_problem

2.2 How to exchange data in distributed processes

2.2.1 Using shared memory for processes on the same machine

2.2.1.1 How to exchange data between processes

OpenDaVINCI has a built-in interprocess communication engine realized with shared memory and semaphores. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/ipcsharedmemory

In order to use shared memory to exchange data between your processes on a local machine, you will find a simple example below. To share data between two processes on the same machine, the example is split into a producer and a consumer example. The former will create the shared memory segment, while the latter is attaching to the shared memory segment to consume the data.

ipcsharedmemoryproducer.cpp:

```
#include <stdint.h>
#include <iostream>
#include <string>
#include <memory>
#include <opendavinci/odcore/base/Lock.h>
#include <opendavinci/odcore/base/Thread.h>
#include <opendavinci/odcore/wrapper/SharedMemory.h>
#include <opendavinci/odcore/wrapper/SharedMemoryFactory.h>

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore;
using namespace odcore::wrapper;

int32_t main(int32_t argc, char **argv) {
    const string NAME = "MySharedMemory";
    const uint32_t SIZE = 26;

    // We are using OpenDaVINCI's std::shared_ptr to automatically
    // release any acquired resources.
    try {
        std::shared_ptr<SharedMemory>␣
↪sharedMemory(SharedMemoryFactory::createSharedMemory(NAME, SIZE));

        if (sharedMemory->isValid()) {
            uint32_t counter = 20;
            while (counter-- > 0) {
                {
                    // Using a scoped lock to lock and automatically unlock a shared␣
↪memory segment.
                    odcore::base::Lock l(sharedMemory);
                    char *p = static_cast<char*>(sharedMemory->getSharedMemory());
                    for (uint32_t i = 0; i < sharedMemory->getSize(); i++) {
                        char c = (char) (65 + ((i+counter)%26));
                        p[i] = c;
                    }
                }

                // Sleep some time.
```

```
                const uint32_t ONE_SECOND = 1000 * 1000;
                odcore::base::Thread::usleepFor(ONE_SECOND);
            }
        }
    }
    catch(string &exception) {
        cerr << "Shared memory could not created: " << exception << endl;
    }
}
```

The producer process needs to include `<opendavinci/odcore/wrapper/SharedMemory.h>` and `<opendavinci/odcore/wrapper/SharedMemoryFactory.h>` that encapsulate the platform-specific implementations.

`SharedMemoryFactory` provides a static method called `createSharedMemory` that allows you to create a shared memory segment that is automatically protected with a system semaphore. Therefore, a name and the size in bytes for the shared memory segment need to be provided.

`SharedMemoryFactory` returns the `SharedMemory` automatically wrapped into a `std::shared_ptr` that takes care of releasing system resources when exiting your program.

Once you have the `std::shared_ptr` at hand, you can check its validity by calling `bool isValid()`. If the shared memory is valid, you can request exclusive access to it by using a scoped lock provided by the class `odcore::base::Lock`. A scoped lock will automatically release a concurrently accessed resource when the current scope is left. As soon as it gets available, you can access it by calling `getSharedMemory()` returning a `char*`.

You can compile and link the producer example as follows:

```
g++ -std=c++11 -I /usr/include -c ipcsharedmemoryproducer.cpp -o␣
↪ipcsharedmemoryproducer.o
g++ -o ipcsharedmemoryproducer ipcsharedmemoryproducer.o -lopendavinci -lpthread
```

ipcsharedmemoryconsumer.cpp:

```
#include <stdint.h>
#include <iostream>
#include <string>
#include <memory>
#include <opendavinci/odcore/base/Lock.h>
#include <opendavinci/odcore/base/Thread.h>
#include <opendavinci/odcore/wrapper/SharedMemory.h>
#include <opendavinci/odcore/wrapper/SharedMemoryFactory.h>

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore;
using namespace odcore::wrapper;

int32_t main(int32_t argc, char **argv) {
    const string NAME = "MySharedMemory";

    // We are using OpenDaVINCI's std::shared_ptr to automatically
    // release any acquired resources.
    try {
        std::shared_ptr<SharedMemory>␣
↪sharedMemory(SharedMemoryFactory::attachToSharedMemory(NAME));
```

```
        if (sharedMemory->isValid()) {
            uint32_t counter = 10;
            while (counter-- > 0) {
                string s;
                {
                    // Using a scoped lock to lock and automatically unlock a shared␣
↪memory segment.
                    odcore::base::Lock l(sharedMemory);
                    char *p = static_cast<char*>(sharedMemory->getSharedMemory());
                    s = string(p);
                }

                cout << "Content of shared memory: '" << s << "'" << endl;

                // Sleep some time.
                const uint32_t ONE_SECOND = 1000 * 1000;
                odcore::base::Thread::usleepFor(0.5 * ONE_SECOND);
            }
        }
    }
    catch(string &exception) {
        cerr << "Shared memory could not created: " << exception << endl;
    }
}
```

The consumer process needs to include `<opendavinci/odcore/wrapper/SharedMemory.h>` and `<opendavinci/odcore/wrapper/SharedMemoryFactory.h>` that encapsulate the platform-specific implementations as well.

On the consumer side, `SharedMemoryFactory` provides a static method called `attachToSharedMemory` that allows you to attach to an existing shared memory segment. Thus, only the name needs to be provided as OpenDaVINCI automatically encodes the the size of the shared memory additionally into the shared memory segment.

`SharedMemoryFactory` returns the `SharedMemory` automatically wrapped into a `std::shared_ptr` that takes care of releasing system resources when exiting your program.

Once you have the `std::shared_ptr` at hand, you can check its validity by calling `bool isValid()`. If the shared memory is valid, you can request exclusive access to it by using a scoped lock provided by the class `odcore::base::Lock`. A scoped lock will automatically release a concurrently accessed resource when the current scope is left. As soon as it gets available, you can access it by calling `getSharedMemory()` returning a `char*`.

You can compile and link the consumer example as follows:

```
g++ -std=c++11 -I /usr/include -c ipcsharedmemoryconsumer.cpp -o␣
↪ipcsharedmemoryconsumer.o
g++ -o ipcsharedmemoryconsumer ipcsharedmemoryconsumer.o -lopendavinci -lpthread
```

To test the program, simply run the producer:

```
$ ./ipcsharedmemoryproducer
```

followed by running the consumer that is printing to the console:

```
$ ./ipcsharedmemoryconsumer
Content of shared memory: 'QRSTUVWXYZABCDEFGHIJKLMNOP'
Content of shared memory: 'PQRSTUVWXYZABCDEFGHIJKLMNO'
Content of shared memory: 'PQRSTUVWXYZABCDEFGHIJKLMNO'
```

```
Content of shared memory: 'OPQRSTUVWXYZABCDEFGHIJKLMN'
Content of shared memory: 'OPQRSTUVWXYZABCDEFGHIJKLMN'
Content of shared memory: 'NOPQRSTUVWXYZABCDEFGHIJKLM'
Content of shared memory: 'NOPQRSTUVWXYZABCDEFGHIJKLM'
Content of shared memory: 'MNOPQRSTUVWXYZABCDEFGHIJKL'
Content of shared memory: 'MNOPQRSTUVWXYZABCDEFGHIJKL'
Content of shared memory: 'LMNOPQRSTUVWXYZABCDEFGHIJK'
```

You can inspect the system resources when running `ipcsharedmemoryconsumer`:

```
$ ipcs
------ Shared Memory Segments --------
key        shmid      owner      perms      bytes      nattch     status
...
0x0000006a 1900559    odv        600        30         1

------ Semaphore Arrays --------
key        semid      owner      perms      nsems

------ Message Queues --------
key        msqid      owner      perms      used-bytes   messages
```

2.2.2 Serial connection

2.2.2.1 How to send bytes over a serial link

OpenDaVINCI has a built-in serial port handling engine based on https://github.com/wjwwood/serial. This library realizes serial communication on Linux- and BSD-based platforms as well as on Windows. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/serialsendbytes

In order to send bytes over a serial link, you will find a simple example below.

SerialSendBytes.cpp:

```
#include <stdint.h>
#include <iostream>
#include <string>
#include <memory>
#include <opendavinci/odcore/wrapper/SerialPort.h>
#include <opendavinci/odcore/wrapper/SerialPortFactory.h>

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore;
using namespace odcore::wrapper;

int32_t main(int32_t argc, char **argv) {
    const string SERIAL_PORT = "/dev/pts/19";
    const uint32_t BAUD_RATE = 19200;

    // We are using OpenDaVINCI's std::shared_ptr to automatically
    // release any acquired resources.
    try {
        std::shared_ptr<SerialPort> serial(SerialPortFactory::createSerialPort(SERIAL_
↪PORT, BAUD_RATE));
```

```
        serial->send("Hello World\r\n");
    }
    catch(string &exception) {
        cerr << "Serial port could not be created: " << exception << endl;
    }
}
```

To send bytes over a serial link, your application needs to include <opendavinci/odcore/wrapper/SerialPort.h> and <opendavinci/odcore/wrapper/SerialPortFactory.h> that encapsulate the platform-specific implementations.

SerialPortFactory provides a static method called createSerialPort that tries to connect to the specified serial port. On success, this call will return a pointer to a SerialPort instance that is used to handle the data transfer. On failure, the method createSerialPort will throw an exception of type string with an error message.

If the connection could be successfully established, the method send can be used to send data of type string to the other end of the serial link.

To conveniently handle the resource management of releasing the acquired system resources, a std::shared_ptr is used that automatically releases memory that is no longer used.

You can compile and link the example:

```
g++ -std=c++11 -I /usr/include -c SerialSendBytes.cpp -o SerialSendBytes.o
g++ -o serialsendbytes SerialSendBytes.o -lopendavinci -lpthread
```

To test the program, we create a simple virtual serial port on Linux using the tool socat:

```
$ socat -d -d pty,raw,echo=0 pty,raw,echo=0
2015/06/13 11:17:17 socat[2737] N PTY is /dev/pts/19
2015/06/13 11:17:17 socat[2737] N PTY is /dev/pts/20
2015/06/13 11:17:17 socat[2737] N starting data transfer loop with FDs [3,3] and [5,5]
```

Please note that the tutorial program uses /dev/pts/19 to send data to; in the case that your setup has a different pts from socat, you need to adjust the source code.

Next, start a screen session on the other end of the serial connection:

```
$ screen /dev/pts/20
```

Now, you can run the resulting program:

```
$ ./serialsendbytes
$
```

The tool screen will print Hello World.

2.2.2.2 How to receive bytes from a serial connection

OpenDaVINCI has a built-in serial port handling engine based on https://github.com/wjwwood/serial. This library realizes serial communication on Linux- and BSD-based platforms as well as on Windows. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/serialreceivebytes

In order to receive bytes over a serial link, you will find a simple example below.

SerialReceiveBytes.hpp:

```
#include <opendavinci/odcore/io/StringListener.h>

// This class will handle the bytes received via a serial link.
class SerialReceiveBytes : public odcore::io::StringListener {

    // Your class needs to implement the method void nextString(const std::string &s).
    virtual void nextString(const std::string &s);
};
```

To receive any data, we firstly declare a class that implements the interface `odcore::io::StringListener`. This method will handle any bytes received from the low level `SerialPort`. Here, your application should realize an application-specific protocol.

SerialReceiveBytes.cpp:

```
#include <stdint.h>
#include <iostream>
#include <string>
#include <memory>
#include <opendavinci/odcore/base/Thread.h>
#include <opendavinci/odcore/wrapper/SerialPort.h>
#include <opendavinci/odcore/wrapper/SerialPortFactory.h>

#include "SerialReceiveBytes.hpp"

using namespace std;

void SerialReceiveBytes::nextString(const string &s) {
    cout << "Received " << s.length() << " bytes containing '" << s << "'" << endl;
}

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore;
using namespace odcore::wrapper;

int32_t main(int32_t argc, char **argv) {
    const string SERIAL_PORT = "/dev/pts/20";
    const uint32_t BAUD_RATE = 19200;

    // We are using OpenDaVINCI's std::shared_ptr to automatically
    // release any acquired resources.
    try {
        std::shared_ptr<SerialPort>
            serial(SerialPortFactory::createSerialPort(SERIAL_PORT, BAUD_RATE));

        // This instance will handle any bytes that are received
        // from our serial port.
        SerialReceiveBytes handler;
        serial->setStringListener(&handler);

        // Start receiving bytes.
        serial->start();

        const uint32_t ONE_SECOND = 1000 * 1000;
        odcore::base::Thread::usleepFor(10 * ONE_SECOND);

        // Stop receiving bytes and unregister our handler.
        serial->stop();
```

```
        serial->setStringListener(NULL);
    }
    catch(string &exception) {
        cerr << "Error while creating serial port: " << exception << endl;
    }
}
```

To receive bytes from a serial link, your application needs to include <opendavinci/odcore/wrapper/SerialPort.h> and <opendavinci/odcore/wrapper/SerialPortFactory.h> that encapsulate the platform-specific implementations.

SerialPortFactory provides a static method called createSerialPort that allows you to receive bytes from a serial link. On success, this call will return a pointer to a SerialPort instance that is used to handle the data transfer. On failure, the method createSerialPort will throw an exception of type string with an error message.

If the serial port could be successfully created, we register our StringListener at the newly created SerialPort to be invoked when new bytes are available to be interpreted by a user-supplied protocol.

Once we have registered our StringListener, the SerialPort is simply started and the main thread is falling asleep for a while in our example. After some time, the program will stop receiving bytes, unregister the StringListener, and release the system resources.

To conveniently handle the resource management of releasing the acquired system resources, a std::shared_ptr is used that automatically releases memory that is no longer used.

Please note that once you have stopped SerialPort you cannot reuse it and thus, you need to create a new one.

You can compile and link the example:

```
g++ -std=c++11 -I /usr/include -c SerialReceiveBytes.cpp -o SerialReceiveBytes.o
g++ -o serialreceivebytes SerialReceiveBytes.o -lopendavinci -lpthread
```

To test the program, we create a simple virtual serial port on Linux using the tool socat:

```
$ socat -d -d pty,raw,echo=0 pty,raw,echo=0
2015/06/13 11:17:17 socat[2737] N PTY is /dev/pts/19
2015/06/13 11:17:17 socat[2737] N PTY is /dev/pts/20
2015/06/13 11:17:17 socat[2737] N starting data transfer loop with FDs [3,3] and [5,5]
```

Please note that the tutorial program uses /dev/pts/20 to send data to; in the case that your setup has a different pts from socat, you need to adjust the source code.

Now, you can start the resulting program to listen for data:

```
$ ./serialreceivebytes
```

Next, we simply pipe some data through the other end of the virtual port:

```
$ echo "Hello World" > /dev/pts/19
```

The resulting program will print:

```
Received partial string of length 12 bytes containing 'Hello World
'
```

2.2.3 UDP connection

2.2.3.1 How to send bytes to a UDP server

OpenDaVINCI has a built-in UDP handling engine realized on Linux-based and BSD-based operating systems using POSIX sockets and on Windows using WinSock. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/udpsendbytes

In order to send bytes to a UDP server, you will find a simple example below.

UDPSendBytes.cpp:

```
#include <stdint.h>
#include <iostream>
#include <string>
#include <memory>
#include <opendavinci/odcore/io/udp/UDPSender.h>
#include <opendavinci/odcore/io/udp/UDPFactory.h>

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore;
using namespace odcore::io::udp;

int32_t main(int32_t argc, char **argv) {
    const string RECEIVER = "127.0.0.1";
    const uint32_t PORT = 1234;

    // We are using OpenDaVINCI's std::shared_ptr to automatically
    // release any acquired resources.
    try {
        std::shared_ptr<UDPSender> udpsender(UDPFactory::createUDPSender(RECEIVER,␣
↪PORT));

        udpsender->send("Hello World\r\n");
    }
    catch(string &exception) {
        cerr << "Data could not be sent: " << exception << endl;
    }
}
```

To send bytes over UDP to a UDP socket, your application needs to include `<opendavinci/odcore/io/udp/UDPSender.h>` and `<opendavinci/odcore/io/udp/UDPFactory.h>` that encapsulate the platform-specific implementations.

`UDPFactory` provides a static method called `createUDPSender` that allows you to send bytes to the specified UDP server. On success, this call will return a pointer to a `UDPServer` instance that is used to handle the data transfer. On failure, the method `createUDPSender` will throw an exception of type `string` with an error message.

If the connection could be successfully established, the method `send` can be used to send data of type `string` to the specified UDP server.

To conveniently handle the resource management of releasing the acquired system resources, a `std::shared_ptr` is used that automatically releases memory that is no longer used.

You can compile and link the example:

```
g++ -std=c++11 -I /usr/include -c UDPSendBytes.cpp -o UDPSendBytes.o
g++ -o udpsendbytes UDPSendBytes.o -lopendavinci -lpthread
```

To test the program, we create a simple UDP server awaiting data by using the tool ‘‘nc‘‘(netcat):

```
$ nc -l -u -p 1234
```

The resulting program can be run:

```
$ ./udpsendbytes
$
```

The tool `nc` will print `Hello World` and then terminate as the connection is closed on exiting `udpsendbytes`.

2.2.3.2 How to receive bytes as a UDP server

OpenDaVINCI has a built-in UDP handling engine realized on Linux-based and BSD-based operating systems using POSIX sockets and on Windows using WinSock. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/udpreceivebytes

In order to receive bytes as a UDP server, you will find a simple example below.

UDPReceiveBytes.hpp:

```
#include <opendavinci/odcore/io/StringListener.h>

// This class will handle the bytes received via a UDP socket.
class UDPReceiveBytes : public odcore::io::StringListener {

    // Your class needs to implement the method void nextString(const std::string &s).
    virtual void nextString(const std::string &s);
};
```

To receive any data, we firstly declare a class that implements the interface `odcore::io::StringListener`. This class will be registered as listener to our UDP socket that we create later.

UDPReceiveBytes.cpp:

```
#include <stdint.h>
#include <iostream>
#include <string>
#include <memory>
#include <opendavinci/odcore/base/Thread.h>
#include <opendavinci/odcore/io/udp/UDPReceiver.h>
#include <opendavinci/odcore/io/udp/UDPFactory.h>

#include "UDPReceiveBytes.hpp"

using namespace std;

void UDPReceiveBytes::nextString(const string &s) {
    cout << "Received " << s.length() << " bytes containing '" << s << "'" << endl;
}

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore;
using namespace odcore::io;
```

```
using namespace odcore::io::udp;

int32_t main(int32_t argc, char **argv) {
    const string RECEIVER = "0.0.0.0";
    const uint32_t PORT = 1234;

    // We are using OpenDaVINCI's std::shared_ptr to automatically
    // release any acquired resources.
    try {
        std::shared_ptr<UDPReceiver>
            udpreceiver(UDPFactory::createUDPReceiver(RECEIVER, PORT));

        // This instance will handle any bytes that are received
        // by our UDP socket.
        UDPReceiveBytes handler;
        udpreceiver->setStringListener(&handler);

        // Start receiving bytes.
        udpreceiver->start();

        const uint32_t ONE_SECOND = 1000 * 1000;
        odcore::base::Thread::usleepFor(10 * ONE_SECOND);

        // Stop receiving bytes and unregister our handler.
        udpreceiver->stop();
        udpreceiver->setStringListener(NULL);
    }
    catch(string &exception) {
        cerr << "Error while creating UDP receiver: " << exception << endl;
    }
}
```

To receive bytes from a UDP socket, your application needs to include `<opendavinci/odcore/io/udp/UDPReceiver.h>` and `<opendavinci/odcore/io/udp/UDPFactory.h>` that encapsulate the platform-specific implementations.

`UDPFactory` provides a static method called `createUDPReceiver` that allows you to receive bytes from a listening UDP socket. On success, this call will return a pointer to a `UDPReceiver` instance that is used to handle the data transfer. On failure, the method `createUDPReceiver` will throw an exception of type `string` with an error message.

If the UDP socket could be successfully created, we register our `StringListener` at the newly created `UDPReceiver` to be invoked when new bytes are available. Handling the bytes between the UDP socket and the `StringListener` notification is happening in the same thread.

Once we have registered our `StringListener`, the `UDPReceiver` is simply started and the main thread is falling asleep for a while in our example. After some time, the program will stop receiving bytes, unregister the `StringListener`, and release the system resources.

To conveniently handle the resource management of releasing the acquired system resources, a `std::shared_ptr` is used that automatically releases memory that is no longer used.

Please note that once you have stopped `UDPReceiver` you cannot reuse it and thus, you need to create a new one.

You can compile and link the example:

```
g++ -std=c++11 -I /usr/include -c UDPReceiveBytes.cpp -o UDPReceiveBytes.o
g++ -o udpreceivebytes UDPReceiveBytes.o -lopendavinci -lpthread
```

The resulting program can be run:

```
$ ./udpreceivebytes
```

To test the program, we pipe a string through the tool `nc`:

```
$ echo "Hello World" | nc -u 127.0.0.1 1234
```

Our program `udpreceivebytes` will print `Hello World`.

2.2.3.3 How to receive packets as a UDP server

OpenDaVINCI has a built-in UDP handling engine realized on Linux-based and BSD-based operating systems using POSIX sockets and on Windows using WinSock. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/udpreceivepackets

In order to receive packets as a UDP server, you will find a simple example below.

UDPReceivePackets.hpp:

```
#include <opendavinci/odcore/io/PacketListener.h>

// This class will handle packets received via a UDP socket.
class UDPReceivePackets : public odcore::wrapper::PacketListener {

    // Your class needs to implement the method void void nextPacket(const␣
↪odcore::io::Packet &p).
    virtual void nextPacket(const odcore::io::Packet &p);
};
```

To receive any packets, we firstly declare a class that implements the interface `odcore::wrapper::PacketListener`. This class will be registered as listener to our UDP socket that we create later. Packets provide the sending address in addition to the pure `StringListener` interface.

UDPReceivePackets.cpp:

```
#include <stdint.h>
#include <iostream>
#include <string>
#include <memory>
#include <opendavinci/odcore/base/Thread.h>
#include <opendavinci/odcore/io/udp/UDPReceiver.h>
#include <opendavinci/odcore/io/udp/UDPFactory.h>

#include "UDPReceivePackets.hpp"

using namespace std;

void UDPReceivePackets::nextPacket(const odcore::data::Packet &p) {
    cout << "Received a packet from " << p.getSender() << " at "
         << p.getReceived().toString() << " "
         << "with " << p.getData().length() << " bytes containing '"
         << p.getData() << "'" << endl;
}

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore;
using namespace odcore::io;
```

```
using namespace odcore::io::udp;

int32_t main(int32_t argc, char **argv) {
    const string RECEIVER = "0.0.0.0";
    const uint32_t PORT = 1234;

    // We are using OpenDaVINCI's std::shared_ptr to automatically
    // release any acquired resources.
    try {
        std::shared_ptr<UDPReceiver>
            udpreceiver(UDPFactory::createUDPReceiver(RECEIVER, PORT));

        // This instance will handle any packets that are received
        // by our UDP socket.
        UDPReceivePackets handler;
        udpreceiver->setPacketListener(&handler);

        // Start receiving bytes.
        udpreceiver->start();

        const uint32_t ONE_SECOND = 1000 * 1000;
        odcore::base::Thread::usleepFor(10 * ONE_SECOND);

        // Stop receiving bytes and unregister our handler.
        udpreceiver->stop();
        udpreceiver->setPacketListener(NULL);
    }
    catch(string &exception) {
        cerr << "Error while creating UDP receiver: " << exception << endl;
    }
}
```

To receive a packet from a UDP socket, your application needs to include `<opendavinci/odcore/io/udp/UDPReceiver.h>` and `<opendavinci/odcore/io/udp/UDPFactory.h>` that encapsulate the platform-specific implementations.

`UDPFactory` provides a static method called `createUDPReceiver` that allows you to receive bytes from a listening UDP socket. On success, this call will return a pointer to a `UDPReceiver` instance that is used to handle the data transfer. On failure, the method `createUDPReceiver` will throw an exception of type `string` with an error message.

If the UDP socket could be successfully created, we register our `PacketListener` at the newly created `UDPReceiver` to be invoked when a new packet is available. In contrast to the `StringListener`, the data processing for handling `Packets` is decoupled between the low level UDP socket and the user-supplied handler. Thus, whenever a new `Packet` has been received, it is enqueued and the user application is invoked from a separate thread to avoid unnecessary waiting times.

Once we have registered our `PacketListener`, the `UDPReceiver` is simply started and the main thread is falling asleep for a while in our example. After some time, the program will stop receiving bytes, unregister the `PacketListener`, and release the system resources.

To conveniently handle the resource management of releasing the acquired system resources, a `std::shared_ptr` is used that automatically releases memory that is no longer used.

Please note that once you have stopped `UDPReceiver` you cannot reuse it and thus, you need to create a new one.

You can compile and link the example:

```
g++ -std=c++11 -I /usr/include -c UDPReceivePackets.cpp -o UDPReceivePackets.o
g++ -o udpreceivepackets UDPReceivePackets.o -lopendavinci -lpthread
```

The resulting program can be run:

```
$ ./udpreceivepackets
```

To test the program, we pipe a string through the tool `nc`:

```
$ echo "Hello World" | nc -u 127.0.0.1 1234
```

Our program `udpreceivepackets` will print:

```
Received a packet from 127.0.0.1, with 13 bytes containing 'Hello World!
'
```

2.2.4 TCP connection

2.2.4.1 How to send bytes to a TCP server

OpenDaVINCI has a built-in TCP connection handling engine realized on Linux-based and BSD-based operating systems using POSIX sockets and on Windows using WinSock. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/tcpsendbytes

In order to send bytes to an existing TCP server, you will find a simple example below.

TCPSendBytes.cpp:

```
#include <stdint.h>
#include <iostream>
#include <string>
#include <memory>
#include <opendavinci/odcore/io/tcp/TCPConnection.h>
#include <opendavinci/odcore/io/tcp/TCPFactory.h>

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore;
using namespace odcore::io::tcp;

int32_t main(int32_t argc, char **argv) {
    const string RECEIVER = "127.0.0.1";
    const uint32_t PORT = 1234;

    // We are using OpenDaVINCI's std::shared_ptr to automatically
    // release any acquired resources.
    try {
        std::shared_ptr<TCPConnection>
            connection(TCPFactory::createTCPConnectionTo(RECEIVER, PORT));

        connection->send("Hello World\r\n");
    }
    catch(string &exception) {
        cerr << "Data could not be sent: " << exception << endl;
```

```
    }
}
```

To send bytes over a TCP link to a TCP server, your application needs to include `<opendavinci/odcore/io/tcp/TCPConnection.h>` and `<opendavinci/odcore/io/tcp/TCPFactory.h>` that encapsulate the platform-specific implementations.

`TCPFactory` provides a static method called `createTCPConnectionTo` that tries to connect to the specified TCP server. On success, this call will return a pointer to a `TCPConnection` instance that is used to handle the data transfer. On failure, the method `createTCPConnectionTo` will throw an exception of type `string` with an error message.

If the connection could be successfully established, the method `send` can be used to send data of type `string` to the other end of the TCP link.

To conveniently handle the resource management of releasing the acquired system resources, a `std::shared_ptr` is used that automatically releases memory that is no longer used.

You can compile and link the example:

```
g++ -std=c++11 -I /usr/include -c TCPSendBytes.cpp -o TCPSendBytes.o
g++ -o tcpsendbytes TCPSendBytes.o -lopendavinci -lpthread
```

To test the program, we create a simple TCP server awaiting connection by using the tool `nc`:

```
$ nc -l -p 1234
```

The resulting program can be run:

```
$ ./tcpsendbytes
$
```

The tool `nc` will print `Hello World` and then terminate as the connection is closed on exiting `tcpsendbytes`.

In the case of a failed connection attempt, the following exception will be printed on the console:

```
$ ./tcpsendbytes
Data could not be sent: [PosixTCPConnection] Error connecting to socket
```

2.2.4.2 How to receive bytes as a TCP server

OpenDaVINCI has a built-in TCP handling engine realized on Linux-based and BSD-based operating systems using POSIX sockets and on Windows using WinSock. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/tcpreceivebytes

In order to receive bytes as a TCP server, you will find a simple example below.

TCPReceiveBytes.hpp:

```
#include <opendavinci/odcore/io/ConnectionListener.h>
#include <opendavinci/odcore/io/StringListener.h>
#include <opendavinci/odcore/io/TCPAcceptorListener.h>
#include <opendavinci/odcore/io/TCPConnection.h>

// This class will handle newly accepted TCP connections.
class TCPReceiveBytes :
    public odcore::io::ConnectionListener,
    public odcore::io::StringListener,
```

```
    public odcore::io::tcp::TCPAcceptorListener {

    // Your class needs to implement the method void nextString(const std::string &s).
    virtual void nextString(const std::string &s);

    // Your class needs to implement the method void onNewConnection(std::shared_ptr
↪<odcore::io::tcp::TCPConnection> connection).
    virtual void onNewConnection(std::shared_ptr<odcore::io::tcp::TCPConnection>␣
↪connection);

    // Your class should implement the method void handleConnectionError() to handle␣
↪connection errors (like terminated connections).
    virtual void handleConnectionError();
};
```

To receive any data, we firstly declare a class that implements the interfaces `odcore::io::StringListener` to receive bytes and `odcore::io::tcp::TCPAcceptorListener` where any newly accepted connections will be reported to. This class will be registered as listener to our accepting TCP socket that we create later. In addition, we also register a `odcore::io::ConnectionLister` that is invoked in the case of any connection error like the connecting client has closed the connection.

TCPReceiveBytes.cpp:

```
#include <stdint.h>
#include <iostream>
#include <string>
#include <memory>
#include <opendavinci/odcore/base/Thread.h>
#include <opendavinci/odcore/io/tcp/TCPAcceptor.h>
#include <opendavinci/odcore/io/tcp/TCPFactory.h>

#include "TCPReceiveBytes.hpp"

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore;
using namespace odcore::io;
using namespace odcore::io:tcp;

void TCPReceiveBytes::handleConnectionError() {
    cout << "Connection terminated." << endl;
}

void TCPReceiveBytes::nextString(const std::string &s) {
    cout << "Received " << s.length() << " bytes containing '" << s << "'" << endl;
}

void TCPReceiveBytes::onNewConnection(std::shared_ptr<odcore::io::tcp::TCPConnection>␣
↪connection) {
    if (connection.isValid()) {
        cout << "Handle a new connection." << endl;

        // Set this class as StringListener to receive
        // data from this connection.
        connection->setStringListener(this);

        // Set this class also as ConnectionListener to
```

```
        // handle errors originating from this connection.
        connection->setConnectionListener(this);

        // Start receiving data from this connection.
        connection->start();

        // We keep this connection open only for one
        // second before we close it.
        const uint32_t ONE_SECOND = 1000 * 1000;
        odcore::base::Thread::usleepFor(ONE_SECOND);

        // Stop this connection.
        connection->stop();

        // Unregister the listeners.
        connection->setStringListener(NULL);
        connection->setConnectionListener(NULL);
    }
}

int32_t main(int32_t argc, char **argv) {
    const uint32_t PORT = 1234;

    // We are using OpenDaVINCI's std::shared_ptr to automatically
    // release any acquired resources.
    try {
        std::shared_ptr<TCPAcceptor>
            tcpacceptor(TCPFactory::createTCPAcceptor(PORT));

        // This instance will handle any new connections.
        TCPReceiveBytes handler;
        tcpacceptor->setAcceptorListener(&handler);

        // Start accepting new connections.
        tcpacceptor->start();

        const uint32_t ONE_SECOND = 1000 * 1000;
        odcore::base::Thread::usleepFor(10 * ONE_SECOND);

        // Stop accepting new connections and unregister our handler.
        tcpacceptor->stop();
        tcpacceptor->setAcceptorListener(NULL);
    }
    catch(string &exception) {
        cerr << "Error while creating TCP receiver: " << exception << endl;
    }
}
```

The outlined implementation will provide an overview of how to get notified about newly connecting clients using TCP; your application should track new connections in a `vector` for instance and manage their individual connection status properly.

To receive bytes from a TCP socket, your application needs to include `<opendavinci/odcore/io/tcp/TCPAcceptor.h>` and `<opendavinci/odcore/io/tcp/TCPFactory.h>` that encapsulate the platform-specific implementations.

`TCPFactory` provides a static method called `createTCPAcceptor` that allows you to accept new TCP connections. Every new connection is wrapped into a pointer to an instance of `TCPConnection` that needs to be handled

by a `TCPAcceptorListener`. The task for the `TCPAcceptorListener` is to get the new `TCPConnection`, register a `StringListener` to receive bytes and a `ConnectionListener` that is called when an error for this TCP connection occurs, e.g. the client closes the connection.

`TCPFactory` will return a pointer to the `TCPAcceptor`, where our `TCPReceiveBytes` handler in turn is registered to handle incoming connection. On failure, the method `createTCPAcceptor` will throw an exception of type `string` with an error message.

If the `TCPAcceptor` could be successfully created, we register our `TCPReceiveBytes` to handle new connections. Afterwards, we start our `TCPAcceptor` to wait for incoming TCP connections. After some time, the program will stop waiting for new connections, unregister the `TCPReceiveBytes`, and release the system resources.

To conveniently handle the resource management of releasing the acquired system resources, a `std::shared_ptr` is used that automatically releases memory that is no longer used.

Please note that once you have stopped `TCPAcceptor` you cannot reuse it and thus, you need to create a new one.

You can compile and link the example:

```
g++ -std=c++11 -I /usr/include -c TCPReceiveBytes.cpp -o TCPReceiveBytes.o
g++ -o tcpreceivebytes TCPReceiveBytes.o -lopendavinci -lpthread
```

The resulting program can be run:

```
$ ./tcpreceivebytes
```

To test the program, we use the test program `tcpsendbytes` as described here https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/tcpsendbytes:

```
$ ./tcpsendbytes
```

Our program `tcpreceivebytes` will print:

```
Handle a new connection.
Received 13 bytes containing 'Hello World
'
Connection terminated.
```

2.3 How to design distributed software systems

2.3.1 How to setup the build environment for your software system

This example demonstrates how to setup your build environment.

2.3.1.1 "Hello World" example - compiling manually

Let's assume you have implemented a basic "Hello World" application to start with as shown in the following.

HelloWorldExample.h:

```
#include <opendavinci/odcore/base/TimeTriggeredConferenceClientModule.h>

class HelloWorldExample : public␣
↪odcore::base::module::TimeTriggeredConferenceClientModule {
    private:
        HelloWorldExample(const HelloWorldExample &/*obj*/);
```

```
        HelloWorldExample& operator=(const HelloWorldExample &/*obj*/);

    public:
        /**
         * Constructor.
         *
         * @param argc Number of command line arguments.
         * @param argv Command line arguments.
         */
        HelloWorldExample(const int32_t &argc, char **argv);

        virtual ~HelloWorldExample();

        odcore::data::dmcp::ModuleExitCodeMessage::ModuleExitCode body();

    private:
        virtual void setUp();

        virtual void tearDown();
};
```

The accompanying implementation for this header file is provided in the following.

HelloWorldExample.cpp:

```
#include <iostream>

#include "HelloWorldExample.h"

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore::base::module;

HelloWorldExample::HelloWorldExample(const int32_t &argc, char **argv) :
    TimeTriggeredConferenceClientModule(argc, argv, "HelloWorldExample")
{}

HelloWorldExample::~HelloWorldExample() {}

void HelloWorldExample::setUp() {
    cout << "This method is called before the component's body is executed." << endl;
}

void HelloWorldExample::tearDown() {
    cout << "This method is called after the program flow returns from the component
↪'s body." << endl;
}

odcore::data::dmcp::ModuleExitCodeMessage::ModuleExitCode HelloWorldExample::body() {
    cout << "Hello OpenDaVINCI World!" << endl;

    return odcore::data::dmcp::ModuleExitCodeMessage::OKAY;
}
```

To start the component, we define the main() function in a separate file.

HelloWorldExampleMain.cpp:

```
#include "HelloWorldExample.h"

int32_t main(int32_t argc, char **argv) {
    HelloWorldExample hwe(argc, argv);

    return hwe.runModule();
}
```

Now, we have three files, HelloWorldExample.h, HelloWorldExample.cpp, and HelloWorldExampleMain.cpp. The first two files contain the software component for the "Hello World" example, the latter file is simply starting the component.

Now, you can compile and link the example manually:

```
$ g++ -std=c++11 -I /usr/include -c HelloWorldExample.cpp -o HelloWorldExample.o
$ g++ -std=c++11 -I /usr/include -c HelloWorldExampleMain.cpp -o␣
↪HelloWorldExampleMain.o
$ g++ -o helloworldexample HelloWorldExampleMain.o HelloWorldExample.o -lopendavinci -
↪lpthread
```

2.3.1.2 "Hello World" example - compiling using CMake

Next, we are going to extend the previous example and introduce CMake as the build system. The advantage of CMake is that you describe the build of your software independent from the build tools like make, KDevelop, or the like.

We create a file named CMakeLists.txt to describe the actual source code artifacts that comprise our final binary. After the definition of the CMake version that is required (2.8) in our example, we name the project that we are building. Next, we need to declare the dependency to OpenDaVINCI (cf. (1)). As OpenDaVINCI can be either installed to /usr from the pre-compiled packages or in a specific directory, we need to adjust this possibility accordingly in the CMakeLists.txt. Therefore, OpenDaVINCI provides a CMake-script to determine the correct settings for locating OpenDaVINCI's include headers and linker settings. This script considers the parameter OPENDAVINCI_DIR where we can specify at commandline where CMake shall search for OpenDaVINCI. If this parameter is left unset, OpenDaVINCI is assumed to be installed in your distributions default locations, like /usr or /usr/local. Next, FIND_PACKAGE(...) is called to actually find OpenDaVINCI.

If the FIND_PACKAGE(...) succeeds, the variables OPENDAVINCI_INCLUDE_DIRS and OPENDAVINCI_LIBRARIES. We are using the former to refer to the include headers so that HelloWorldExample.h can be compiled using the OpenDaVINCI classes.

Next, we specify the sources (cf. (3)) that are required to create the binary. Afterwards, we define the executable and the libraries that are required to link. The last line specifies where the resulting shall be installed to:

```
CMAKE_MINIMUM_REQUIRED (VERSION 2.8)

PROJECT (helloworldexample)

# Compile flags to enable C++11.
SET (CXX_OPTIONS       "-std=c++11")
SET (CMAKE_CXX_FLAGS "${CMAKE_CXX_FLAGS} -fPIC ${CXX_OPTIONS} -pipe")

# (1) Find OpenDaVINCI.
IF("${OPENDAVINCI_DIR}" STREQUAL "")
    SET(OPENDAVINCI_DIR "${CMAKE_INSTALL_PREFIX}")
ELSE()
    SET (CMAKE_MODULE_PATH "${OPENDAVINCI_DIR}/share/cmake-${CMAKE_MAJOR_VERSION}.$
↪{CMAKE_MINOR_VERSION}/Modules" ${CMAKE_MODULE_PATH})
ENDIF()
```

```
FIND_PACKAGE (OpenDaVINCI REQUIRED)

# (2) Set header files from OpenDaVINCI.
INCLUDE_DIRECTORIES (${OPENDAVINCI_INCLUDE_DIRS})

# (3) Build the project.
SET(SOURCES HelloWorldExample.cpp HelloWorldExampleMain.cpp)
ADD_EXECUTABLE (helloworldexample ${SOURCES})
TARGET_LINK_LIBRARIES (helloworldexample ${OPENDAVINCI_LIBRARIES})

# (4) Install the binary.
INSTALL(TARGETS helloworldexample RUNTIME DESTINATION bin COMPONENT tutorials)
```

Having the CMakeLists.txt file enables us to create the build environment. Therefore, we first create a build folder to separate the compiled object code from the sources:

```
$ mkdir build
$ cd build
```

Next, we call CMake to create the build environment for us (make for instance):

```
$ cmake ..
```

In this case, the OpenDaVINCI libraries would be expected to reside at /usr (or /usr/local). If you have the OpenDaVINCI libraries installed at a different location, you need to call CMake using the commandline parameter OPENDAVINCI_DIR:

```
$ cmake -D OPENDAVINCI_DIR=<location of OpenDaVINCI include files and library> ..
```

The aforementioned call would result in trying to install the binary to /usr (or /usr/local). To specify a different installation folder, you need to invoke CMake as follows:

```
$ cmake -D OPENDAVINCI_DIR=<location of OpenDaVINCI include files and library> -D␣
↪CMAKE_INSTALL_PREFIX=<location where you want to install the binaries> ..
```

After running cmake, we run make to build the binary:

```
$ make
```

2.3.2 How to design a time-triggered software component

OpenDaVINCI allows the development of distributed software components. These components can run on the same machine or on different ones using various types of communication and scheduling. Both are provided transparently to the user of the OpenDaVINCI middleware.

This example demonstrates how to design a time-triggered software component. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/timetrigger

2.3.2.1 "Hello World" example

A time-triggered software component is derived from `odcore::base::TimeTriggeredConferenceClientModule`, provided in `<opendavinci/odcore/base/module/TimeTriggeredConferenceClientModule.h>`.

TimeTriggerExample.h:

```
#include <opendavinci/odcore/base/TimeTriggeredConferenceClientModule.h>

class TimeTriggerExample : public␣
↪odcore::base::module::TimeTriggeredConferenceClientModule {
    private:
        TimeTriggerExample(const TimeTriggerExample &/*obj*/);
        TimeTriggerExample& operator=(const TimeTriggerExample &/*obj*/);

    public:
        /**
         * Constructor.
         *
         * @param argc Number of command line arguments.
         * @param argv Command line arguments.
         */
        TimeTriggerExample(const int32_t &argc, char **argv);

        virtual ~TimeTriggerExample();

        odcore::data::dmcp::ModuleExitCodeMessage::ModuleExitCode body();

    private:
        virtual void setUp();

        virtual void tearDown();
};
```

The class `odcore::base::module::TimeTriggeredConferenceClientModule` provides three methods that need to be implemented by the user: `setUp()`, `body()`, and `tearDown()`. These methods reflect the basic runtime cycle of a software component: An initialization phase, followed by a time-triggered execution of an algorithm implemented in the method `body()`, before the cycle ends with a call to `tearDown()` intended to clean up any acquired resources.

In addition, this class uses a private and unimplemented copy constructor and assignment operator so that the compiler can warn if an object of this class is unintentionally copied or assigned.

The accompanying implementation for this header file is provided in the following.

TimeTriggerExample.cpp:

```
#include <iostream>

#include "TimeTriggerExample.h"

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore::base::module;

TimeTriggerExample::TimeTriggerExample(const int32_t &argc, char **argv) :
    TimeTriggeredConferenceClientModule(argc, argv, "TimeTriggerExample")
{}

TimeTriggerExample::~TimeTriggerExample() {}

void TimeTriggerExample::setUp() {
    cout << "This method is called before the component's body is executed." << endl;
}
```

```
void TimeTriggerExample::tearDown() {
    cout << "This method is called after the program flow returns from the component
↪'s body." << endl;
}

odcore::data::dmcp::ModuleExitCodeMessage::ModuleExitCode TimeTriggerExample::body() {
    cout << "Hello OpenDaVINCI World!" << endl;

    return odcore::data::dmcp::ModuleExitCodeMessage::OKAY;
}

int32_t main(int32_t argc, char **argv) {
    TimeTriggerExample tte(argc, argv);

    return tte.runModule();
}
```

Firstly, the constructor is implemented, delegating any commandline arguments to the constructor of the class `TimeTriggeredConferenceClientModule` to obey the design principle:

Design Principle "Single-Point-of-Truth - SPoT": Favor a centrally maintained configuration over distributed and undocumented commandline parameters

The third parameter to the constructor of `TimeTriggeredConferenceClientModule` is the name of this module, which is used to structure the centrally maintained configuration file.

The implementation of the methods `setUp()` and `tearDown()` simply contain explanatory text. They are meant to be used to acquire system resources or to open peripheral components like cameras or sensors.

The main method `body()` is meant to be used for the implementation of the main data processing algorithm. In this example, it simply prints an explanatory message. The main method returns the return code 0 encoded as `OKAY`.

The main function is simply instantiating an object of the class `TimeTriggerExample` and runs it by calling the method `runModule()` that is provided from its super-classes.

You can compile and link the example:

```
$ g++ -std=c++11 -I /usr/include -c TimeTriggerExample.cpp -o TimeTriggerExample.o
$ g++ -o timetriggerexample TimeTriggerExample.o -lopendavinci -lpthread
```

To test the program, we need to run the software component life-cycle management tool `odsupercomponent`; details for that tool are provided in its accompanying manual page (man odsupercomponent). To use this tool it is required to provide a configuration file. As the aforementioned example application does not use any configuration data, we simply create an empty file:

```
$ touch configuration
```

If OpenDaVINCI is used on a Linux host **without** a network connection, the local loopback device `lo` needs to be configured to allow UDP multicast sessions before `odsupercomponent` can be started:

```
$ sudo ifconfig lo multicast

$ sudo route add -net 224.0.0.0 netmask 240.0.0.0 dev lo
```

If you use the `ip` command, you need to do:

```
$ sudo ip link set lo multicast on

$ sudo ip route add 224.0.0.0/4 dev lo
```

Next, we can run the life-cycle management application `odsupercomponent`:

```
$ odsupercomponent --cid=111 --configuration=/path/to/configuration
```

The first parameter specifies a unique container conference session identifier from within the range [2,254]. Thus, it is possible to host several sessions on the same host.

Now, you can start the example application providing the same container conference session identifier:

```
$ ./timetriggerexample --cid=111
```

The application will print the following on the console:

```
This method is called before the component's body is executed.
Hello OpenDaVINCI World!
This method is called after the program flow returns from the component's body.
```

If the container conference session identifier is omitted, the following exception will be thrown:

```
terminate called after throwing an instance of
↪'odcore::exceptions::InvalidArgumentException'
  what():  InvalidArgumentException: Invalid number of arguments. At least a␣
↪conference group id (--cid=) needed. at /home/berger/GITHUB/Mini-Smart-Vehicles/
↪sources/OpenDaVINCI-msv/libopendavinci/src/core/base/AbstractCIDModule.cpp: 53
Aborted
```

If no `odsupercomponent` is running, the application will exit with return code 4.

2.3.2.2 Adding configuration parameters

The next example demonstrates how to specify and use configuration parameters. Therefore, the implementation of `body()` is changed to firstly print further information about the runtime configuration and secondly, to access configuration data.

TimeTriggerExample.cpp:

```
#include <iostream>

#include "TimeTriggerExample.h"

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore::base;

TimeTriggerExample::TimeTriggerExample(const int32_t &argc, char **argv) :
    TimeTriggeredConferenceClientModule(argc, argv, "TimeTriggerExample")
{}

TimeTriggerExample::~TimeTriggerExample() {}

void TimeTriggerExample::setUp() {
    cout << "This method is called before the component's body is executed." << endl;
}

void TimeTriggerExample::tearDown() {
    cout << "This method is called after the program flow returns from the component
↪'s body." << endl;
```

```
}

odcore::data::dmcp::ModuleExitCodeMessage::ModuleExitCode TimeTriggerExample::body() {
    cout << "Hello OpenDaVINCI World!" << endl;

    cout << "This is my name: " << getName() << endl;
    cout << "This is my execution frequency: " << getFrequency() << endl;
    cout << "This is my identifier: " << getIdentifier() << endl;

    cout << "  " << getKeyValueConfiguration().getValue<string>("timetriggerexample.
↪key1") << endl;
    cout << "  " << getKeyValueConfiguration().getValue<uint32_t>("timetriggerexample.
↪key2") << endl;
    cout << "  " << getKeyValueConfiguration().getValue<float>("timetriggerexample.
↪key3") << endl;
    cout << "  " << getKeyValueConfiguration().getValue<string>("timetriggerexample.
↪key4") << endl;
    cout << "  " << (getKeyValueConfiguration().getValue<bool>("timetriggerexample.
↪key5") == 1) << endl;

    return odcore::data::dmcp::ModuleExitCodeMessage::OKAY;
}

int32_t main(int32_t argc, char **argv) {
    TimeTriggerExample tte(argc, argv);

    return tte.runModule();
}
```

The super-classes provide methods to get information about the runtime configuration of a software component. `getName()` simply returns the name as specified to the constructor `TimeTriggeredConferenceClientModule`. `getFrequency()` returns the execution frequency for the software component; its value can be adjusted by specifying the commandline parameter `--freq=` to the software component. The last method `getIdentifier()` returns a unique identifier that can be specified at commandline by using the parameter `--id=` to distinguish several instances of the same software component; its use is shown for the configuration parameter `timetriggerexample.key4` below.

The configuration file is adjusted as follows as an example:

```
# This is an example configuration file.
timetriggerexample.key1 = value1
timetriggerexample.key2 = 1234
timetriggerexample.key3 = 42.32

timetriggerexample.key4 = Default
timetriggerexample:1.key4 = ValueForComponent1
timetriggerexample:2.key4 = ValueForComponent2

timetriggerexample.key5 = 1
```

This configuration file is parsed by `odsupercomponent` and used to provide component-dependent subsets from this file. The general format is:

```
<application name> . <key> [:<identifier>] = <value>
```

The application name is used to structure the content of the file; in this example, `timetriggerexample` specifies all parameters that are provided from `odsupercomponent` to our application. The application itself uses the template method `getKeyValueConfiguration().getValue<T>(const string &key)` to retrieve values

provided in the required data type. To access the numerical value for the second key, the application would access the value as follows:

```
uint32_t value = getKeyValueConfiguration().getValue<uint32_t>("timetriggerexample.
↪key2");
```

The object handling the application-specific key-value-configuration is case-insensitive regarding the keys; in any case, the application's name needs to precede a key's name.

In the configuration, a special section can be specified using the name `global.` preceding a set of keys. All keys with this preceding name are provided to all applications and thus, shared among them.

If the same software component needs to be used with different configuration parameters, OpenDaVINCI offers the commandline parameter `--id=` so that different instances of the same application can be distinguished in the configuration. In our example, the key named `timetriggerexample.key4` provides different values regarding the commandline parameters. For example, if the application is started as follows:

```
$ ./timetriggerexample --cid=111
```

the following request:

```
cout << "  " << getKeyValueConfiguration().getValue<string>("timetriggerexample.key4
↪") << endl;
```

would return the value `Default`. If, in contrast, the application is started by specifying the identifier 1:

```
$ ./timetriggerexample --cid=111 --id=2
```

the request would return the value `ValueForComponent2`.

2.3.2.3 Adding time-based algorithm triggering

The next example demonstrates how to use frequency-based algorithm execution. Therefore, the implementation of `body()` is changed to add a loop that is intended to be executed until the module is stopped.

TimeTriggerExample.cpp:

```
#include <iostream>

#include "TimeTriggerExample.h"

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore::base;

TimeTriggerExample::TimeTriggerExample(const int32_t &argc, char **argv) :
    TimeTriggeredConferenceClientModule(argc, argv, "TimeTriggerExample")
{}

TimeTriggerExample::~TimeTriggerExample() {}

void TimeTriggerExample::setUp() {
    cout << "This method is called before the component's body is executed." << endl;
}

void TimeTriggerExample::tearDown() {
    cout << "This method is called after the program flow returns from the component
↪'s body." << endl;
```

```
}

odcore::data::dmcp::ModuleExitCodeMessage::ModuleExitCode TimeTriggerExample::body() {
    cout << "Hello OpenDaVINCI World!" << endl;

    cout << "This is my name: " << getName() << endl;
    cout << "This is my execution frequency: " << getFrequency() << endl;
    cout << "This is my identifier: " << getIdentifier() << endl;

    cout << "  " << getKeyValueConfiguration().getValue<string>("timetriggerexample.
↪key1") << endl;
    cout << "  " << getKeyValueConfiguration().getValue<uint32_t>("timetriggerexample.
↪key2") << endl;
    cout << "  " << getKeyValueConfiguration().getValue<float>("timetriggerexample.
↪key3") << endl;
    cout << "  " << getKeyValueConfiguration().getValue<string>("timetriggerexample.
↪key4") << endl;
    cout << "  " << (getKeyValueConfiguration().getValue<bool>("timetriggerexample.
↪key5") == 1) << endl;

    while (getModuleStateAndWaitForRemainingTimeInTimeslice() ==␣
↪odcore::data::dmcp::ModuleStateMessage::RUNNING) {
        cout << "Inside the main processing loop." << endl;
    }

    return odcore::data::dmcp::ModuleExitCodeMessage::OKAY;
}

int32_t main(int32_t argc, char **argv) {
    TimeTriggerExample tte(argc, argv);

    return tte.runModule();
}
```

The method `getModuleStateAndWaitForRemainingTimeInTimeslice()` is provided from the superclasses and enforces a specific runtime execution frequency. The frequency can be specified by the commandline parameter `--freq=` in Hertz. For example, running the program as follows:

```
$ ./timetriggerexample --cid=111 --freq=2
```

would print `Inside the main processing loop.` two times per second. Thus, the method `getModuleStateAndWaitForRemainingTimeInTimeslice()` calculates how much time from the current time slice has been consumed (in this case, 500ms would be available per time slice) from the algorithm in the while-loop body, and would simply sleep for the rest of the current time slice.

The program can be terminated by pressing Ctrl-C, which would result in setting the module state to not running, leaving the while-loop body, and calling the method `tearDown()`. Furthermore, stopping `odsupercomponent` would also result in stopping automatically all dependent software components.

2.3.2.4 Real-time scheduling

The standard Linux kernel can meet soft real-time requirements. For time-critical algorithms requiring hard real-time, the Linux kernel with the CONFIG_PREEMPT_RT configuration item enabled can be used. More information is available here: https://rt.wiki.kernel.org/index.php/RT_PREEMPT_HOWTO.

To run an application with real-time prioritization, it must be linked with the real-time library `rt`:

```
$ g++ -std=c++11 -I /usr/include -c TimeTriggerExample.cpp -o TimeTriggerExample.o
$ g++ -o timetriggerexample TimeTriggerExample.o -lopendavinci -lpthread -lrt
```

On execution, simply specify the parameter `--realtime=` from within the range [1,49] to enable real-time scheduling transparently. In addition, you need to run the application with superuser privileges to allow the configuration of the correct scheduling priority as follows:

```
$ sudo ./timetriggerexample --cid=111 --freq=10 --realtime=20 --verbose=1
```

The output of the application would look like:

```
Creating multicast UDP receiver at 225.0.0.111:12175.
Creating multicast UDP receiver at 225.0.0.111:19751.
(ClientModule) discovering supercomponent...
(ClientModule) supercomponent found at IP: 10.0.2.15, Port: 19866, managedLevel: 0
(ClientModule) connecting to supercomponent...
(DMCP-ConnectionClient) sending configuration request...IP: 10.0.2.15, Port: 19866,␣
↪managedLevel: 0
(DMCP-Client) Received Configuration
timetriggerexample.key1=value1
timetriggerexample.key2=1234
timetriggerexample.key3=42.32
timetriggerexample.key4=Default
timetriggerexample.key5=1

(ClientModule) connecting to supercomponent...done - managed level: 0
This method is called before the component's body is executed.
Hello OpenDaVINCI World!
This is my name: TimeTriggerExample
This is my execution frequency: 10
This is my identifier:
  value1
  1234
  42.32
  Default
Starting next cycle at 1437420074s/101149us.
Inside the main processing loop.
Starting next cycle at 1437420074s/201230us.
Inside the main processing loop.
Starting next cycle at 1437420074s/301194us.
Inside the main processing loop.
Starting next cycle at 1437420074s/400376us.
Inside the main processing loop.
Starting next cycle at 1437420074s/501003us.
Inside the main processing loop.
Starting next cycle at 1437420074s/601151us.
Inside the main processing loop.
Starting next cycle at 1437420074s/700427us.
Inside the main processing loop.
Starting next cycle at 1437420074s/800241us.
Inside the main processing loop.
Starting next cycle at 1437420074s/900387us.
Inside the main processing loop.
Starting next cycle at 1437420075s/209us.
Inside the main processing loop.
...
```

Please observe that your implementation within the `body()` shall not allocate further memory to avoid unexpected

page faults resulting in a risk to miss deadlines.

2.3.3 How to design a data-triggered software component

OpenDaVINCI allows the development of distributed software components. These components can run on the same machine or on different ones using various types of communication and scheduling. Both is provided transparently to the user of the OpenDaVINCI middleware.

This example demonstrates how to design a data-triggered software component. The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/datatrigger

The example consists of two components: `TimeTriggeredSender` that is supposed to send regularly data updates and `DataTriggeredReceiver`, which will be notified by any data sent via network. For further explanations about a time-triggered modules, please see: https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/timetrigger

2.3.3.1 Time-triggered sender

A time-triggered software component is derived from `odcore::base::TimeTriggeredConferenceClientModule`, provided in `<opendavinci/odcore/base/module/TimeTriggeredConferenceClientModule.h>` to realize the sending functionality.

TimeTriggeredSender.h:

```
#include <opendavinci/odcore/base/module/TimeTriggeredConferenceClientModule.h>

class TimeTriggeredSender : public␣
↪odcore::base::module::TimeTriggeredConferenceClientModule {
    private:
        /**
         * "Forbidden" copy constructor. Goal: The compiler should warn
         * already at compile time for unwanted bugs caused by any misuse
         * of the copy constructor.
         *
         * @param obj Reference to an object of this class.
         */
        TimeTriggeredSender(const TimeTriggeredSender &/*obj*/);

        /**
         * "Forbidden" assignment operator. Goal: The compiler should warn
         * already at compile time for unwanted bugs caused by any misuse
         * of the assignment operator.
         *
         * @param obj Reference to an object of this class.
         * @return Reference to this instance.
         */
        TimeTriggeredSender& operator=(const TimeTriggeredSender &/*obj*/);

    public:
        /**
         * Constructor.
         *
         * @param argc Number of command line arguments.
         * @param argv Command line arguments.
         */
        TimeTriggeredSender(const int32_t &argc, char **argv);
```

```
        virtual ~TimeTriggeredSender();

        odcore::data::dmcp::ModuleExitCodeMessage::ModuleExitCode body();

    private:
        virtual void setUp();

        virtual void tearDown();
};
```

The class `odcore::base::module::TimeTriggeredConferenceClientModule` provides three methods that need to be implemented by the user: `setUp()`, `body()`, and `tearDown()`. These methods reflect the basic runtime cycle of a software component: An initialization phase, followed by a time-triggered execution of an algorithm implemented in the method `body()`, before the cycle ends with a call to `tearDown()` intended to clean up any acquired resources.

In addition, this class uses a private and unimplemented copy constructor and assignment operator so that the compiler can warn if an object of this class is unintentionally copied or assigned.

The accompanying implementation for this header file is provided in the following.

TimeTriggeredSender.cpp:

```
#include <iostream>

#include "opendavinci/odcore/data/TimeStamp.h"

#include "TimeTriggeredSender.h"

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore::base::module;
using namespace odcore::data;

TimeTriggeredSender::TimeTriggeredSender(const int32_t &argc, char **argv) :
    TimeTriggeredConferenceClientModule(argc, argv, "TimeTriggeredSender")
    {}

TimeTriggeredSender::~TimeTriggeredSender() {}

void TimeTriggeredSender::setUp() {
    cout << "This method is called before the component's body is executed." << endl;
}

void TimeTriggeredSender::tearDown() {
    cout << "This method is called after the program flow returns from the component
↪'s body." << endl;
}

odcore::data::dmcp::ModuleExitCodeMessage::ModuleExitCode TimeTriggeredSender::body()
↪{
    uint32_t i = 0;
    while (getModuleStateAndWaitForRemainingTimeInTimeslice() ==␣
↪odcore::data::dmcp::ModuleStateMessage::RUNNING) {
        cout << "Sending " << i << "-th time stamp data...";
        TimeStamp ts(i, 2*i++);
        Container c(ts);
        getConference().send(c);
```

```
        cout << "done." << endl;
    }

    return odcore::data::dmcp::ModuleExitCodeMessage::OKAY;
}

int32_t main(int32_t argc, char **argv) {
    TimeTriggeredSender tts(argc, argv);

    return tts.runModule();
}
```

Firstly, the constructor is implemented, delegating any commandline arguments to the constructor of the class `TimeTriggeredConferenceClientModule` to obey the design principle:

Design Principle "Single-Point-of-Truth - SPoT": Favor a centrally maintained configuration over distributed and undocumented commandline parameters

The third parameter to the constructor of `TimeTriggeredConferenceClientModule` is the name of this module, which is used to structure the centrally maintained configuration file.

The implementation of the methods `setUp()` and `tearDown()` simply contain explanatory text. They are meant to be used to acquire system resources or to open peripheral components like cameras or sensors.

The main method `body()` is meant to be used for the implementation of the main data processing algorithm. The main while-loop is executed based on the specified runtime frequency of the software component. To send data with OpenDaVINCI, it must be packed into a `Container` that adds additional information like type of the contained payload, the sent time point when the container left the sending software computer (for instance a sending computer), and the time point, when the container was received at the other end (e.g. another computer).

As an example, we simply send an instance of the class `TimeStamp` where we pass some example data to its constructor. Next, we create a `Container` by encapsulating object to be sent.

To finally send data with OpenDaVINCI, we use the method `getConference().send(Container &c)` provided for any class deriving from `TimeTriggeredConferenceClientModule`. The main communication principle provided with OpenDaVINCI is publish/subscribe: https://en.wikipedia.org/wiki/Publish%E2%80%93subscribe_pattern. Depending on the command line parameters passed to `odsupercomponent`, the concrete communication is realized either as packets sent via UDP multicast, or via `odsupercomponent` acting as a central communication hub (this functionality is for instance necessary for distributed simulations). For the user application, the concrete pattern in use is transparent and our data is simply handed over to OpenDaVINCI to conduct the necessary steps by calling `getConference().send(c)`. The main method returns the return code 0 encoded as `OKAY`.

The main function is simply instantiating an object of the class `TimeTriggerExample` and runs it by calling the method `runModule()` that is provided from its super-classes.

You can compile and link the example:

```
$ g++ -std=c++11 -I /usr/include -c TimeTriggeredSender.cpp -o TimeTriggeredSender.o
$ g++ -o timetriggeredsender TimeTriggeredSender.o -lopendavinci -lpthread
```

2.3.3.2 Data-triggered receiver

To receive the sent data, a data-triggered software component is derived from `odcore::base::DataTriggeredConferenceClientModule`, provided in `<opendavinci/odcore/base/module/DataTriggeredConferenceClientModule.h>` to realize the receiving functionality.

DataTriggeredReceiver.h:

```
#include <opendavinci/odcore/base/module/DataTriggeredConferenceClientModule.h>

class DataTriggeredReceiver : public␣
↪odcore::base::module::DataTriggeredConferenceClientModule {
    private:
        /**
         * "Forbidden" copy constructor. Goal: The compiler should warn
         * already at compile time for unwanted bugs caused by any misuse
         * of the copy constructor.
         *
         * @param obj Reference to an object of this class.
         */
        DataTriggeredReceiver(const DataTriggeredReceiver &/*obj*/);

        /**
         * "Forbidden" assignment operator. Goal: The compiler should warn
         * already at compile time for unwanted bugs caused by any misuse
         * of the assignment operator.
         *
         * @param obj Reference to an object of this class.
         * @return Reference to this instance.
         */
        DataTriggeredReceiver& operator=(const DataTriggeredReceiver &/*obj*/);

    public:
        /**
         * Constructor.
         *
         * @param argc Number of command line arguments.
         * @param argv Command line arguments.
         */
        DataTriggeredReceiver(const int32_t &argc, char **argv);

        virtual ~DataTriggeredReceiver();

        virtual void nextContainer(odcore::data::Container &c);

    private:
        virtual void setUp();

        virtual void tearDown();
};
```

The class `odcore::base::module::DataTriggeredConferenceClientModule` provides three methods that need to be implemented by the user: `setUp()`, `tearDowny()`, and `nextContainer(odcore::data::Container &c)`. These methods reflect the basic runtime cycle of a software component: An initialization phase, followed by a data-triggered execution of an algorithm implemented in the method `nextContainer()`, before the cycle ends with a call to `tearDown()` intended to clean up any acquired resources.

In addition, this class uses a private and unimplemented copy constructor and assignment operator so that the compiler can warn if an object of this class is unintentionally copied or assigned.

The accompanying implementation for this header file is provided in the following.

DataTriggeredReceiver.cpp:

```
#include <iostream>

#include "DataTriggeredReceiver.h"
#include "opendavinci/odcore/data/TimeStamp.h"

using namespace std;

// We add some of OpenDaVINCI's namespaces for the sake of readability.
using namespace odcore::base::module;
using namespace odcore::data;

DataTriggeredReceiver::DataTriggeredReceiver(const int32_t &argc, char **argv) :
    DataTriggeredConferenceClientModule(argc, argv, "DataTriggeredReceiver")
{}

DataTriggeredReceiver::~DataTriggeredReceiver() {}

void DataTriggeredReceiver::setUp() {
    cout << "This method is called before the component's body is executed." << endl;
}

void DataTriggeredReceiver::tearDown() {
    cout << "This method is called after the program flow returns from the component
↪'s body." << endl;
}

void DataTriggeredReceiver::nextContainer(Container &c) {
    cout << "Received container of type " << c.getDataType() <<
                                " sent at " << c.getSentTimeStamp().getYYYYMMDD_
↪HHMMSSms() <<
                            " received at " << c.getReceivedTimeStamp().getYYYYMMDD_
↪HHMMSSms() << endl;

    if (c.getDataType() == TimeStamp::ID()) {
        TimeStamp ts = c.getData<TimeStamp>();
        cout << "Received the following time stamp: " << ts.toString() << endl;
    }
}

int32_t main(int32_t argc, char **argv) {
    DataTriggeredReceiver dtr(argc, argv);

    return dtr.runModule();
}
```

Firstly, the constructor is implemented, delegating any commandline arguments to the constructor of the class `DataTriggeredConferenceClientModule` to obey the design principle:

Design Principle "Single-Point-of-Truth - SPoT": Favor a centrally maintained configuration over distributed and undocumented commandline parameters

The third parameter to the constructor of `DataTriggeredConferenceClientModule` is the name of this module, which is used to structure the centrally maintained configuration file.

The implementation of the methods `setUp()` and `tearDown()` simply contain explanatory text. They are meant to be used to acquire system resources or to open peripheral components like cameras or sensors.

The data-triggered method `nextContainer(odcore::data::Container &c)` is called whenever a new `Container` is received. The first lines simply print some meta-information about received container like contained

data type as an enum-encoded number, time stamp when the container left the sending software component, and the time stamp when it was received at our end. As we are interested in data of type `TimeStamp::ID()`, we are checking for that type.

Once we have received the data of interest, the content of the container is unpacked by using the template method `Container::getData<T>()` where we specify with T the desired type. In our case, we access its content by specifying the type `TimeStamp`. Finally, the values of `TimeStamp` are printed to stdout by using the data structure's method `toString()`.

The main function is simply instantiating an object of the class `TimeTriggerExample` and runs it by calling the method `runModule()` that is provided from its super-classes.

You can compile and link the example:

```
$ g++ -std=c++11 -I /usr/include -c DataTriggeredReceiver.cpp -o␣
↪DataTriggeredReceiver.o
$ g++ -o datatriggeredreceiver DataTriggeredReceiver.o -lopendavinci -lpthread
```

2.3.3.3 Running the example program

To test the programs, we need to run the software component life-cycle management tool `odsupercomponent`; details for that tool are provided in its accompanying manual page (man odsupercomponent). To use this tool it is required to provide a configuration file. As the aforementioned example applications do not use any configuration data, we simply create an empty file:

```
$ touch configuration
```

If OpenDaVINCI is used on a Linux host **without** a network connection, the local loopback device `lo` needs to be configured to allow UDP multicast sessions before `odsupercomponent` can be started:

```
$ sudo ifconfig lo multicast

$ sudo route add -net 224.0.0.0 netmask 240.0.0.0 dev lo
```

If you use the `ip` command, you need to do:

```
$ sudo ip link set lo multicast on

$ sudo ip route add 224.0.0.0/4 dev lo
```

Next, we can run the life-cycle management application `odsupercomponent`:

```
$ odsupercomponent --cid=111 --configuration=/path/to/configuration
```

The first parameter specifies a unique container conference session identifier from within the range [2,254]. Thus, it is possible to host several sessions on the same host.

Now, you can start the data triggered receiver application providing the same container conference session identifier:

```
$ ./datatriggeredreceiver --cid=111
```

The application will start to print something similar to the following on the console:

```
Received container of type 8 sent at 2015-07-31 13:53:23.847738 received at 2015-07-
↪31 13:53:23.848420
Received container of type 8 sent at 2015-07-31 13:53:25.849773 received at 2015-07-
↪31 13:53:25.850541
```

```
Received container of type 8 sent at 2015-07-31 13:53:27.851393 received at 2015-07-
↪31 13:53:27.851924
Received container of type 8 sent at 2015-07-31 13:53:29.852550 received at 2015-07-
↪31 13:53:29.853406
Received container of type 8 sent at 2015-07-31 13:53:31.854014 received at 2015-07-
↪31 13:53:31.854474
...
```

Containers of this type carry information about `ModuleStatistics` that are used and evaluated by `odsupercomponent`.

Next, we start the time triggered sender providing the same container conference session identifier:

```
$ ./timetriggeredsender --cid=111
```

The application will start to print the following on the console:

```
Sending 0-th time stamp data...done.
Sending 1-th time stamp data...done.
Sending 2-th time stamp data...done.
Sending 3-th time stamp data...done.
...
```

The data-triggered application in turn will print the following on the console:

```
...
Received container of type 12 sent at 2015-07-31 13:53:33.68143 received at 2015-07-
↪31 13:53:33.68858
Received the following time stamp: 1s/0us.
Received container of type 8 sent at 2015-07-31 13:53:33.855026 received at 2015-07-
↪31 13:53:33.855697
Received container of type 12 sent at 2015-07-31 13:53:34.67304 received at 2015-07-
↪31 13:53:34.67797
Received the following time stamp: 2s/2us.
Received container of type 12 sent at 2015-07-31 13:53:35.68291 received at 2015-07-
↪31 13:53:35.69396
Received the following time stamp: 3s/4us.
Received container of type 8 sent at 2015-07-31 13:53:35.856238 received at 2015-07-
↪31 13:53:35.856762
Received container of type 12 sent at 2015-07-31 13:53:36.68194 received at 2015-07-
↪31 13:53:36.69174
Received the following time stamp: 4s/6us.
Received container of type 12 sent at 2015-07-31 13:53:37.67420 received at 2015-07-
↪31 13:53:37.68540
Received the following time stamp: 5s/8us.
Received container of type 8 sent at 2015-07-31 13:53:37.858281 received at 2015-07-
↪31 13:53:37.858938
Received container of type 12 sent at 2015-07-31 13:53:38.67384 received at 2015-07-
↪31 13:53:38.67959
Received the following time stamp: 6s/10us.
Received container of type 12 sent at 2015-07-31 13:53:39.67400 received at 2015-07-
↪31 13:53:39.68423
Received the following time stamp: 7s/12us.
...
```

If the container conference session identifier is omitted, the following exception will be thrown:

```
terminate called after throwing an instance of
↪'core::exceptions::InvalidArgumentException'
  what():  InvalidArgumentException: Invalid number of arguments. At least a␣
↪conference group id (--cid=) needed. at /home/berger/GITHUB/Mini-Smart-Vehicles/
↪sources/OpenDaVINCI/libopendavinci/src/core/base/module/AbstractCIDModule.cpp: 53
Aborted
```

If no `odsupercomponent` is running, the application will exit with return code 4.

2.4 How to use simulation and visualization

This tutorial explains how to use OpenDaVINCI for simulation and visualization (Ubuntu 14.04).

2.4.1 Installation

OpenDaVINCI has several extended libraries for simulation and visualization. The first extended library is odsimulation-odsimtools, which contains components such as odsimvehicle, odsimcamera, and odsimirus, for simulation. The second extended library is opendavinci-odcockpit used for visualization. odcockpit supports visualization for both simulation and real systems.

The tutorial on installing precompiled OpenDaVINCI libraries (http://opendavinci.readthedocs.org/en/latest/installation.pre-compiled.html#adding-opendavinci-to-your-ubuntu-14-04-linux-distribution) does not install these two libraries by default. In order to install odsimulation-odsimtools and opendavinci-odcockpit for simulation and visualization purposes, replace Step 4 at http://opendavinci.readthedocs.org/en/latest/installation.pre-compiled.html#adding-opendavinci-to-your-ubuntu-14-04-linux-distribution:

```
$ sudo apt-get install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent
```

with:

```
$ sudo apt-get install opendavinci-lib opendavinci-odtools opendavinci-
↪odsupercomponent odsimulation-odsimtools opendavinci-odcockpit
```

After the installation, you will find all the OpenDaVINCI binaries (including binaries for simulation and visualization: odsimvehicle, odsimcamera, odsimirus, and odcockpit) in /usr/bin/.

2.4.2 Running the boxparker example in simulation

The boxparker example demonstrates a self-parking algorithm in the OpenDaVINCI simulation environment. A tutorial on how to build the boxparker from sources and run it in Docker image can be found at https://github.com/se-research/OpenDaVINCI/tree/master/automotive/miniature/boxparker. This tutorial gives instructions on running boxparker in simulation without Docker. The boxparker example involves the execution of (1) odsupercomponent: the lifecycle management component of OpenDaVINCI; (2) odsimvehicle: for vehicle movement simulation; (3) odsimirus: for generating distances from obstacles in simulation; (4) odcockpit: the visualization tool; (5) boxparker: the boxparker application.

This tutorial assumes that (1) OpenDaVINCI has been installed at /opt/od/ after being built from sources; and (2) boxparker has been compiled by following https://github.com/se-research/OpenDaVINCI/tree/master/automotive/miniature/boxparker. Then the binaries of the first 4 components can be found at /opt/od/bin, while the boxparker binary should be at automotive/miniature/boxparker/build within the OpenDaVINCI source code folder.

First, download the configuration and scenario files from http://www.cse.chalmers.se/~bergerc/dit168/example.zip, including a configuration file used by odsupercomponent, and two scenario files Car1.objx and Parking_boxes.scnx. Copy these files to /opt/od/bin/ and then go to this directory:

```
$ cd /opt/od/bin/
```

Run odsupercomponent:

```
$ LD_LIBRARY_PATH=/opt/od/lib ./odsupercomponent --cid=111
```

In a new terminal, run odsimvehicle:

```
$ LD_LIBRARY_PATH=/opt/od/lib ./odsimvehicle --cid=111 --freq=10
```

In a new terminal, run odsimirus:

```
$ LD_LIBRARY_PATH=/opt/od/lib ./odsimirus --cid=111 --freq=10
```

In a new terminal, run odcockpit:

```
$ LD_LIBRARY_PATH=/opt/od/lib ./odcockpit --cid=111
```

In odcockpit window, open the BirdsEyeMap plugin. You will see a static car and its surroundings for parking.

Go to the boxparker binary directory and run boxparker in a new terminal:

```
$ ./boxparker --cid=111 --freq=10
```

The car in the BirdsEyeMap window in odcockpit will start moving and stop after it successfully finds a parking slot. Meanwhile, you can open the IrUsMap window and IrUsCharts window on the left side to observe the infrared and ultrasonic sensor data readings.

2.4.3 Noise model for odsimirus

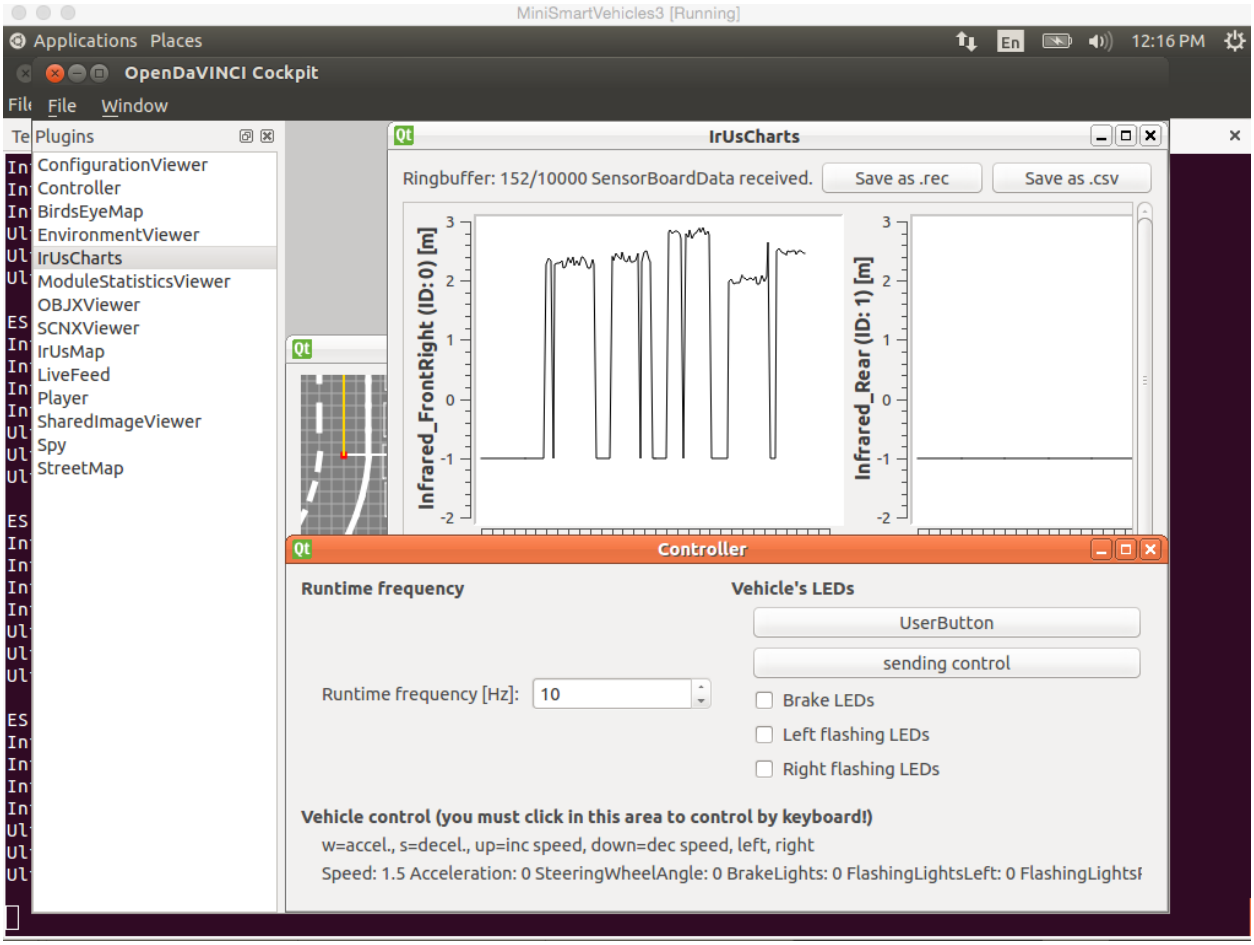
OpenDaVINCI provides a noise model for the odsimirus component to test the robustness of an algorithm (e.g., lane following) in simulation. The noise model is specified in the configuration file for odsupercomponent. For instance, the following specifies the noise model for sensor 0:

- odsimirus.sensor0.faultModel.noise = 0.1
- odsimirus.sensor0.faultModel.skip = 0.05

The first parameter ranges from 0 to 1 and reflects an additional noise to be added from the range [-1,+1]. The implementation is at https://github.com/se-research/OpenDaVINCI/blob/master/libopendlv/src/model/PointSensor.cpp#L164.

The second parameter ranges from 0 to 1 and reflects the dropped frames/missing readings. The implementation is at https://github.com/se-research/OpenDaVINCI/blob/master/libopendlv/src/model/PointSensor.cpp#L187.

The figure below shows a visualization screenshot using the aforementioned parameters.



2.5 How to read content from a zip file

OpenDaVINCI has a built-in function for decompressing zip files.

The sources for this example are available at https://github.com/se-research/OpenDaVINCI/tree/master/tutorials/readzipfile

In order to read content from a zip file, you will find a simple example below.

readzipfile.cpp:

```
#include <fstream>
#include <iostream>
#include <sstream>
#include <string>
#include <opendavinci/odcore/wrapper/CompressionFactory.h>
#include <opendavinci/odcore/wrapper/DecompressedData.h>

using namespace std;

int32_t main(int32_t argc, char **argv) {
    // Read a zip file in binary form. It is originally a csv file containing sample␣
↪data of a 64-layer Velodyne sensor.
    //The csv file stores the data of 10 points, including the x, y, z coordinate and␣
↪intensity value of each point. All values are represented by float numbers.
```

```
    fstream fin("velodyneDataPoint.zip", ios::binary | ios::in);
    std::shared_ptr<odcore::wrapper::DecompressedData> dd =␣
↪odcore::wrapper::CompressionFactory::getContents(fin);  //Decompress the zip file␣
↪and use a shared pointer to point to the decompressed data
    fin.close();
    vector<string> entries = dd->getListOfEntries();
    //In this example, the decompressed data contains only one entry, which is the␣
↪name of the csv file before compression
    //entries.at(0) returns the first entry
    cout<<"Number if entries: "<<entries.size()<<"; the name of the first entry: "<
↪<entries.at(0)<<endl;
    std::shared_ptr<istream> stream = dd->getInputStreamFor(entries.at(0));//Prepare␣
↪an input stream from the csv file to fill a buffer
    stringstream decompressedData;  //a buffer storing all the information of the csv␣
↪file
    if(stream.get()){
        char c;
        while(stream->get(c)){
            decompressedData<<c;  //Fill the buffer
        }
    }
    //Now decompressedData contains all the data from the original csv file. Use␣
↪decompressedData to extract information from the csv file
    string value;
    getline(decompressedData,value); //Skip the title row of the csv file
    vector<float> xDataV;
    vector<float> yDataV;
    vector<float> zDataV;
    vector<float> intensityV;
    while(getline(decompressedData,value)){  //Read the csv file row by row
        stringstream lineStream(value);
        string cell;
        getline(lineStream,cell,','); //Read the x, y, z coordinate and intensity of␣
↪each point
        xDataV.push_back(stof(cell));
        getline(lineStream,cell,',');
        yDataV.push_back(stof(cell));
        getline(lineStream,cell,',');
        zDataV.push_back(stof(cell));
        getline(lineStream,cell,',');
        intensityV.push_back(stof(cell));
    }
    cout<<"Number of rows read: "<<xDataV.size()<<endl;  //Display the number of␣
↪points extracted from the csv file
    for(uint32_t i=0;i<10;i++){
        cout<<"x: "<<xDataV[i]<<", y: "<<yDataV[i]<<", z: "<<zDataV[i]<<", intensity:
↪"<<intensityV[i]<<endl;  //List the x, y, z coordinate and intensity of the 10␣
↪points
    }
}
```

This example reads a zip file `velodyneDataPoint.zip` which is original a csv file `velodyneDataPoint.csv` before compression. The csv file contains sample data of a 64-layer Velodyne sensor. It stores the x, y, z coordinate and intensity value of 10 points. Hence, the csv file has 11 rows (one row for each point plus the title row on top) and 4 columns (x, y, z, intensity). All values are represented by float numbers.

To read content from a zip file, your application needs to include `<opendavinci/odcore/wrapper/CompressionFactory.h>` and `<opendavinci/odcore/wrapper/DecompressedData.h>` that en-

capsulate the platform-specific implementations.

`CompressionFactory` provides a static method called `getContents` that allows you to decompress a zip file. To conveniently handle the resource management of releasing the acquired system resources, a `std::shared_ptr` is used that automatically releases memory that is no longer used.

A `getListOfEntries` method is used to return the list of entries in the decompressed data. A zip file containing multiple files has multiple entries, one entry for each file. `velodyneDataPoint.zip` contains 1 entry, which is the name of the csv file before compression: velodyneDataPoint.csv, which is returned by `entries.at(0)` in this example. Then `getInputStreamFor(entries.at(0))` prepares an input stream from the csv file to fill a buffer `decompressedData` that stores all the information of the csv file. `decompressedData` will be used to extract rows and columns from the csv file.

You can compile and link the example:

```
g++ -std=c++11 -I /usr/include -c readzipfile.cpp -o readzipfile.o
g++ -o readzipfile readzipfile.o -lopendavinci -lpthread
```

To test the program, run:

```
$ ./readzipfile
$
```

The x, y, z coordinate and intensity of the 10 points extracted from the csv file will be printed to the console:

```
Number of entries: 1; the name of the first entry: velodyneDataPoint.csv
Number of rows read: 89105
x: 1.24821, y: 13.424, z: -1.52942, intensity: 22
x: 0.851616, y: 14.2127, z: -1.54146, intensity: 28
x: -0.777795, y: 18.337, z: 0.287256, intensity: 102
x: -1.46898, y: 18.3918, z: 0.386122, intensity: 69
x: 0.26113, y: 14.4262, z: -1.48172, intensity: 34
x: -0.272345, y: 14.8803, z: -1.43373, intensity: 40
x: 0.38511, y: 12.197, z: -1.66423, intensity: 32
x: -0.0547113, y: 12.806, z: -1.67453, intensity: 27
x: -0.86384, y: 15.1217, z: -1.37554, intensity: 37
x: -1.45687, y: 15.7513, z: -1.34796, intensity: 44
```

CHAPTER 3

How to install OpenDaVINCI on Linux-based Platforms

3.1 Compiling OpenDaVINCI on ArchLinux

Download and install ArchLinux and install using the following instructions: https://wiki.archlinux.org/index.php/Installation_guide

Update the keys and the package database:

```
$ pacman-key --init
$ yes | pacman --noconfirm -Sc
$ yes | pacman --noconfirm -Sy pacman
$ pacman-db-upgrade
$ yes | pacman --noconfirm -S archlinux-keyring
$ pacman-key --init
$ yes | pacman --noconfirm -Syu
```

Install OpenDaVINCI dependencies:

```
$ sudo pacman --no-confirm -S apache-ant jdk8-openjdk boost cmake ffmpeg2.8 freeglut␣
↪gcc git junit make opencv python2 qt4 qwt5
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.2 Compiling OpenDaVINCI on CentOS7

Download and install CentOS 7 and install its latest package updates:

```
$ sudo yum -y update
$ sudo yum -y upgrade
```

Install OpenDaVINCI dependencies:

```
$ sudo yum -y install ant ant-junit automake boost-devel cmake freeglut-devel gcc gcc-
↪c++ git python27 iproute make opencv-devel psmisc qt4-devel qwt5-qt4-devel kernel-
↪devel wget
```

Clean up installation:

```
$ sudo yum autoremove
$ sudo yum clean all
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.3 Compiling OpenDaVINCI on Debian 7.8

Download and install Debian 7.8 and install its latest package updates:

```
$ sudo apt-get update
$ sudo apt-get upgrade
$ sudo apt-get dist-upgrade
```

Install development packages for OpenDaVINCI sources:

```
$ sudo apt-get install build-essential cmake git
```

Install the required development packages for libodsimulation sources:

```
$ sudo apt-get install libcv-dev libhighgui-dev freeglut3 libqt4-dev libqwt5-qt4-dev␣
↪libqwt5-qt4 libqt4-opengl-dev freeglut3-dev qt4-dev-tools libboost-dev libopencv-
↪photo-dev libopencv-contrib-dev
```

Install development packages for DataStructureGenerator sources:

```
$ sudo apt-get install ant openjdk-7-jdk
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.4 Compiling OpenDaVINCI on Debian 8.1

Download and install Debian 8.1 and install its latest package updates:

```
$ sudo apt-get update
$ sudo apt-get upgrade
$ sudo apt-get dist-upgrade
```

Install development packages for OpenDaVINCI sources:

```
$ sudo apt-get install build-essential cmake git
```

Install the required development packages for libodsimulation sources:

```
$ sudo apt-get install libcv-dev libhighgui-dev freeglut3 libqt4-dev libqwt5-qt4-dev␣
↪libqwt5-qt4 libqt4-opengl-dev freeglut3-dev qt4-dev-tools libboost-dev libopencv-
↪photo-dev libopencv-contrib-dev
```

Install development packages for DataStructureGenerator sources:

```
$ sudo apt-get install ant openjdk-7-jdk
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.5 Compiling OpenDaVINCI on Debian 8.2

Download and install Debian 8.2 and install its latest package updates:

```
$ sudo apt-get update
$ sudo apt-get upgrade
$ sudo apt-get dist-upgrade
```

Install development packages for OpenDaVINCI sources:

```
$ sudo apt-get install build-essential cmake git
```

Install the required development packages for libodsimulation sources:

```
$ sudo apt-get install libcv-dev libhighgui-dev freeglut3 libqt4-dev libqwt5-qt4-dev␣
↪libqwt5-qt4 libqt4-opengl-dev freeglut3-dev qt4-dev-tools libboost-dev libopencv-
↪photo-dev libopencv-contrib-dev
```

Install development packages for DataStructureGenerator sources:

```
$ sudo apt-get install ant openjdk-7-jdk
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.6 Compiling OpenDaVINCI on Elementary OS

Download and install Elementary OS and install its latest package updates:

```
$ sudo apt-get update
$ sudo apt-get upgrade
$ sudo apt-get dist-upgrade
```

Install development packages for OpenDaVINCI sources:

```
$ sudo apt-get install build-essential cmake git
```

Install the required development packages for libodsimulation sources:

```
$ sudo apt-get install libcv-dev libhighgui-dev freeglut3 libqt4-dev libqwt5-qt4-dev␣
↪libqwt5-qt4 libqt4-opengl-dev freeglut3-dev qt4-dev-tools libboost-dev libopencv-
↪photo-dev libopencv-contrib-dev
```

Install development packages for DataStructureGenerator sources:

```
$ sudo apt-get install ant openjdk-7-jdk
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.7 Compiling OpenDaVINCI on Fedora 20

Download and install Fedora 20 and install its latest package updates:

```
$ sudo yum update
$ sudo yum upgrade
$ sudo yum distro-sync
```

Install the required development packages for OpenDaVINCI sources:

```
$ sudo yum install cmake gcc gcc-c++ git
```

Install the required development packages for libodsimulation sources:

```
$ sudo yum install freeglut qt4 boost boost-devel qt4-devel freeglut-devel opencv-
↪devel qwt5-qt4-devel
```

Install the required development packages for the DataStructureGenerator sources:

```
$ sudo yum install java-1.7.0-openjdk ant
```

Clean up installation:

```
$ sudo yum autoremove
$ sudo yum clean all
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.8 Compiling OpenDaVINCI on Fedora 21

Download and install Fedora 21 and install its latest package updates:

```
$ sudo yum -y update
$ sudo yum -y upgrade
```

Install OpenDaVINCI dependencies:

```
$ sudo yum -y install ant ant-junit automake boost-devel cmake freeglut-devel gcc gcc-
↪c++ git python2 iproute kernel-devel make opencv-devel psmisc qt4-devel qwt5-qt4-
↪devel tar wget
```

Clean up installation:

```
$ sudo yum autoremove
$ sudo yum clean all
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.9 Compiling OpenDaVINCI on Fedora 22

Download and install Fedora 22 and install its latest package updates:

```
$ sudo dnf -y update
$ sudo dnf -y upgrade
```

Install OpenDaVINCI dependencies:

```
$ sudo dnf -y install ant ant-junit automake boost-devel cmake freeglut-devel gcc gcc-
↪c++ git python2 iproute kernel-devel make opencv-devel psmisc qt4-devel qwt5-qt4-
↪devel tar wget
```

Clean up installation:

```
$ sudo dnf autoremove
$ sudo dnf clean all
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.10 Compiling OpenDaVINCI on Fedora 23

Download and install Fedora 23 and install its latest package updates:

```
$ sudo dnf -y update
$ sudo dnf -y upgrade
```

Install OpenDaVINCI dependencies:

```
$ sudo dnf -y install ant ant-junit automake boost-devel cmake freeglut-devel git␣
↪python2 gcc gcc-c++ iproute kernel-devel make opencv-devel psmisc qt4-devel qwt5-
↪qt4-devel tar wget
```

Clean up installation:

```
$ sudo dnf autoremove
$ sudo dnf clean all
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.11 Compiling OpenDaVINCI on Mageia

Download and install Mageia and install its latest package updates:

```
$ sudo urpmi.update -a
```

Install the required development packages for OpenDaVINCI sources:

```
$ sudo urpmi cmake gcc gcc-c++ git
```

Install the required development packages for libodsimulation sources:

```
$ sudo urpmi libqt4-devel lib64freeglut3 lib64freeglut-devel lib64boost-devel opencv-
↪devel
```

Install qwt5-qt4 for OpenDLV sources:

```
$ sudo urpmi lib64qwt5-devel
```

Add two missing symbolic links:

```
$ sudo ln -sf /usr/include/qwt /usr/include/qwt-qt4
$ sudo ln -sf /usr/lib64/libqwt5-qt4.so /usr/lib64/libqwt-qt4.so
```

Install the required development packages for the DataStructureGenerator sources:

```
$sudo urpmi java-1.7.0-openjdk-devel ant ant-junit
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.12 Compiling OpenDaVINCI on Linux Mint 17 (32bit and 64bit)

Download and install Linux Mint 17 and install its latest package updates:

```
$ sudo apt-get update
$ sudo apt-get upgrade
$ sudo apt-get dist-upgrade
```

Install development packages for OpenDaVINCI sources:

```
$ sudo apt-get install build-essential cmake git
```

Install the required development packages for libodsimulation sources:

```
$ sudo apt-get install libcv-dev libhighgui-dev freeglut3 libqt4-dev libqwt5-qt4-dev␣
↪libqwt5-qt4 libqt4-opengl-dev freeglut3-dev qt4-dev-tools libboost-dev libopencv-
↪photo-dev libopencv-contrib-dev
```

Install development packages for DataStructureGenerator sources:

```
$ sudo apt-get install ant openjdk-7-jdk
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.13 Compiling OpenDaVINCI on OpenSuSE 13.1

Download and install openSuSE 13.1 and install its latest package updates:

```
$ sudo zypper refresh
$ sudo zypper update
```

Install required development packages for OpenDaVINCI sources:

```
$ sudo zypper install cmake gcc gcc-c++ git
```

Install required development packages for libodsimulation sources:

```
$ sudo zypper install opencv-devel boost-devel freeglut-devel libqt4-devel ant ant-
↪junit qwt-devel
```

Install and configure Oracle's Java according to the following guide http://tutorialforlinux.com/2013/12/12/how-to-install-oracle-java-jdk-7-on-opensuse-13-1-gnome3-3264bit-easy-guide/

```
$ sudo apt-get install ant openjdk-7-jdk
```

Install required development packages for DataStructureGenerator sources:

```
$sudo zypper install ant
```

Clean up installation:

```
$ sudo zypper clean
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.14 Compiling OpenDaVINCI on OpenSuSE 13.2

Download and install openSuSE 13.2 and install its latest package updates:

```
$ sudo zypper --non-interactive --no-gpg-checks refresh
$ sudo zypper --non-interactive --no-gpg-checks update
```

Install OpenDaVINCI dependencies:

```
$ sudo zypper --non-interactive --no-gpg-checks install ant ant-junit boost-devel␣
↪cmake git freeglut-devel gcc gcc-c++ iproute2 make python opencv-devel psmisc␣
↪libqt4-devel qwt-devel wget
```

Clean up installation:

```
$ sudo zypper clean
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.15 Compiling OpenDaVINCI on Scientific Linux 7

Download and install Scientific Linux 7 and install its latest package updates:

```
$ sudo yum update
$ sudo yum upgrade
$ sudo yum distro-sync
```

Install the required development packages for OpenDaVINCI sources:

```
$ sudo yum install cmake gcc gcc-c++ git
```

Install the required development packages for libodsimulation sources:

```
$ sudo yum install freeglut qt4 boost boost-devel qt4-devel freeglut-devel opencv-
↪devel
```

Install qwt5-qt4:

```
$ sudo yum install bzip2
$ wget http://downloads.sourceforge.net/project/qwt/qwt/5.2.3/qwt-5.2.3.tar.bz2
$ tar -xvjf qwt-5.2.3.tar.bz2
$ sudo ln -sf /usr/bin/qmake-qt4 /usr/bin/qmake
$ cd qwt-5.2.3 && qmake qwt.pro && make
$ sudo make install
```

Add two missing symbolic links:

```
$ sudo ln -sf /usr/local/qwt-5.2.3/include /usr/include/qwt-qt4
$ sudo ln -sf /usr/local/qwt-5.2.3/lib/libqwt.so.5.2.3 /usr/include/libqwt-qt4.so
```

Install the required development packages for the DataStructureGenerator sources:

```
$sudo yum install java-1.7.0-openjdk ant ant-junit
```

Clean up installation:

```
$sudo yum autoremove
$sudo yum clean all
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.16 Compiling OpenDaVINCI on Ubuntu 14.04 LTS (32bit and 64bit)

Download and install Ubuntu 14.04 LTS and install its latest package updates:

```
$ sudo apt-get update -y
$ sudo apt-get upgrade -y
$ sudo apt-get dist-upgrade -y
```

Install OpenDaVINCI dependencies:

```
$ sudo apt-get install -y --no-install-recommends ant build-essential cmake default-
↪jre default-jdk freeglut3 freeglut3-dev git libboost-dev libopencv-dev libopencv-
↪core-dev libopencv-highgui-dev libopencv-imgproc-dev libpopt-dev libqt4-dev libqt4-
↪opengl-dev libqwt5-qt4-dev libqwt5-qt4 qt4-dev-tools rpm psmisc wget
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.17 Compiling OpenDaVINCI on Ubuntu 15.04

Download and install Ubuntu 15.04 and install its latest package updates:

```
$ sudo apt-get update -y
$ sudo apt-get upgrade -y
$ sudo apt-get dist-upgrade -y
```

Install OpenDaVINCI dependencies:

```
$ sudo apt-get install -y --no-install-recommends ant build-essential cmake default-
↪jre default-jdk freeglut3 freeglut3-dev git libboost-dev libopencv-dev libopencv-
↪core-dev libopencv-highgui-dev libopencv-imgproc-dev libpopt-dev libqt4-dev libqt4-
↪opengl-dev libqwt5-qt4-dev libqwt5-qt4 qt4-dev-tools rpm psmisc wget
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Install ffmpeg:

```
$ sudo apt-get install -y --no-install-recommends ffmpeg
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.18 Compiling OpenDaVINCI on Ubuntu 15.10

Download and install Ubuntu 15.10 and install its latest package updates:

```
$ sudo apt-get update -y
$ sudo apt-get upgrade -y
$ sudo apt-get dist-upgrade -y
```

Install OpenDaVINCI dependencies:

```
$ sudo apt-get install -y --no-install-recommends ant build-essential cmake default-
↪jre default-jdk freeglut3 freeglut3-dev git libboost-dev libopencv-dev libopencv-
↪core-dev libopencv-highgui-dev libopencv-imgproc-dev libpopt-dev libqt4-dev libqt4-
↪opengl-dev libqwt5-qt4-dev libqwt5-qt4 qt4-dev-tools rpm psmisc wget
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Install ffmpeg:

```
$ sudo apt-get install -y --no-install-recommends ffmpeg
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.19 Compiling OpenDaVINCI on Ubuntu 16.04

Download and install Ubuntu 16.04 and install its latest package updates:

```
$ sudo apt-get update -y
$ sudo apt-get upgrade -y
$ sudo apt-get dist-upgrade -y
```

Install OpenDaVINCI dependencies:

```
$ sudo apt-get install -y --no-install-recommends ant build-essential cmake default-
↪jre default-jdk freeglut3 freeglut3-dev git libboost-dev libopencv-dev libopencv-
↪core-dev libopencv-highgui-dev libopencv-imgproc-dev libpopt-dev libqt4-dev libqt4-
↪opengl-dev libqwt5-qt4-dev libqwt5-qt4 qt4-dev-tools rpm psmisc wget
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Install ffmpeg:

```
$ sudo apt-get install -y --no-install-recommends ffmpeg
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.20 Compiling OpenDaVINCI on Zorin 9.1

Download and install Zorin 9.1 and install its latest package updates:

```
$ sudo apt-get update
$ sudo apt-get upgrade
$ sudo apt-get dist-upgrade
```

Install development packages for OpenDaVINCI sources:

```
$ sudo apt-get install build-essential cmake git
```

Install development packages for DataStructureGenerator sources:

```
$ sudo apt-get install ant openjdk-7-jdk
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

3.21 Compiling OpenDaVINCI on Zorin 10

Download and install Zorin 10 and install its latest package updates:

```
$ sudo apt-get update
$ sudo apt-get upgrade
$ sudo apt-get dist-upgrade
```

Install development packages for OpenDaVINCI sources:

```
$ sudo apt-get install build-essential cmake git
```

Install development packages for DataStructureGenerator sources:

```
$ sudo apt-get install ant openjdk-7-jdk
```

Clean up installation:

```
$ sudo apt-get clean
$ sudo apt-get autoremove
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Create an installation folder:

```
$ sudo mkdir -p /opt/od && sudo chown $USER:$USER /opt/od
```

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/opt/od ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make
```

CHAPTER 4

How to install OpenDaVINCI on BSD-based Platforms

4.1 Compiling OpenDaVINCI on DragonFlyBSD 4.0.5 (64bit)

Download and install DragonFlyBSD 4.0.5 and update the packages list as root:

```
# pkg update
```

Install the bash shell:

```
# pkg install shells/bash
```

Change the shell by running:

```
$ chsh
```

Install the compiler:

```
# pkg install lang/gcc
# pkg install devel/cmake
# pkg install devel/git
# pkg install lang/python
```

Install Java to generate data structures:: # pkg install devel/apache-ant # pkg install java/openjdk7

Add the following lines to /etc/fstab:

```
fdesc    /dev/fd       fdescfs      rw  0    0
proc     /proc         procfs        rw  0    0
```

Add a symbolic link to python as root user:

```
# ln -sf /usr/local/bin/python /usr/bin/python
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/usr/local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

4.2 Compiling OpenDaVINCI on DragonFlyBSD 4.2 (64bit)

Download and install DragonFlyBSD 4.2 and update the packages list as root:

```
# pkg update
```

Install the bash shell:

```
# pkg install shells/bash
```

Change the shell by running:

```
$ chsh
```

Install the compiler:

```
# pkg install lang/gcc
# pkg install devel/cmake
# pkg install devel/git
# pkg install lang/python
```

Install Java to generate data structures:: # pkg install devel/apache-ant # pkg install java/openjdk7

Add the following lines to /etc/fstab:

```
fdesc    /dev/fd       fdescfs      rw  0    0
proc     /proc         procfs        rw  0    0
```

Add a symbolic link to python as root user:

```
# ln -sf /usr/local/bin/python /usr/bin/python
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/usr/local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

4.3 Compiling OpenDaVINCI on DragonFlyBSD 4.4 (64bit)

Download and install DragonFlyBSD 4.4 and update the packages list as root:

```
# pkg update
```

Install the bash shell:

```
# pkg install shells/bash
```

Change the shell by running:

```
$ chsh
```

Install the compiler:

```
# pkg install lang/gcc
# pkg install devel/cmake
# pkg install devel/git
# pkg install lang/python
```

Install Java to generate data structures:: # pkg install devel/apache-ant # pkg install java/openjdk8

Add the following lines to /etc/fstab:

```
fdesc    /dev/fd       fdescfs      rw  0    0
proc     /proc         procfs        rw  0    0
```

Add a symbolic link to python as root user:

```
# ln -sf /usr/local/bin/python /usr/bin/python
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/usr/local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

4.4 Compiling OpenDaVINCI on FreeBSD 10.1 (32bit and 64bit)

Download and install FreeBSD 10.1 and update the packages list as root (FreeBSD will install automatically the package management tool, simply press 'y' to accept):

```
# pkg update
```

Install the bash shell for more convenient typing:

```
# pkg install shells/bash
```

Add the following line to /etc/fstab as indicated by the installer:

```
fdesc    /dev/fd      fdescfs      rw  0    0
```

Change the shell by running:

```
$ chsh
```

Install the compiler:

```
# pkg install lang/gcc
# pkg install devel/cmake
# pkg install devel/git
# pkg install lang/python
```

Add a symbolic link to python as root user:

```
# ln -sf /usr/local/bin/python /usr/bin/python
```

Install Java to generate data structures:

```
# pkg install devel/apache-ant
# pkg install openjdk
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/usr/local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

4.5 Compiling OpenDaVINCI on NetBSD 6.1.5 (32bit and 64bit)

Download and install NetBSD 6.1.4 and update the packages list as root:

```
# pkgin update
```

Install the bash shell:

```
# pkgin install bash
```

Change the shell by running:

```
$ chsh
```

Set up the right locale:

```
$ cat >.profile <<EOF
export LANG="en_US.UTF-8"
export LC_CTYPE="en_US.UTF-8"
export LC_ALL=""
EOF
```

Install the compiler:

```
# pkgin install gcc
# pkgin install cmake
# pkgin install git
# pkgin install python27
```

Add a symbolic link to python as root user:

```
# ln -sf /usr/pkg/bin/python2.7 /usr/bin/python
```

Install Java to generate data structures:

```
# cd /usr/pkgsrc/distfiles && wget http://ftp.osuosl.org/pub/funtoo/distfiles/oracle-
↪java/jdk-7u72-linux-i586.tar.gz
# cd /usr/pkgsrc/emulators/suse121_base && make install clean
# cd /usr/pkgsrc/emulators/suse121_x11 && make install clean
# cd /usr/pkgsrc/lang/sun-jdk7 && echo "ACCEPTABLE_LICENSES+=oracle-binary-code-
↪license" >> /etc/mk.conf && make install clean
# echo "procfs /usr/pkg/emul/linux/proc procfs rw,linux" >> /etc/fstab
# cd /usr/pkg/bin && ln -sf sun7-java java
# cd /usr/pkg/bin && ln -sf sun7-javac javac
$ echo "ulimit -d 400000" >> .profile
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/usr/local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

4.6 Compiling OpenDaVINCI on NetBSD 7.0 (64bit)

Install the compiler:

```
# export PKG_PATH=http://ftp.NetBSD.org/pub/pkgsrc/packages/NetBSD/amd64/7.0/All
# pkg_add -v cmake
# pkg_add -v git
# pkg_add -v mozilla-rootcerts
# mozilla-rootcerts install
# pkg_add -v python27
# pkg_add -v gcc49
# pkg_add -v openjdk7
# pkg_add -v apache-ant
```

Add a symbolic link to python as root user:

```
# ln -sf /usr/pkg/bin/python2.7 /usr/pkg/bin/python
```

Add a symbolic link to Java as root user:

```
# ln -sf /usr/pkg/bin/openjdk7-java /usr/pkg/bin/java
# ln -sf /usr/pkg/bin/openjdk7-javac /usr/pkg/bin/javac
# ln -sf /usr/pkg/bin/openjdk7-javah /usr/pkg/bin/javah
# ln -sf /usr/pkg/bin/openjdk7-javadoc /usr/pkg/bin/javadoc
# ln -sf /usr/pkg/bin/openjdk7-jar /usr/pkg/bin/jar
```

Add a /usr/pkg/bin to the search path of the local user:

```
$ export PATH=/usr/pkg/bin:$PATH
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/usr/local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

4.7 Compiling OpenDaVINCI on OpenBSD 5.7 (32bit and 64bit)

Download and install OpenBSD 5.7.

Set the PKG_PATH (32bit version):

```
# export PKG_PATH=http://ftp.eu.openbsd.org/pub/OpenBSD/5.7/packages/i386/
```

Set the PKG_PATH (64bit version):

```
# export PKG_PATH=http://ftp.eu.openbsd.org/pub/OpenBSD/5.7/packages/amd64/
```

Install the bash shell:

```
# pkg_add -v -i bash
```

You can change the shell by running:

```
$ chsh
```

Install the compiler:

```
# pkg_add -v -i bash
# pkg_add -v -i python # (choose version 2.7)
# pkg_add -v -i cmake
# pkg_add -v -i git
# pkg_add -v -i gcc-4.9.2p1
# pkg_add -v -i g++-4.9.2p1
```

Install Java to generate data structures:

```
# pkg_add -v -i apache-ant
# pkg_add -v -i jdk
# pkg_add -v -i jre
# cd /usr/local/bin && ln -sf /usr/local/jdk-1.7.0/bin/java java
# cd /usr/local/bin && ln -sf /usr/local/jdk-1.7.0/bin/javac javac
```

Add a symbolic link to python as root user:

```
# ln -sf /usr/local/bin/python2.7 /usr/bin/python
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && export CC=egcc && export CXX=eg++ && cmake -D CMAKE_INSTALL_PREFIX=/usr/
↪local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

4.8 Compiling OpenDaVINCI on OpenBSD 5.8 (32bit and 64bit)

Download and install OpenBSD 5.8.

Set the PKG_PATH (32bit version):

```
# export PKG_PATH=http://ftp.eu.openbsd.org/pub/OpenBSD/5.8/packages/i386/
```

Set the PKG_PATH (64bit version):

```
# export PKG_PATH=http://ftp.eu.openbsd.org/pub/OpenBSD/5.8/packages/amd64/
```

Install the bash shell:

```
# pkg_add -v -i bash
```

You can change the shell by running:

```
$ chsh
```

Install the compiler:

```
# pkg_add -v -i bash
# pkg_add -v -i python # (choose version 2.7)
# pkg_add -v -i cmake
# pkg_add -v -i git
# pkg_add -v -i gcc-4.9.3p0
# pkg_add -v -i g++-4.9.3p0
```

Install the Java:

```
# pkg_add -v -i apache-ant
# pkg_add -v -i jdk
# pkg_add -v -i jre
# cd /usr/local/bin && ln -sf /usr/local/jdk-1.8.0/bin/javac javac
# cd /usr/local/bin && ln -sf /usr/local/jdk-1.8.0/bin/javah javah
# cd /usr/local/bin && ln -sf /usr/local/jdk-1.8.0/bin/java java
# cd /usr/local/bin && ln -sf /usr/local/jdk-1.8.0/bin/jar jar
# cd /usr/local/bin && ln -sf /usr/local/jdk-1.8.0/bin/javadoc javadoc
```

Add a symbolic link to python as root user:

```
# ln -sf /usr/local/bin/python2.7 /usr/bin/python
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && export CC=egcc && export CXX=eg++ && cmake -D CMAKE_INSTALL_PREFIX=/usr/
↪local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

4.9 Compiling OpenDaVINCI on MacOSX 10

Install Xcode: https://developer.apple.com/xcode/downloads/

Install CMake: http://www.cmake.org/download/

Install Java to generate data structures: http://java.com/en/download/

Install Python 2.79: https://www.python.org/downloads/mac-osx/

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_C_COMPILER=/usr/bin/cc -D CMAKE_CXX_COMPILER=/usr/bin/
↪c++ -D CMAKE_INSTALL_PREFIX=/usr/local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

CHAPTER 5

How to install OpenDaVINCI on Minix

5.1 Compiling OpenDaVINCI on Minix3

Download and install Minix3 and install its latest package updates:

```
# pkgin update
```

Install development packages for OpenDaVINCI sources:

```
# pkgin install python27
# pkgin install cmake
# pkgin install git-base
# pkgin install clang
```

Install development packages for DataStructureGenerator sources:

```
# export PKG_PATH=http://ftp.eu.openbsd.org/pub/OpenBSD/5.6/packages/i386/
# pkg_add -v -i apache-ant
# pkg_add -v -i jdk
# pkg_add -v -i jre
# cd /usr/local/bin && ln -sf /usr/local/jdk-1.7.0/bin/java java
# cd /usr/local/bin && ln -sf /usr/local/jdk-1.7.0/bin/javac javac
```

Add a symbolic link to python as root user:

```
# ln -sf /usr/local/bin/python2.7 /usr/bin/python
```

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/usr/local ..
```

Build, run the tests, and install the OpenDaVINCI:

```
$ make all
```

CHAPTER 6

How to install OpenDaVINCI on Windows-based Platforms

6.1 Compiling OpenDaVINCI on Windows 7, 8.1, and 10 (32bit and 64bit)

Download and install CMake for Windows (let the install add the CMake binary to the all users' path): http://www.cmake.org/files/v3.0/cmake-3.0.0-win32-x86.exe

Download and install Python 2.7.8 for Windows: https://www.python.org/ftp/python/2.7.8/python-2.7.8.msi. Let the installer add Python to the the system path so that you can run Python from the command line.

Download and install Git for Windows (choose "Use Git from Windows Command Prompt" & "Checkout Windows-style & commit Unix style": http://git-scm.com/download/win

Install Java to generate data structures: http://java.com/en/download/

Download and install Visual Studio 2013 Community Edition: http://go.microsoft.com/fwlink/?LinkId=517284

Clone the latest OpenDaVINCI sources from https://github.com/se-research/OpenDaVINCI or download the latest OpenDaVINCI sources as zip file: https://github.com/se-research/OpenDaVINCI/archive/master.zip.

Change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder (NMake files for building on console):

```
$ cd build
$ cmake -G "NMake Makefiles" -D CMAKE_INSTALL_PREFIX=myInstallDir ..
```

Build the OpenDaVINCI sources:

```
$ nmake
```

If you want to use Visual Studio for editing, let cmake create the build scripts:

```
$ cd build
$ cmake -G "Visual Studio 12 2013" -D CMAKE_INSTALL_PREFIX=../myInstallDir ..
```

CHAPTER 7

How to compile OpenDaVINCI with Clang

To compile OpenDaVINCI using Clang, change to your source folder and create a build directory:

```
$ cd OpenDaVINCI && mkdir build
```

Use cmake to create the build scripts for your build folder and specify the Clang toolchain:

```
$ cd build && cmake -D CMAKE_INSTALL_PREFIX=/usr/local -DCMAKE_TOOLCHAIN_FILE=../
↪cmake/clang-Toolchain.cmake ..
```

CHAPTER 8

Examples for typical usage senarios with OpenDaVINCI

8.1 Using the logging interface in OpenDaVINCI

OpenDaVINCI has a built-in logging engine. Its fundamental concept is realized by `odsupercomponent` as it is required to start a communication session for distributed modules anyways.

In order to use the logging engine in a user-supplied module, you can simply call the following method from within your module deriving from `DataTriggeredConferenceClientModule` or `TimeTriggeredConferenceClientModule`:

```
void toLogger(const odcore::data::LogMessage::LogLevel &logLevel, const string &msg);
```

Example:

```
toLogger(odcore::data::LogMessage::INFO, "this is an info message");
```

By using this method, `"this is an info message"` is sent to the UDP multicast conference using the logging level `logLevel`. The `logLevel` can be either `odcore::data::LogMessage::NONE`, `odcore::data::LogMessage::INFO`, `odcore::data::LogMessage::WARN`, or `odcore::data::LogMessage::DEBUG`. `odsupercomponent` is receiving the log data and storing it to a file depending on its command line parameters.

On startup of `odsupercomponent`, you need to specify the following command line parameters to setup the logging:

1. `--logLevel`
2. `--logFile`

The first parameter specifies the logging level up to which messages from distributed modules are stored in the log file. Thus, if you specify `--logLevel=INFO` any messages that are tagged as `odcore::data::LogMessage::NONE` or `odcore::data::LogMessage::INFO` will be stored but `odcore::data::LogMessage::WARN` and `odcore::data::LogMessage::DEBUG` are discarded.

If you omit the parameter, `odcore::data::LogMessage::NONE` is assumed.

The second parameter specifies the log file where the log data is stored. The data itself has the following format:

```
<time stamp in microseconds> ; <name of the sending module> ; <numerical log level, 0
↪- 3> ; <message> ;
```

Example:

```
$ odsupercomponent --cid=111 --loglevel=info --logfile=mylogfile.log
```

This feature was contributed by Ashfaq Hussain Farooqui (https://twitter.com/me_rafiki) and will be available from release 1.3.0.