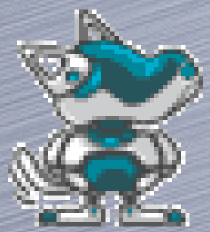
Campus Universitari de la Mediterrània

Aibo programming course



July 2005, Summer Course

by Ricardo Téllez

Aibo programming course

- Introduction (1/2h)
- OPEN-R basics (1.5h)
- Sensors (2h)
- Actuators (2h)
- Neural controller (2h)
- Camera (1h)
- Webots simulator (1h)

Introduction

Introduction

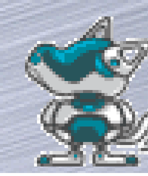
- Aibo is a robot dog created by Sony
- Fully programmable
- Several models

Introduction

- For the ERS-7 model
- 18 DOF
- Paw sensors (4)
- Distance sensors (3)
- Touch sensors (4)
- Color camera (1)
- Stereo mic (2)
- Accelerometers (3)

Introduction

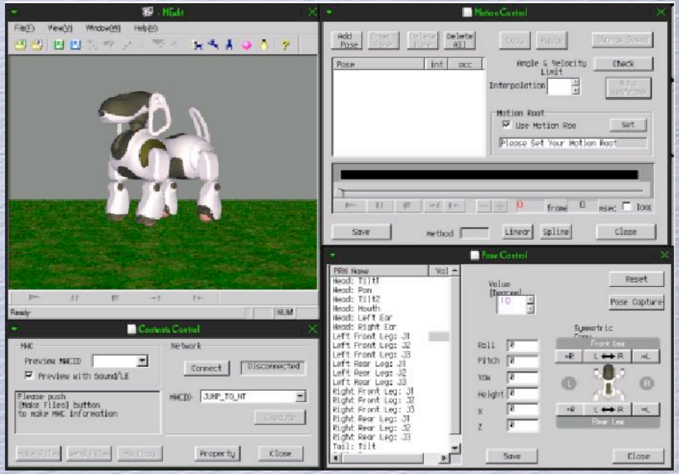
- Aibo programs are stored in memory sticks (MS)
- MS are plugged in into Aibo to run the program
- Any type of controller



Introduction

Programming environment by Sony

- R-CODE (scripting language)
- OPEN-R (C++ environment)
- Remote Framework (MSFC environment)
- MEdit (motion editor)



Introduction

Third part programming environments

- Tekkotsu (developed at CMU)
  - C++ programming environment on top of OPEN-R
- URBI (developed at ENSTA)
  - Powerful scripting that allows remote control of Aibo. Includes C++ libraries for autonomous mode

Introduction

- Example of an URBI program...
- Winner of the Aibo Does Daftpunk contest

Introduction

Setting the environment

- Installing OPEN-R SDK on PC (done)
- Installing base system on MS (done)
  - different wireless modes: basic, wlan or wconsole
  - different memory modes: memprot, nomemprot
- Setting up wireless network (done)
- Compiling & running sample program
- Setting the FTP server

Setting the FTP server

- Compile the TinyFTPD sample program
  - > make; make install
- Install generated object on MS
  - > cp TinyFTPD/MS/OPEN-R/MW/OBJS/TINYFTPD.BIN /mnt/usb/OPEN-R/MW/OBJS
- Install the password file on MS
  - > cp TinyFTPD/MS/OPEN-R/MW/CONF/PASSWD /mnt/usb/OPEN-R/MW/CONF
- Add line to OBJECT.CFG file
  - > /OPEN-R/MW/OBJS/TINYFTPD.BIN

OPEN-R Basics

OPEN-R Basics

- OPEN-R program composed of **objects** running **concurrently** that **communicate** to each other
- Objects are like processes.
- Objects inherit from OObject.
- Objects are composed of internal states
- Must define virtual functions:
  - DoInit, DoStart, DoStop, DoDestroy
- Example: HelloWord

Compilation Basics

- Example: compilation and execution of the HelloWorld sample program
- Configuration of the Makefile
- Configuration of the HelloWorld.ocf file
- Configuration of the object.cfg file

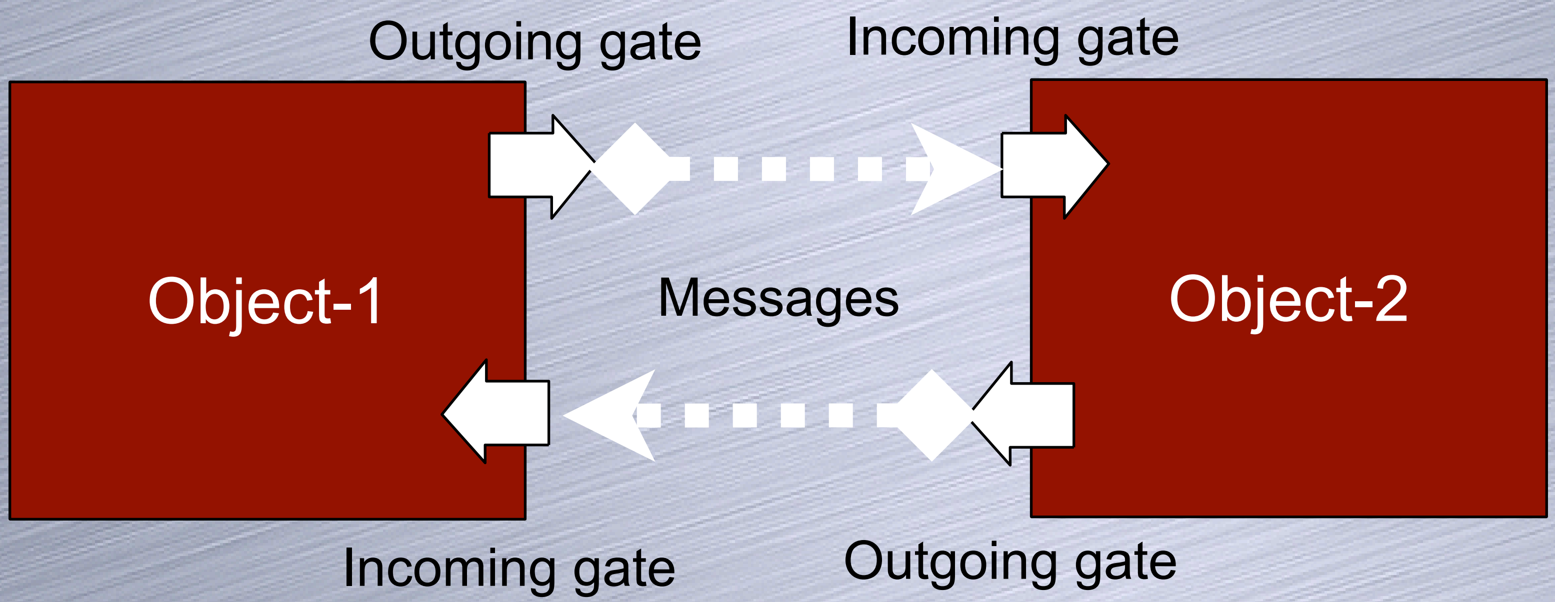
Compilation Basics

Compiling a sample program

- Go to HelloWord program directory:
  - > cd sample_programs/common/HelloWord
- Compile the program:
  - > make; make install
- Transfer the program to the MS:
  - > cp -r HelloWord/MS/OPEN-R MS/
- Insert MS on Aibo and switch it on
- Telnet to Aibo to see the result:
  - > telnet 147.83.60.22x 59000

Objects communication

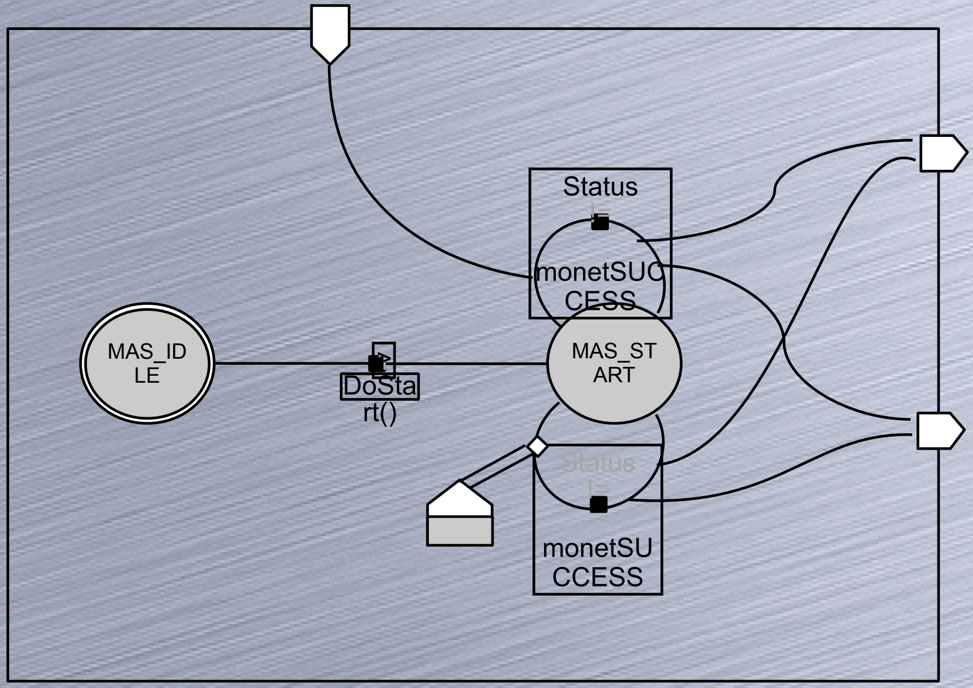
- Objects communicate trough **gates** by using message passing



- Gates are **unidirectional** and are **identified by a name**
- ObjectComm sample program

Objects communications

- *Objects are composed of **internal states**.*
- *Transitions between states are started by reception of messages from other objects (event oriented programming)*



*The sender of the message is called the **subject**. The receiver is called the **observer***

Messages can be of any type of data.

*The **Assert_Ready** (AR) message indicates readiness*

Objects Communication

- Subjects are referred by the **subject[]** array and observers by **observer[]**

To send a message

1. Initialize message's contents

```
strcpy(str, "!!! Hello world !!!");
```

2. Assign message

```
subject[sbjSendString]->SetData(str, sizeof(str));
```

3. Notify observer

```
subject[sbjSendString]->NotifyObservers();
```

To receive a message

1. Retrieve message by casting

```
const char* text = (const char *)event.Data(0);
```

2. Process message

```
OSYSPRINT(("SampleObserver::Notify() %s\n", text));
```

3. Send AR to subject

```
observer[event.ObsIndex()]->AssertReady();
```

Objects Communication

- The **stub.cfg** file defines the gates of the object. May require Dummy gates

```
ObjectName : SampleObserver
NumOfOSubject   : 1
NumOfOObserver  : 1
Service : "SampleObserver.DummySubject.DoNotConnect.S", null, null
Service : "SampleObserver.ReceiveString.char.O", null, Notify()
```

- The **connect.cfg** file defines how objects connect to each other

```
SampleSubject.SendString.char.S SampleObserver.ReceiveString.char.O
```

- **object.cfg** contains list of objects to execute

```
/MS/OPEN-R/MW/OBJS/POWERMON.BIN
/MS/OPEN-R/MW/OBJS/SUBJECT.BIN
/MS/OPEN-R/MW/OBJS/OBSERVER.BIN
```

Objects Communication

An object's life

Object initialised: send AR to subjects

Object waits on a state for a message from one of its subjects

When received a message, the object activates a method to process it

When message processed, it sends an AR message to the subject

Virtual Functions

DoInit procedure

- Called when object loaded in memory
- Sets up gates and registers observers and subjects of the object
- Use OPEN-R macros to do the job

```
OStatus
SampleObserver::DoInit(const
OSystemEvent& event)
{
NEW_ALL_SUBJECT_AND_OBSERVER;
REGISTER_ALL_ENTRY;

SET_ALL_READY_AND_NOTIFY_ENTRY;
return oSUCCESS;
}
```

Virtual Functions

DoStart procedure

- Called when DoInit finished in all objects
- Sends AR message to all observers
- May change from IDLE to another state
- Use OPEN-R macros to do the job

```
OStatus
SampleObserver::DoStart(const
OSystemEvent& event)
{
ENABLE_ALL_SUBJECT;

ASSERT_READY_TO_ALL_OBSERVER;
    return oSUCCESS;
}
```

Virtual Functions

DoStop procedure

- Called at shutdown of the system
- Sends NAR message to all observers
- May change to IDLE state
- Use OPEN-R macros to do the job

```
OStatus
SampleObserver::DoStop(const
OSystemEvent& event)
{
DISABLE_ALL_SUBJECT;

DEASSERT_READY_TO_ALL_
OBSERVER;
    return oSUCCESS;
}
```

Virtual Functions

DoDestroy procedure

- Called after DoStop finished in all objects
- Deletes all objects
- Use OPEN-R macros to do the job

```
OStatus
SampleObserver::DoDestroy(const
OSystemEvent& event)
{

DELETE_ALL_SUBJECT_AND_OBSERVER;
    return oSUCCESS;
}
```

Sensors

System Objects

Two system objects

- **OVirtualRobotComm** is in charge of the access to sensors, actuators and camera
- **OVirtualAudioComm** is in charge of all the things related to sound (play and record)

Programmer's objects must communicate with them in order to obtain sensors and audio values, and to send commands to actuators

They act like any other OPEN-R object

Primitives

- *Any sensor and actuator is defined by its own* ***primitive locator***

  Ex:

"PRM:/a1-Sensor:a1",   // ACCELEROMETER Y

- *To access a sensor or actuator, a* ***primitive ID*** *is required.*
- *Translation from primitive locator to primitive ID is done by the* ***OPENR::OpenPrimitive*** *call:*

```
for (int i = 0; i < NUM_ERS7_SENSORS; i++)
    result = OPENR::OpenPrimitive(ERS7_SENSOR_LOCATOR[i], &sensorID);
```

Specifying connection

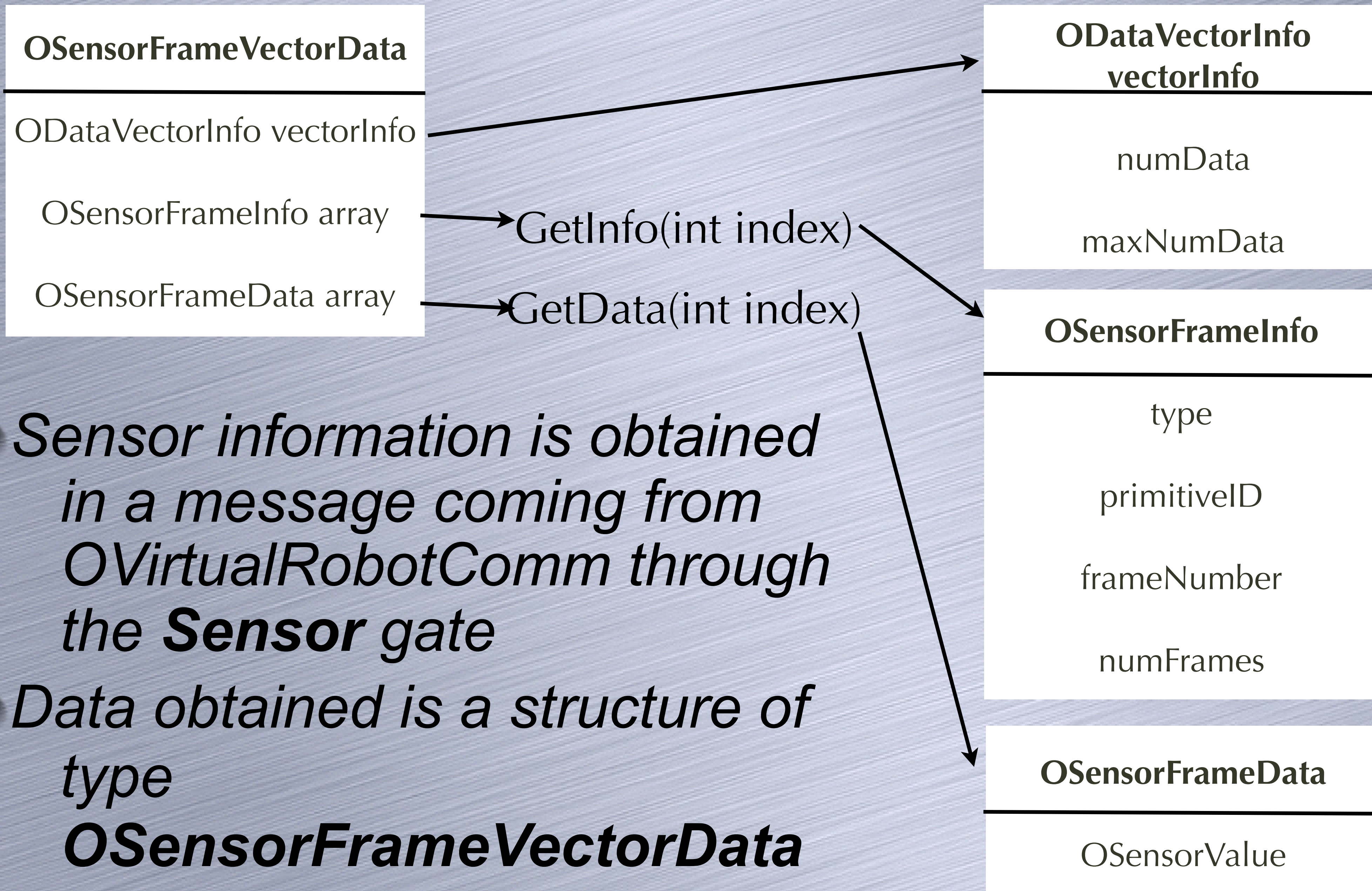
- Sensor values are delivered in **frames** of 8ms
- Connection to OVirtualRobotComm must be specified.
  - Create a gate in stub.cfg and define handling proc.

```
ObjectName : SensorObserver7
NumOfOSubject   : 1
NumOfOObserver  : 1
Service : "SensorObserver.SensorERS7.OSensorFrameVectorData.O", null, NotifyERS7()
Service : "SensorObserver.DummySubject.DoNotConnect.S", null, null
```

  - Define the connection in connect.cfg.

```
OVirtualRobotComm.Sensor.OSensorFrameVectorData.S
SensorObserver.SensorERS7.OSensorFrameVectorData.O
```

Message Data



- *Sensor information is obtained in a message coming from OVirtualRobotComm through the* ***Sensor*** *gate*
- *Data obtained is a structure of type* ***OSensorFrameVectorData***

Accessing Values

Steps to access a value (1/2)

- A message is received from OVirtualRobotComm. The associated routine is activated.
- Get primitive ID of sensor you want to access, and identify it inside the OSensorFrameInfo array

```
for (int j = 0; j < sensorVec->vectorInfo.numData; j++) {
        OSensorFrameInfo* info = sensorVec->GetInfo(j);
        if (info->primitiveID == sensorID) {
            ers7idx[i] = j;
            break;
        }
}
```

Accessing Values

Steps to access a value (2/2)

- Use the index obtained to access the actual values at the OSensorFrameData
- Process the data and send the AR message when finished

```
void SensorObserver7::NotifyERS7(const ONotifyEvent& event)
{
    OSensorFrameVectorData* sensorVec = (OSensorFrameVectorData*)event.Data(0);
    if (initSensorIndex == false) {
        InitERS7SensorIndex(sensorVec);
        initSensorIndex = true;    }
    OSYSPRINT(("ERS-7 numData %d frameNumber %d\n",
            sensorVec->vectorInfo.numData, sensorVec->info[0].frameNumber));
    PrintERS7Sensor(sensorVec);
    observer[event.ObsIndex()]->AssertReady();
}
```

Accessing Values

```
void
SensorObserver7::PrintSensorValue(OSensorFrameVectorData* sensorVec, int index)
{
    [...]

    OSensorFrameData* data = sensorVec->GetData(index);
    OSYSPRINT(("[%2d] val    %d %d %d %d\n",
            index,
            data->frame[0].value, data->frame[1].value,
            data->frame[2].value, data->frame[3].value));
[...]
}
void
SensorObserver7::PrintJointValue(OSensorFrameVectorData* sensorVec, int index)
{
[...]
    OSensorFrameData* data = sensorVec->GetData(index);
    OJointValue* jval = (OJointValue*)data->frame;
    OSYSPRINT(("[%2d] val    %d %d %d %d\n", index, jval[0].value, jval[1].value,
            jval[2].value, jval[3].value));
[...]
}
```

A casting must be performed!

Actuators

Actuators

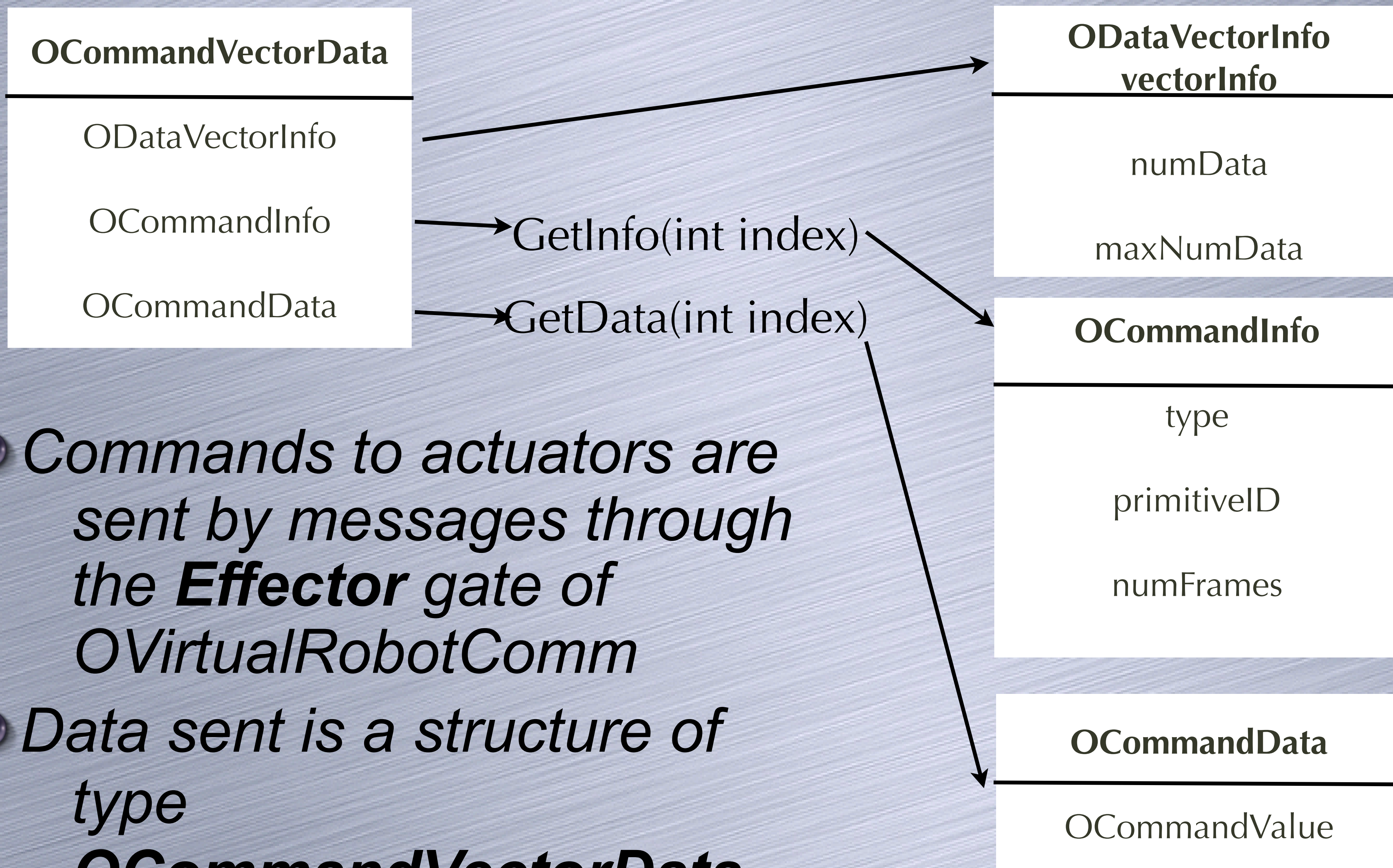
- Actuator values are delivered in **frames** of 8ms
- Connection to OVirtualRobotComm must be specified.
  - Create a gate in stub.cfg and define handling proc.

```
ObjectName : MovingHead7
NumOfOSubject   : 1
NumOfOObserver  : 1
Service : "MovingHead7.Move.OCommandVectorData.S", null, Ready()
Service : "MovingHead7.DummyObserver.DoNotConnect.O", null, null
```

  - Define the connection in connect.cfg.

```
MovingHead7.Move.OCommandVectorData.S
OVirtualRobotComm.Effector.OCommandVectorData.O
```

Actuators



- *Commands to actuators are sent by messages through the* ***Effector*** *gate of OVirtualRobotComm*
- *Data sent is a structure of type* ***OCommandVectorData***

Accessing actuators: steps

- Initializing the system
- Getting primitive IDs
- Setting joints gains (only for joints)
- Calibrating the joints (only for joints)
- Selecting a shared memory region
- Setting the effector value

Accessing actuators

- Initializing the motor system (only for joints)

```
OPENR::SetMotorPower(opowerON)
```

- Getting primitive IDs

```
static const char* const JOINT_LOCATOR[] = {
    "PRM:/r1/c1-Joint2:11",      // TILT1
    "PRM:/r1/c1/c2-Joint2:12",   // PAN
    "PRM:/r1/c1/c2/c3-Joint2:13" // TILT2
};
OPrimitiveID      jointID[NUM_JOINTS];
MovingHead7::OpenPrimitives()
{
    for (int i = 0; i < NUM_JOINTS; i++) {
        OStatus result = OPENR::OpenPrimitive(JOINT_LOCATOR[i],
        &jointID[i]);
[...]
}
```

Setting Joints Gains

- Define joint gains values, usually in *.h

```
static const word   TILT1_PGAIN         = 0x000a;
static const word   TILT1_IGAIN         = 0x0004;
static const word   TILT1_DGAIN         = 0x0002;
```

- Enable and set the gains

```
void MovingHead7::SetJointGain()
{
    OPENR::EnableJointGain(jointID[TILT1_INDEX]);
    OPENR::SetJointGain(jointID[TILT1_INDEX],
                        TILT1_PGAIN,
                        TILT1_IGAIN,
                        TILT1_DGAIN,
                        PSHIFT, ISHIFT, DSHIFT);
[...]
}
```

Calibrating the Joints

- Reads the actual value of the joints and applies it to them for calibration

```
MovingResult
MovingHead7::AdjustDiffJointValue()
{
    OJointValue current[NUM_JOINTS];
    for (int i = 0; i < NUM_JOINTS; i++) {
        OPENR::GetJointValue(jointID[i], &current[i]);
        SetJointValue(region[0], i,
                      degrees(current[i].value/1000000.0),
                      degrees(current[i].value/1000000.0));
    }

    subject[sbjMove]->SetData(region[0]);
    subject[sbjMove]->NotifyObservers();

    return MOVING_FINISH;
}
```

Selecting a RCRegion

First step: creating RCRegions

- Commands are not directly sent to effectors: we use **shared memory regions** of type **RCRegion**.
- RCRegions act like a buffer, bringing smoothness and allowing large commands
- Steps for the creation of a RCRegion:
  - Create a command structure
  - Create an RCRegion assigning the command structure
  - Fill in the RCRegion with the general parameters required for the command that will contain

Selecting a RCRegion

First step: creating RCRegions

- Create the command structure

```
void MovingHead7::NewCommandVectorData()
result = OPENR::NewCommandVectorData(NUM_JOINTS,
                                     &cmdVecDataID, &cmdVecData);
```

- Create the RCRegion

```
region[i] = new RCRegion(cmdVecData->vectorInfo.memRegionID,
                         cmdVecData->vectorInfo.offset,
                         (void*)cmdVecData,
                         cmdVecData->vectorInfo.totalSize);
```

- Fill the RCRegion with command data

```
cmdVecData->SetNumData(NUM_JOINTS);
for (int j = 0; j < NUM_JOINTS; j++) {
     info = cmdVecData->GetInfo(j);
     info->Set(odataJOINT_COMMAND2, jointID[j],
   ocommandMAX_FRAMES);
}
```

Selecting a RCRegion

Second step: selecting RCRegions for commands

- When required a memory region is selected where to put the effector command.

```
RCRegion*  MovingHead7::FindFreeRegion()
{
    for (int i = 0; i < NUM_COMMAND_VECTOR; i++) {
        if (region[i]->NumberOfReference() == 1) return
        region[i];
    }
    return 0;
}
```

Setting the effector value

- After selecting a region, the initial and final values of the joint are calculated. Then, a **user function** is called to perform the actual sequence of frame commands

```
RCRegion* rgn = FindFreeRegion();
OSYSDEBUG(("FindFreeRegion()%x \n", rgn));
SetJointValue(rgn, TILT1_INDEX, s_tilt1, s_tilt1 + d_tilt1);
SetJointValue(rgn, PAN_INDEX,   s_pan,   s_pan   + d_pan);
SetJointValue(rgn, TILT2_INDEX, s_tilt2, s_tilt2 + d_tilt2);
```

Setting the effector value

- The user function implements the filling of the RCRegion with a **sequence of data**, indicating the value the effector must have at each frame

```
void
MovingHead7::SetJointValue(RCRegion* rgn, int idx, double start, double end)
                                              {
    OCommandVectorData* cmdVecData = (OCommandVectorData*)rgn->Base();

    OCommandInfo* info = cmdVecData->GetInfo(idx);
    info->Set(odataJOINT_COMMAND2, jointID[idx], ocommandMAX_FRAMES);

    OCommandData* data = cmdVecData->GetData(idx);
    OJointCommandValue2* jval = (OJointCommandValue2*)data->value;

    double delta = end - start;
    for (int i = 0; i < ocommandMAX_FRAMES; i++) {
        double dval = start + (delta * i) / (double)ocommandMAX_FRAMES;
                                   jval[i].value = oradians(dval);
    }
}
```

Setting the Effector Value

- Finally, we put the data (that is in the RCRegion) in the gate that communicates with the OVirtualRobotComm, and notify it that a new command is there.

```
subject[sbjMove]->SetData(rgn);
subject[sbjMove]->NotifyObservers();
```

Neural Controller

Description of the problem

- Creation of an OPEN-R program that must make oscillate each joint of one of Aibo's legs.
- One feedforward neural network for each joint
- Network weights have previously obtained by training in simulation
- Feedforward C++ object and weights for the three nets are provided

Description of the Problem

- Neural nets must be composed of:
  - two input units: 1st indicates present state of joint, 2nd indicates previous step state
  - five hidden units, with bias
  - one output unit, indicating the velocity to apply to the joint
- Time step is maxNUMFRAMES * 8 ms = 128 ms
- Use OPENR::GetJointValue function to read sensors

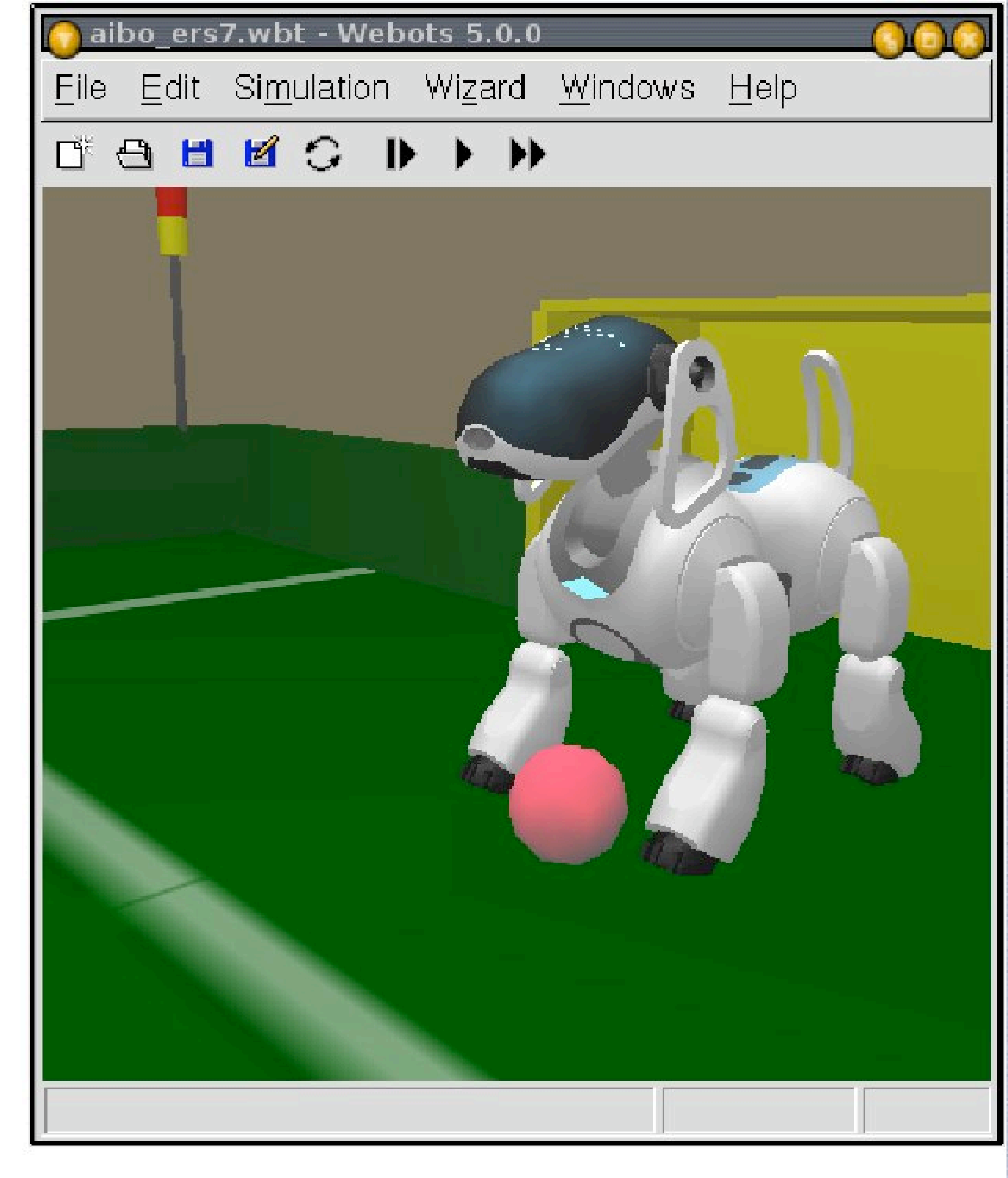
Design steps

1. Generate the configuration files
2. Write virtual functions
3. Calculate primitive IDs
4. Create shared memory regions
5. Set joints gains and calibrate them
6. Create the Ready function
7. Implement the neural controller
8. Create the SetJointValue function

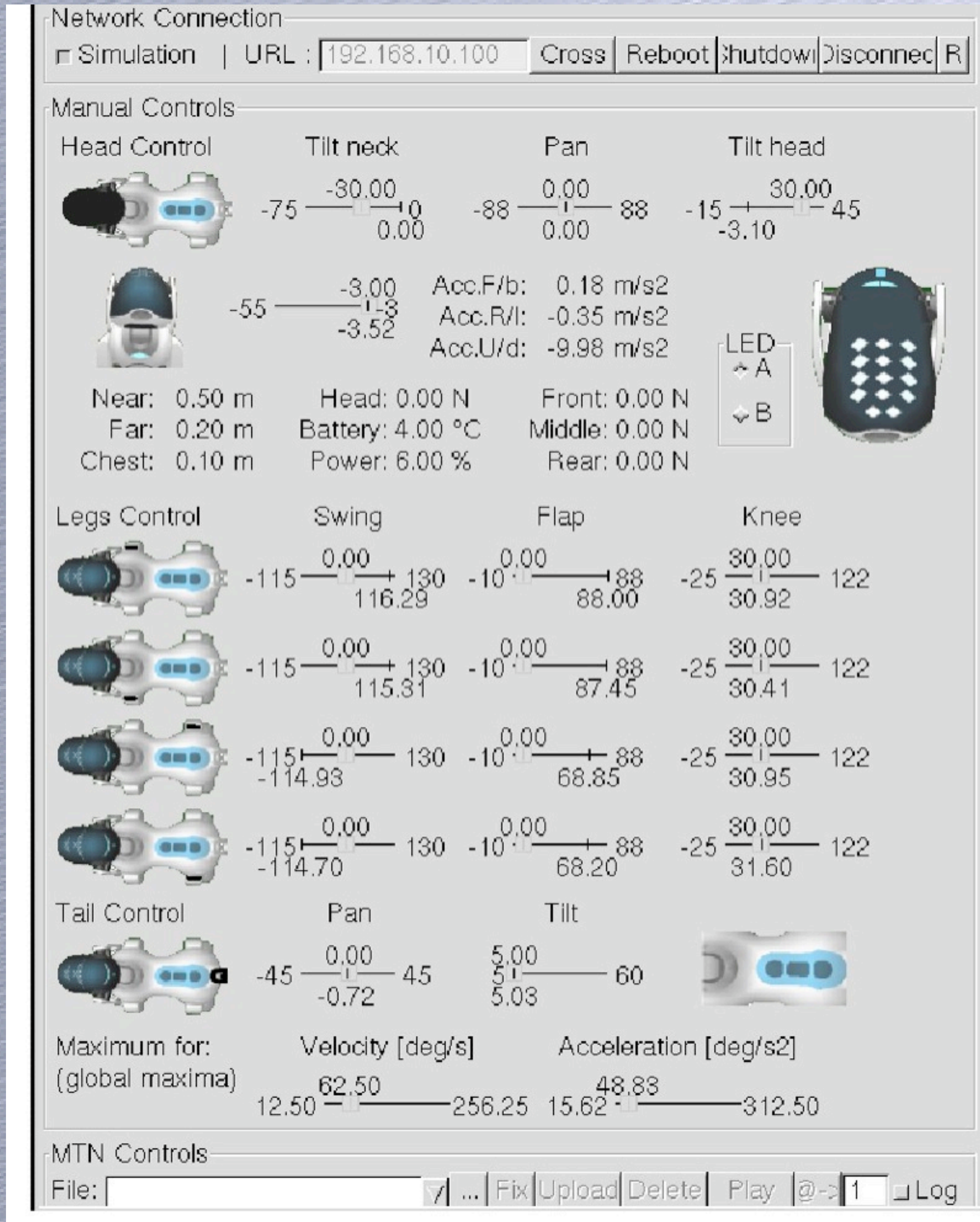
Webots-Aibo session

Webots Control

- To remotely control Aibo through Webots, installation of the Webots server on a MS is required



Control Panel



- The control panel allows for:
  - Read sensor data from the robot
  - Act on the robot effectors
  - Reproduce MTN files

Cross-Compilation

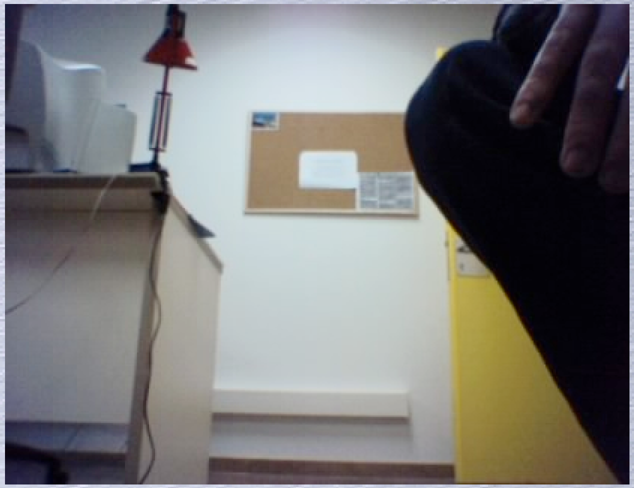
- We will use the ers7_mimic controller
- Use three different files for compilation
  - The *Makefile* file to compile Webots controller
  - The *Makefile.sources* file to specify which files should be cross-compiled
  - The *Makefile.openr* to cross-compile
- For cross-compilation type

  >make -f Makefile.openr
- Objects to install in the MS are at the OPEN-R directory generated in the controller directory

Camera

Camera Data

- Images can be received in three different resolutions (layers)
- An additional layer for color detection
- Images are received in YCrCb format



Camera Data

- Camera can be configured in **gain**, **white balance** and **shutter speed**
- Images from Aibo's camera are received in messages coming from OVirtualRobotComm through the **FbkImageSensor** gate

Camera Message

- Specify the connection to the virtual object at *stub.cfg*

```
ObjectName : ImageObserver
NumOfOSubject    : 1
NumOfOObserver   : 1
Service : "ImageObserver.Image.OFbkImageVectorData.O", null, Notify()
Service : "ImageObserver.DummySubject.DoNotConnect.S", null, null
```

- And connect the objects at *connect.cfg*

```
OVirtualRobotComm.FbkImageSensor.OFbkImageVectorData.S
ImageObserver.Image.OFbkImageVectorData.O
```

Obtaining the layers

- Obtain the image message

```
OFbkImageVectorData* fbkImageVectorData
        = (OFbkImageVectorData*)event.Data(0);
```

- And obtain the layers

```
void ImageObserver::SaveRawData(char* path,
                                OFbkImageVectorData* imageVec,
                            OFbkImageLayer layer)
{
    OFbkImageInfo* info = imageVec->GetInfo(layer);
    byte*          data = imageVec->GetData(layer);
    size_t size;
    if (layer == ofbkimageLAYER_C) {
        size = info->width * info->height;
    } else { // ofbkimageLAYER_H or ofbkimageLAYER_M or
      ofbkimageLAYER_L
        if (info->type == odataFBK_YCrCb) {
            size = 3 * info->width * info->height;
        } else if (info->type == odataFBK_YCrCb_HPF) {
            size = 6 * info->width * info->height;
        }
```