

SIMCEO

Simulink Client

CEO Server

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Contents

1	Introduction	4
2	Installation	4
2.1	AWS command line interface	4
2.2	Matlab-ZMQ	4
2.3	UBJSON	5
3	Implementation	5
4	The <code>simulink</code> python module	5
4.1	The broker class	8
4.2	The S classes	11
4.2.1	The SGMT class	11
	Start	12
	Update	12
	InitializeConditions	13
	Outputs	13
4.2.2	The SATmosphere class	14
4.2.3	The SOpticalPath class	14
	Start	15
	Terminate	16
	Update	17
	Outputs	17
	InitializeConditions	19
4.3	The CalibrationMatrix class	24
4.4	The Sensor abstract class	26
5	The <code>ceo</code> Matlab package	27
5.1	The broker class	27
5.1.1	<code>run_instance</code>	30
5.1.2	<code>terminate_instance</code>	31
5.1.3	<code>start_instance</code>	32
5.2	The dealer class	37
5.2.1	Public methods	40
5.2.2	Private methods	42
5.3	The <code>loadprm</code> function	45
5.4	The SCEO S-function	45
5.4.1	<code>setup</code>	46
5.4.2	<code>Start</code>	47
5.4.3	<code>Outputs</code>	47
5.4.4	<code>Terminate</code>	48
5.5	The block masks	49
5.5.1	Optical Path	49
5.5.2	GMT Mirror	53

6	The CEO server	54
7	Index	56
8	List of code chunks	56

1 Introduction

This document describes SIMCEO, an interface between CEO and Simulink. SIMCEO allows to seamlessly integrate CEO functionalities into a Simulink model. A Simulink library, *CEO*, provides a set of blocks that are used to instantiate CEO objects. The blocks either send data to the CEO objects updating the state of these objects, or query data from the CEO objects. The data received from the CEO objects is then forwarded to the other blocks of the Simulink model.

2 Installation

This section describes the installation of the SIMCEO client i.e. the Matlab and Simulink part of SIMCEO.

To install SIMCEO on your computer, creates a directory **SIMCEO**, downloads the archive **simceo.zip** and extracts it in the **SIMCEO** directory.

In addition to Matlab and Simulink, the client relies on aws cli, ZeroMQ and UBJSON.

2.1 AWS command line interface

The AWS command line interface (**aws cli**) allows to launch/terminate and to start/stop the AWS instances where the SIMCEO server resides. To install it, follows the instructions at

<http://docs.aws.amazon.com/cli/latest/userguide/installing.html>

Once installed, open a terminal and at the shell prompt enter:

```
>> aws configure --profile gmto.control
```

and answers the questions using the **gmto.control.credentials** file provided separately.

At Matlab prompt enter: `>> system('aws --version')`. If Matlab cannot find **aws**, replace **aws** in **etc/simceo.json** by the full path to **aws**.

2.2 Matlab-ZMQ

Matlab-ZMQ¹ is a Matlab wrapper for ZeroMQ. ZeroMQ² is the messaging library used for the communications between SIMCEO client and server. Both Matlab-ZMQ and ZeroMQ are shipped pre-compiled with SIMCEO. You need however to add, to the Matlab search path, the path to ZeroMQ. To do so, move Matlab current folder to SIMCEO folder and at the Matlab prompt enter:

```
>> addpath([pwd, '/matlab-zmq/your-os/lib/'])
```

```
>> savepath
```

where **your-os** is either **unix**, **mac** **windows7** or **windows10**.

¹<https://github.com/fagg/matlab-zmq>

²<http://zeromq.org/>

2.3 UBJSON

Universal Binary JSON (UBJSON³) is the message format used to exchange data between SIMCEO client and server. The Matlab UBJSON encoder and decoder is JSONLAB. SIMCEO comes with its own version of JSONLAB that fixes a few bugs. To add JSONLAB to the Matlab search path, move Matlab current folder to SIMCEO folder and at the Matlab prompt enter:

```
>> addpath([pwd,'/jsonlab/'])
>> savepath
```

3 Implementation

The interface between CEO and Simulink has two components a Matlab package *ceo* on the user computer, the client, and a python module *simulink* on a CEO AWS instance, the server. A flowchart of SIMCEO is shown in Fig. 3. The Matlab package is written with custom blocks using a *Level-2 Matlab S-function*. A *Level-2 Matlab S-function* consists in a collection of functions that are called by the Simulink engine when a model is running. Inside the *Level-2 Matlab S-function*, the functions *Start*, *Terminate* and *Outputs* are used to exchange information with CEO. The Matlab class *broker* is responsible for starting the CEO server in the AWS cloud and for managing the communication with the server.

The requests from the client are managed by the *broker* class of the *simulink* python module on the server. The *simulink* module is providing three python classes to deal with Simulink requests: *SGMT*, *SAtmosphere* and *SOpticalPath*.

The communication between the client and the server uses the Request/Reply messaging pattern of ZeroMQ. The messages exchanged between the client and the server are formatted according to the UBJSON format.

4 The simulink python module

The python interface consists in the module *simulink*:

```
5 <simceo.py 5>≡
    import sys
    import threading
    import time
    import zmq
    import ubjson
    import ceo
    import numpy as np
    from collections import OrderedDict
    import os
```

³<http://ubjson.org/>

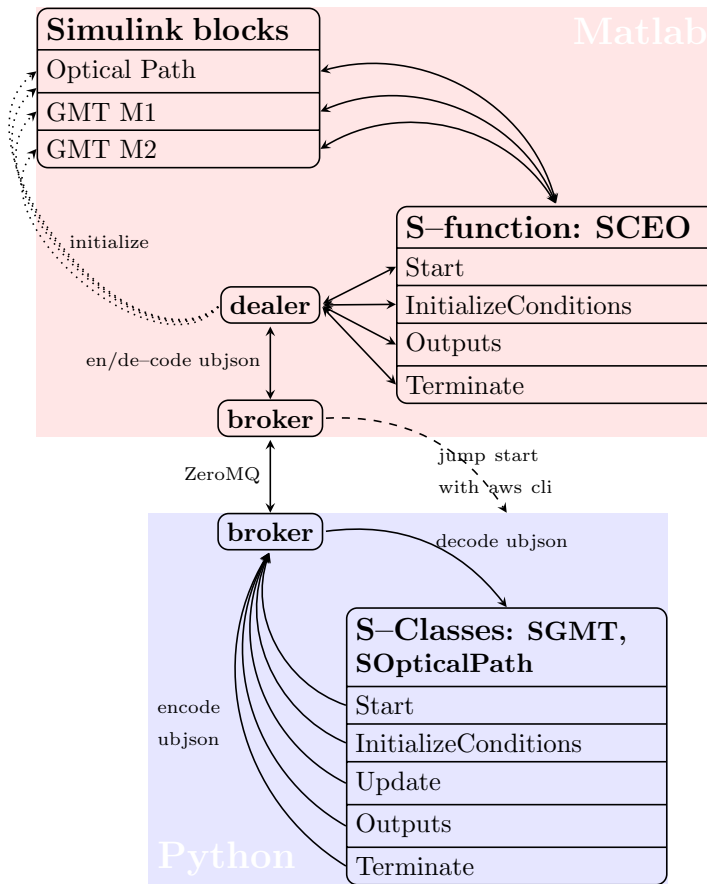


Figure 1: SIMCEO flowchart.

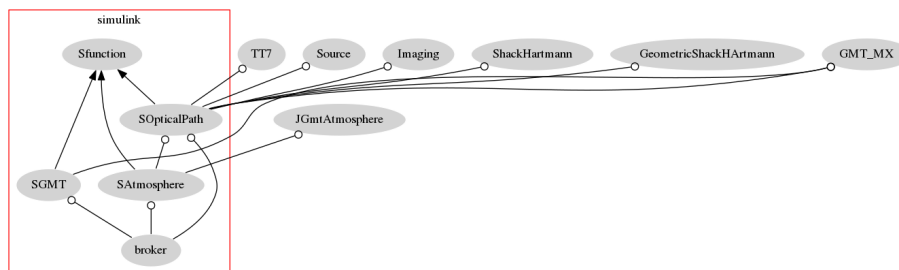


Figure 2: The classes in the simulink python module and their relations with the CEO classes.

```

import shelve
import traceback
import scipy.linalg as LA

SIMCEOPATH = os.path.abspath(os.path.dirname(__file__))
currentTime = 0.0;

class testComm:
    def __init__(self):
        pass
    def hello(self,N=1):
        data = np.ones(N)
        return dict(data=data.tolist())

class Timer(object):
    def __init__(self, name=None):
        self.name = name

    def __enter__(self):
        self.tstart = time.time()

    def __exit__(self, type, value, traceback):
        if self.name:
            print "[%s]" % self.name,
            print 'Elapsed time: %s' % (time.time() - self.tstart)

<CalibrationMatrix 24>

<S-function 11a>

<SGMT 11b>
<SAtmosphere 14a>
<SOpticalPath 14b>

<broker 8a>

if __name__ == "__main__":

    print "*****"
    print "**    STARTING SIMCEO SERVER    **"
    print "*****"
    agent = broker()
    agent.start()

```

4.1 The broker class

The broker class receives requests from the Simulink S-functions, processes the requests and sends a replies to the Simulink client. It inherits from the *threading.Thread* class.

```
8a  <broker 8a>≡ (5)
    class broker(threading.Thread):

        def __init__(self):

            threading.Thread.__init__(self)

            self.context = zmq.Context()
            self.socket = self.context.socket(zmq.REP)
            self.address = "tcp://*:3650"
            self.socket.bind(self.address)

            self.ops = []
            self.n_op = 0
            self.satm = SATmosphere(self.ops)
            self.sgmt = SGMT(self.ops, self.satm)

        def __del__(self):

            self.release()

        def release(self):

            self.socket.close()
            self.context.term()

        <broker get item 10a>

        <broker run 8b>
        The run method
8b  <broker run 8b>≡ (8a)
        def run(self):

            while True:

                <broker run details 9a>
```


waits for a request from a Simulink S-function:

```
9a  <broker run details 9a>≡ (8b) 9b>
    msg = self.socket.recv()
    #jmsg = ubjson.loadb(msg)
    try:
        jmsg = ubjson.loadb(msg)
    except Exception as E:
        #print "Error raised by ubjson.loadb by that does not stop us!"
        print msg
        raise
```

The message received from the S-function contains

- the Simulink simulation time *currentTime*,
- a class identifier, *class_id*: **GMT** for *SGMT*, **ATM** for *SAtmosphere* or **OP** for *SOpticalPath*,
- a method identifier, *method_id*: **Start**, **Terminate**, **Update** or **Outputs**,
- a dictionary of the arguments to the method, *args*.

The class method is invoked with:

```
9b  <broker run details 9a>+≡ (8b) <9a 10b>
    global currentTime
    currentTime = float( jmsg["currentTime"][0][0] )
    class_id = jmsg["class_id"]
    method_id = jmsg["method_id"]
    #print "@ %.3fs: %s->%s"%(currentTime,jmsg["tag"],method_id)
    #tid = ceo.StopWatch()
    try:
        #tid.tic()
        args_out = getattr( self[class_id], method_id )( **jmsg["args"] )
        #tid.toc()
        #print "%s->%s: %.2f"%(class_id,method_id,tid.elapsedTime)
    except Exception as E:
        print "@(broker)> The server has failed!"
        print jmsg
        traceback.print_exc()
        print "@(broker)> Recovering gracefully..."
        class_id = ""
        args_out = "The server has failed!"
```

The dictionary-like call is implemented with

```

10a  <broker get item 10a>≡ (8a)
def __getitem__(self, key):
    if key=="GMT":
        return self.sgmt
    elif key=="ATM":
        return self.satm
    elif key[:2]=="OP":
        if key[2:]:
            op_idx = int(key[2:]) - self.n_op + len(self.ops)
            return self.ops[op_idx]
        else:
            self.ops.append( SOpticalPath( len(self.ops) ,
                                           self.sgmt.gmt ,
                                           self.satm ) )

            self.n_op = len(self.ops)
            return self.ops[-1]
    elif key=='testComm':
        return testComm()
    else:
        raise KeyError("Available keys are: GMT, ATM or OP")

```

Each optical paths that is defined in the Simulink model is affected an unique ID tag made of the string **OP** followed by the index of the object in the optical path list *ops*. If the ID tag of the optical path is just **OP**, a new *SOpticalPath* object is instantiated and appended to the list of optical path.

When the *Terminate* method of an *SOpticalPath* object is called, the object is removed from the optical path list *ops*.

```

10b  <broker run details 9a>+≡ (8b) <9b 10c>
    if class_id[:2]=="OP" and method_id=="Terminate":
        self.ops.pop(0)

```

The value return by the method of the invoked object is sent back to the S-function:

```

10c  <broker run details 9a>+≡ (8b) <10b
    self.socket.send(ubjson.dumps(args_out,no_float32=True))

```

4.2 The S classes

The S classes, *SGMT*, *SAtmosphere* and *SOpticalPath*, are providing the interface with CEO classes. They mirror the *Level-2 Matlab S-functions* by implementing the same method *Start*, *InitializeConditions*, *Terminate*, *Update* and *Outputs*. Each method is triggered by the corresponding function in the Matlab S-function with the exception of the *Update* method that is triggered by the *Outputs* function of the S-function.

An abstract class, *Sfunction*, implements the four S-function method:

```
11a  <S-function 11a>≡ (5)
      from abc import ABCMeta, abstractmethod

      class Sfunction:
          __metaclass__ = ABCMeta
          @abstractmethod
          def Start(self):
              pass
          @abstractmethod
          def Terminate(self):
              pass
          @abstractmethod
          def Update(self):
              pass
          @abstractmethod
          def Outputs(self):
              pass
          @abstractmethod
          def InitializeConditions(self):
              pass
```

4.2.1 The SGMT class

The *SGMT* class is the interface class between a CEO *GMT_MX* object and a *GMT Mirror* Simulink block.

```
11b  <SGMT 11b>≡ (5) 12b>
      class SGMT(Sfunction):

          def __init__(self, ops, satm):
              self.gmt = ceo.GMT_MX()

          def Terminate(self, args=None):
              self.gmt = ceo.GMT_MX()
              return "GMT deleted!"
```

Start The message that triggers the call to the *Start* method is

12a $\langle SGMT \text{ Start message } 12a \rangle \equiv$

```
{
  "class_id": "GMT",
  "method_id": "Start",
  "args":
  {
    "mirror": "M1"|"M2",
    "mirror_args":
    {
      "mirror_modes": u"bending modes"|u"zernike",
      "N_MODE": 162,
      "radial_order": ...
    }
  }
}
```

12b $\langle SGMT \text{ } 11b \rangle + \equiv$

(5) $\langle 11b \text{ } 13a \rangle$

```
def Start(self,mirror=None,mirror_args=None):
    self.gmt[mirror] = getattr(ceo,"GMT_"+mirror)( **mirror_args )
    return "GMT"
```

Update The message that triggers the call to the *Update* method is

12c $\langle SOpticalPath \text{ Update message } 12c \rangle \equiv$

17b \triangleright

```
{
  "class_id": "GMT",
  "method_id": "Update",
  "args":
  {
    "mirror": "M1"|"M2",
    "inputs_args":
    {
      "TxyzRxyz": null,
      "mode_coefs": null
    }
  }
}
```

13a $\langle SGMT\ 11b \rangle + \equiv$ (5) $\langle 12b\ 13b \rangle$

```

def Update(self, mirror=None, inputs_args=None):
    for key in inputs_args:
        data = np.array( inputs_args[key], order='C', dtype=np.float64 )
        data = np.transpose( np.reshape( data , (-1,7) ) )
        if key=="TxyzRxyz":
            self.gmt[mirror].motion_CS.origin[:] = data[:, :3]
            self.gmt[mirror].motion_CS.euler_angles[:] = data[:, 3:]
            self.gmt[mirror].motion_CS.update()
        elif key=="mode_coefs":
            self.gmt[mirror].modes.a = np.copy( data, order='C')
            self.gmt[mirror].modes.update()

```

InitializeConditions

13b $\langle SGMT\ 11b \rangle + \equiv$ (5) $\langle 13a\ 13c \rangle$

```

def InitializeConditions(self, args=None):
    pass

```

Outputs

13c $\langle SGMT\ 11b \rangle + \equiv$ (5) $\langle 13b \rangle$

```

def Outputs(self, args=None):
    pass

```

4.2.2 The SATmosphere class

The *SATmosphere* class is the interface class between a CEO *GmtAtmosphere* object and a *Atmosphere* Simulink block.

```
14a  <SATmosphere 14a>≡ (5)
      class SATmosphere(Sfunction):

          def __init__(self, ops):
              self.atm = None

          def Start(self, **kwargs):
              self.atm = ceo.JGmtAtmosphere( **kwargs )
              return "ATM"

          def Terminate(self, args=None):
              self.atm = None
              return "Atmosphere deleted!"

          def InitializeConditions(self, args=None):
              pass

          def Outputs(self, args=None):
              pass

          def Update(self, args=None):
              pass
```

4.2.3 The SOpticalPath class

The *SOpticalClass* gathers a source object *src*, the GMT model object *gmt*, an atmosphere object *atm*, a sensor object *sensor* and a calibration source *calib_src*.

```
14b  <SOpticalPath 14b>≡ (5) 16a▷
      class SOpticalPath(Sfunction):

          def __init__(self, idx, gmt, satm):
              self.idx = idx
              self.gmt = gmt
              self.satm = satm
              self.sensor = None
```

Defines:

idx, used in chunk 16a.

sensor, used in chunks 16–18, 22, and 49.

Start The message that triggers the call to the *Start* method is

```
15  <SOpticalPath Start message 15>≡
    {
      "class_id": "OP",
      "method_id": "Start",
      "args":
        {
          "source_args": { ... } ,
          "sensor_class": null|"Imaging"|"ShackHartmann",
          "sensor_args": null|{ ... },
          "calibration_source": null|{ ... },...
          "miscellaneous_args": null|{...}
        }
    }
```

```

16a    <SOpticalPath 14b>+≡ (5) <14b 17a>
        def Start(self,source_args=None, sensor_class=None, sensor_args=None,
                    calibration_source_args=None, miscellaneous_args=None):

            #self.propagateThroughAtm = miscellaneous_args['propagate_through_atmosphere']
            self.src = ceo.Source( **source_args )

            if sensor_class is not None:

                self.sensor = getattr(ceo,sensor_class)( **sensor_args )
                if calibration_source_args is None:
                    self.calib_src = self.src
                else:
                    self.calib_src = ceo.Source( **calibration_source_args )

                self.src.reset()
                self.gmt.reset()
                self.gmt.propagate(self.src)
                self.sensor.reset()
                self.sensor.calibrate(self.src,0)
                #self.sensor.calibrate(self.calib_src, sensor_args['intensityThreshold'])
                #print "intensity_threshold: %f"%sensor_args['intensityThreshold']

                self.sensor.reset()
                self.comm_matrix = {}

                self.src>>filter(None,(self.gmt,self.sensor))

            return "OP"+str(self.idx)

```

Defines:

- exposure_start, never used.
- exposure_time, never used.
- propagateThroughAtm, never used.
- src, used in chunks 17c, 18b, and 22.

Uses idx 14b and sensor 14b.

Terminate The message that triggers the call to the *Terminate* method is

```

16b    <SOpticalPath Terminate message 16b>≡
        {
            "class_id": "OP",
            "method_id": "Terminate",
            "args":
                {
                    "args": null
                }
        }

```


17a $\langle SOpticalPath\ 14b \rangle + \equiv$ (5) $\langle 16a\ 17c \rangle$

```

def Terminate(self, args=None):
    return "OpticalPath deleted!"

```

Update The message that triggers the call to the *Update* method is

17b $\langle SOpticalPath\ Update\ message\ 12c \rangle + \equiv$ $\langle 12c \rangle$

```

{
  "class_id": "OP",
  "method_id": "Update",
  "args":
  {
    "inputs": null
  }
}

```

17c $\langle SOpticalPath\ 14b \rangle + \equiv$ (5) $\langle 17a\ 18a \rangle$

```

def Update(self, inputs=None):
    +self.src
    #self.src.reset()
    #self.gmt.propagate(self.src)
    #self.sensor.propagate(self.src)

```

Uses sensor 14b and src 16a.

Outputs The message that triggers the call to the *Outputs* method is

17d $\langle SOpticalPath\ Outputs\ message\ 17d \rangle \equiv$

```

{
  "class_id": "OP",
  "method_id": "Outputs",
  "args":
  {
    "outputs": ["wfe_rms"|"segment_wfe_rms"|"piston"|"segment_piston"|"ee80"]
  }
}

```

18a $\langle \text{SOpticalPath 14b} \rangle + \equiv$ (5) $\langle 17c \ 18b \rangle$

```
def Outputs(self, outputs=None):
    if self.sensor is None:
        doutputs = OrderedDict()
        for element in outputs:
            doutputs[element] = self[element]
    else:
        #+self.sensor
        self.sensor.process()
        doutputs = OrderedDict()
        for element in outputs:
            doutputs[element] = self[element]
        self.sensor.reset()

    return doutputs
```

Uses sensor 14b.

and the dictionary implementation is

18b $\langle \text{SOpticalPath 14b} \rangle + \equiv$ (5) $\langle 18a \ 22 \rangle$

```
def __getitem__(self, key):
    if key=="wfe_rms":
        return self.src.wavefront.rms(units_exponent=-6).tolist()
    elif key=="segment_wfe_rms":
        return self.src.phaseRms(where="segments",
                                   units_exponent=-6).tolist()
    elif key=="piston":
        return self.src.piston(where="pupil",
                                   units_exponent=-6).tolist()
    elif key=="segment_piston":
        return self.src.piston(where="segments",
                                   units_exponent=-6).tolist()
    elif key=="tip tilt":
        buf = self.src.wavefront.gradientAverage(1, self.src.rays.L)
        buf *= ceo.constants.RAD2ARCSEC
        return buf.tolist()
    elif key=="segment_tip tilt":
        buf = self.src.segmentsWavefrontGradient().T
        buf *= ceo.constants.RAD2ARCSEC
        return buf.tolist()
    elif key=="ee80":
        #print "EE80= %.3f or %.3f"%(self.sensor.ee80(from_ghost=False), self.sensor.ee80(from_ghost=True))
        return self.sensor.ee80(from_ghost=False).tolist()
    else:
        c = self.comm_matrix[key].dot( self.sensor.Data ).reshape(1,-1)
        return c.tolist()
```

Uses sensor 14b and src 16a.

InitializeConditions The message that triggers a call to the *InitializeConditions* method is

```
19  <SOpticalPath InitializeConditions message 19>≡                                20>
    {
      "class_id": "OP",
      "method_id": "InitializeConditions",
      "args":
        {
          "calibrations":
            {
              "M2_TT":
                {
                  "method_id": "calibrate",
                  "args":
                    {
                      "mirror": "M2",
                      "mode": "segment tip-tilt",
                      "stroke": 1e-6
                    }
                }
            },
          "pseudo_inverse":
            {
              "nThreshold": null
            },
          "filename": null
        }
    }
```

20 $\langle S_{\text{OpticalPath InitializeConditions message 19}} \rangle + \equiv$

$\langle 19 \ 21 \rangle$

```
{
  "class_id": "OP",
  "method_id": "InitializeConditions",
  "args":
  {
    "calibrations":
    {
      "M12_Rxyz": [
        {
          "method_id": "calibrate",
          "args":
          {
            "mirror": "M1",
            "mode": "Rxyz",
            "stroke": 1e-6
          }
        },
        {
          "method_id": "calibrate",
          "args":
          {
            "mirror": "M2",
            "mode": "Rxyz",
            "stroke": 1e-6
          }
        }
      ]
    },
    "pseudo-inverse":
    {
      "nThreshold": [0],
      "concatenate": true
    },
    "filename": null
  }
}
```

21 $\langle S_{\text{OpticalPath}} \text{ InitializeConditions message } 19 \rangle + \equiv$ 20

```

{
  "class_id": "OP",
  "method_id": "InitializeConditions",
  "args":
  {
    "calibrations":
    {
      "AGWS":
      {
        "method_id": "AGWS_calibrate",
        "args":
        {
          "decoupled": true,
          "stroke": [1e-6,1e-6,1e-6,1e-6,1e-6],
          "fluxThreshold": 0.5
        }
      }
    },
    "pseudo-inverse":
    {
      "nThreshold": [2,2,2,2,2,2,0],
      "insertZeros": [null,null,null,null,null,null,[2,4,6]]
    },
    "filename": null
  }
}

```

```

22    <SOpticalPath 14b>+≡(5) <18b
    def InitializeConditions(self, calibrations=None, filename=None,
                            pseudo_inverse=None):
    print "@(SOpticalPath:InitializeConditions)>"
    if calibrations is not None:
        if filename is not None:
            filepath = os.path.join(SIMCEOPATH,"calibration_dbs",filename)
            db = shelve.open(filepath)

            if os.path.isfile(filepath+".dir"):
                print " . Loading command matrix from existing database %s!"%filename
                for key in db:
                    C = db[key]
                    #C.nThreshold = [SVD_truncation[k]]
                    self.comm_matrix[key] = C
                    db[key] = C
                db.close()
                return

        with Timer():
            if len(calibrations)>1:
                for key in calibrations: # Through calibrations
                    calibs = calibrations[key]
                    if not isinstance(calibs,list):
                        calibs = [calibs]
                    D = []
                    for c in calibs: # Through calib
                        self.gmt.reset()
                        self.src.reset()
                        self.sensor.reset()
                        D.append( getattr( self.gmt, c["method_id"] )( self.sensor,
                                                                    self.src,
                                                                    **c["args"] ) )

                    self.gmt.reset()
                    self.src.reset()
                    self.sensor.reset()
                    C = ceo.CalibrationVault(D, **pseudo_inverse )
                    self.comm_matrix[key] = C
            else:
                for key in calibrations: # Through calibrations
                    calibs = calibrations[key]
                    #Gif not isinstance(calibs,list):
                    #    calibs = [calibs]
                    #GD = []
                    #for c in calibs: # Through calib
                    self.gmt.reset()

```

```

        self.src.reset()
        self.sensor.reset()
        C = getattr( self.gmt, calibs["method_id"] )( self.sensor,
                                                    self.src,
                                                    calibrationVaultKwargs=ps
                                                    **calibs["args"])

        self.gmt.reset()
        self.src.reset()
        self.sensor.reset()
        self.comm_matrix[key] = C

    if filename is not None:
        print " . Saving command matrix to database %s!"%filename
        db[str(key)] = C
        db.close()

```

Uses sensor 14b and src 16a.

4.3 The CalibrationMatrix class

The *CalibrationMatrix* class is a container for several matrices:

- the poke matrix D ,
- the eigen modes U, V and eigen values S of the singular value decomposition of $D = USV^T$
- the truncated inverse M of D , $M = V\Lambda U^T$ where

$$\begin{aligned}\Lambda_i &= 1/S_i, \quad \forall i < n \\ \Lambda_i &= 0, \quad \forall i \geq n\end{aligned}$$

```

24  <CalibrationMatrix 24>≡ (5)
    class CalibrationMatrix(object):

        def __init__(self, D, n,
                      decoupled=True, flux_filter2=None,
                      n_mode = None):
            print "@(CalibrationMatrix)> Computing the SVD and the pseudo-inverse..."
            self._n = n
            self.decoupled = decoupled
            if self.decoupled:
                self.nSeg = 7
                self.D = D
                D_s = [ np.concatenate([D[0][:,k*3:k*3+3],
                                         D[1][:,k*3:k*3+3],
                                         D[2][:,k*3:k*3+3],
                                         D[3][:,k*3:k*3+3],
                                         D[4][:,k*n_mode:k*n_mode+n_mode]],axis=1) for k in range(7)
                for k in range(7):
                    D_s[k][np.isnan(D_s[k])] = 0
                lenslet_array_shape = flux_filter2.shape

                ### Identification process
                # The non-zeros entries of the calibration matrix are identified by filtering
                # which are a 1000 less than the maximum of the absolute values of the matrix
                # collapsing (summing) the matrix along the mirror modes axis.
                Qxy = [ np.reshape( np.sum(np.abs(D_s[k])>1e-2*np.max(np.abs(D_s[k])),axis=1)),axis=1)
                # The lenslet flux filter is applied to the lenslet segment filter:
                Q = [ np.logical_and(X,flux_filter2) for X in Qxy ]
                # A filter made of the lenslet used more than once is created:
                Q3 = np.dstack(Q).reshape(flux_filter2.shape + (self.nSeg,))
                Q3clps = np.sum(Q3,axis=2)
                Q3clps = Q3clps>1
                # The oposite filter is applied to the lenslet segment filter leading to 7 val

```



```

        # one filter per segment and no lenslet used twice:
        self.VLs = [ np.logical_and(X,~Q3clps) for X in Q]

        # Each calibration matrix is reduced to the valid lenslet:
        D_sr = [ D_s[k][self.VLs[k].ravel(),:] for k in range(self.nSeg) ]
        print [ D_sr[k].shape for k in range(self.nSeg)]
        # Computing the SVD for each segment:
        self.UsVT = [LA.svd(X,full_matrices=False) for X in D_sr]

        # and the command matrix of each segment
        self.M = [ self.__recon__(k) for k in range(self.nSeg) ]
    else:
        self.D = np.concatenate( D, axis=1 )
        with Timer():
            self.U,self.s,self.V = LA.svd(self.D,full_matrices=False)
            self.V = self.V.T
            iS = 1./self.s
            if self._n>0:
                iS[-self._n:] = 0
            self.M = np.dot(self.V,np.dot(np.diag(iS),self.U.T))

def __recon__(self,k):
    iS = 1./self.UsVT[k][1]
    if self._n>0:
        iS[-self._n:] = 0
    return np.dot(self.UsVT[k][2].T,np.dot(np.diag(iS),self.UsVT[k][0].T))

@property
def nThreshold(self):
    "# of discarded eigen values"
    return self._n
@nThreshold.setter
def nThreshold(self, value):
    print "@(CalibrationMatrix)> Updating the pseudo-inverse..."
    self._n = value
    if self.decoupled:
        self.M = [ self.__recon__(k) for k in range(self.nSeg) ]
    else:
        iS = 1./self.s
        if self._n>0:
            iS[-self._n:] = 0
        self.M = np.dot(self.V,np.dot(np.diag(iS),self.U.T))

def dot( self, s ):
    if self.decoupled:
        return np.concatenate([ np.dot(self.M[k],s[self.VLs[k].ravel()]) for k in range(self.nSeg) ])

```

```

else:
    return np.dot(self.M,s)

```

4.4 The Sensor abstract class

```

26  <Sensor abstract class 26>≡
    class Sensor:
        __metaclass__ = ABCMeta
        @abstractmethod
        def calibrate(self):
            pass
        @abstractmethod
        def reset(self):
            pass
        @abstractmethod
        def analyze(self):
            pass
        @abstractmethod
        def propagate(self):
            pass
        @abstractmethod
        def process(self):
            pass

```

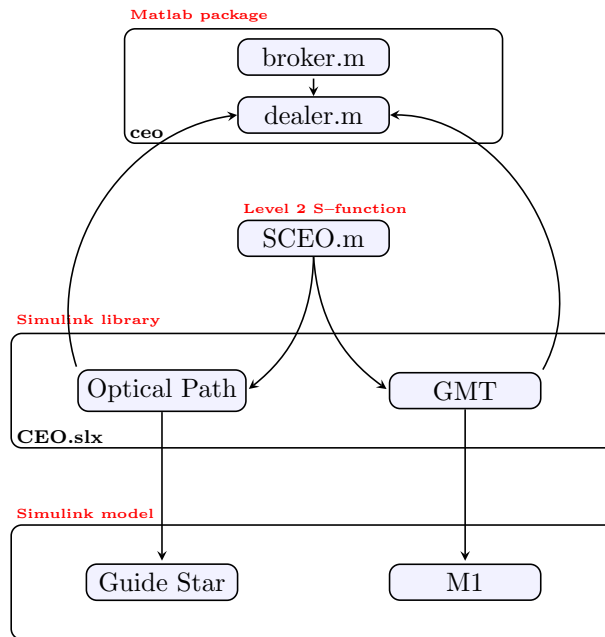


Figure 3: SIMCEO Matlab client flowchart.

5 The ceo Matlab package

5.1 The broker class

```

27 <broker.m 27>≡
    classdef (Sealed=true) broker < handle
        % broker An interface to a CEO server
        % The broker class launches an AWS instance and sets up the connection
        % to the CEO server

        properties
            awspath % full path to the AWS CLI
            instance_id % The AWS instance ID number
            public_ip % The AWS instance public IP
            zmqReset % ZMQ connection reset flag
            elapsedTime
        end

        properties (Access=private)
            etc
            instance_end_state
            ctx

```

```

        socket
    end

    methods

        <broker client 29a>

        <release ressources 33c>

        <launch AWS AMI 30a>

        <start AWS instance 32a>

        <terminate AWS instance 31c>
    end

    methods(Static)

        <instanciation and retrieval 34>

        <request and reply 35>

        <reset ZMQ socket 36a>

        <time spent 36b>

    end

end

Uses awspath 29a, etc 29a, instance_end_state 29b, instance_id 29a, public_ip 33a,
and zmqReset 29a.

```

The Matlab broker class starts an AWS machine and sets-up ZeroMQ context and socket.

29a $\langle broker client 29a \rangle \equiv$ (27)

```
function self = broker(varargin)

    self.ctx      = zmq.core.ctx_new();
    self.socket = zmq.core.socket(self.ctx, 'ZMQ_REQ');
    self.zmqReset = true;

    self.elapsedTime = 0;

    currentpath = mfilename('fullpath');
    k = strfind(currentpath,filesep);
    self.etc = fullfile(currentpath(1:k(end)),'..','etc');
    cfg = loadjson(fullfile(self.etc,'simceo.json'));
    self.awspath      = cfg.awsclipath;
    self.instance_id  = cfg.aws_instance_id;
     $\langle broker client: AWS instance launch 29b \rangle$ 
end
```

Defines:

awspath, used in chunks 27, 30–33, and 36a.
 etc, used in chunks 27, 30b, 31b, and 54.
 instance_id, used in chunks 27, 29–33, and 36a.
 self.elapsedTime, used in chunks 35 and 36b.
 zmqReset, used in chunks 27 and 36a.

If no instance ID is given, a new machine is launched based on a given AWS AMI.

29b $\langle broker client: AWS instance launch 29b \rangle \equiv$ (29a)

```
if isempty(self.instance_id)
    run_instance(self)
    self.instance_end_state = 'terminate';
else
    start_instance(self)
    self.instance_end_state = 'stop';
end
```

Defines:

instance_end_state, used in chunks 27 and 31c.

Uses instance_id 29a, run_instance 30a, and start_instance 32a.

5.1.1 run_instance

If no instance ID is set in the `simceo.json` configuration file, a new instance is created from the AMI whose ID is given in `etc/ec2runinst.json` file.

```
30a  <launch AWS AMI 30a>≡ (27)
      function run_instance(self)
          <launching an instance 30b>
          <waiting for the running state 32c>
          <waiting for initialization 30c>
          <branding instance 31a>
          <setting up cloudwatch 31b>
          <getting the public IP 33a>
      end
```

Defines:

`run_instance`, used in chunks 29b and 36a.

The sequence of operations is:

1. launching the instance,

```
30b  <launching an instance 30b>≡ (30a)
      cmd = sprintf(['%s ec2 run-instances --profile gmt0.control ',...
                    '--cli-input-json file://%s'],...
                    self.awspath, fullfile(self.etc,'ec2runinst.json'));
      [status,instance_json] = system(cmd);
      if status~=0
          error('Launching AWS AMI failed:\n%s',instance_json)
      end
      instance = loadjson(instance_json);
      self.instance_id = instance.Instances{1}(1).InstanceId;
```

Uses `awspath` 29a, `etc` 29a, and `instance_id` 29a.

2. waiting for the confirmation that the instance is running (See page 32),

3. waiting for the confirmation that the instance has finished to initialize,

```
30c  <waiting for initialization 30c>≡ (30a)
      fprintf('>>>> WAITING FOR AWS INSTANCE %s TO INITIALIZE ... \n',self.instance_id)
      fprintf('(This usually takes a few minutes!)\n')
      tic
      cmd = sprintf(['%s ec2 wait instance-status-ok --instance-ids %s ',...
                    '--profile gmt0.control'],...
                    self.awspath,self.instance_id);
      [status,~] = system(cmd);
      toc
      if status~=0
          error('Starting AWS machine %s failed!',self.instance_id')
      end
```

Uses `awspath` 29a and `instance_id` 29a.

4. setting up the instance name

```
31a  <branding instance 31a>≡ (30a)
      [~,username] = system('whoami');
      [~,hostname] = system('hostname');
      cmd = sprintf('%s ec2 create-tags --resources %s --tags Key=Name,Value=%s',...
                    self.awspath,self.instance_id,...
                    ['SIMCEO(',strtrim(username),...
                     '@',strtrim(hostname),')']);
      system(cmd);
      Uses awspath 29a and instance_id 29a.
```

5. setting up an alarm that terminates an instance idle for man than 4hours,

```
31b  <setting up cloudwatch 31b>≡ (30a)
      cmd = sprintf(['%s cloudwatch put-metric-alarm ',...
                    '--profile gmtto.control ',...
                    '--dimensions Name=InstanceId,Value=%s ',...
                    '--cli-input-json file://%s'],...
                    self.awspath,...
                    self.instance_id,...
                    fullfile(self.etc,'cloudwatch.json'));
      [status,~] = system(cmd);
      if status~=0
          error('Setting alarm for AWS machine %s failed!',self.instance_id')
      end
      Uses awspath 29a, etc 29a, and instance_id 29a.
```

6. getting the public IP of the instance (See page 33).

5.1.2 terminate_instance

```
31c  <terminate AWS instance 31c>≡ (27)
      function terminate_instance(self)
          if strcmp(self.instance_end_state,'terminate')
              fprintf('@(broker)> Terminating instance %s!\n',self.instance_id)
              [status,~] = system(sprintf(['%s ec2 %s-instances',...
                                           ' --instance-ids %s --profile gmtto.control'],...
                                           self.awspath, self.instance_end_state,...
                                           self.instance_id));

              if status~=0
                  error('Terminating AWS instance %s failed!',self.instance_id')
              end
          end
      end
      Defines:
          terminate_instance, used in chunk 33c.
      Uses awspath 29a, instance_end_state 29b, and instance_id 29a.
```

5.1.3 start_instance

If an instance ID has been set in the `simceo.json` configuration file, this instance is started.

```
32a  <start AWS instance 32a>≡ (27)
      function start_instance(self)
        <starting an instance 32b>
        <waiting for the running state 32c>
        <getting the public IP 33a>
      end
```

Defines:

`start_instance`, used in chunk 29b.

The sequence of operations is:

1. starting the instance:

```
32b  <starting an instance 32b>≡ (32a)
      cmd = sprintf(['%s ec2 start-instances --instance-ids %s',...
                    ' --profile gmto.control'],...
                    self.awspath,self.instance_id);
      fprintf('%s\n',cmd)
      fprintf('@(broker)> Starting AWS machine %s...\n',self.instance_id)
      [status,cmdout] = system(cmd);
      if status~=0
        error('Starting AWS machine %s failed:\n%s',self.instance_id,cmdout)
      end
```

Uses `awspath` 29a and `instance_id` 29a.

2. waiting for the confirmation that the instance is running

```
32c  <waiting for the running state 32c>≡ (30a 32a)
      fprintf('>>>> WAITING FOR AWS INSTANCE %s TO START ... \n',self.instance_id)
      tic
      [status,~] = system(sprintf(['%s ec2 wait instance-running --instance-ids %s',...
                                   ' --profile gmto.control'],...
                                   self.awspath,self.instance_id));
      toc
      if status~=0
        error('Starting AWS machine %s failed!',self.instance_id')
      end
```

Uses `awspath` 29a and `instance_id` 29a.

3. getting the public IP of the instance.

```
33a  <getting the public IP 33a>≡ (30a 32a)
      cmd = sprintf(['%s ec2 describe-instances --instance-ids %s',...
                    ' --output text',...
                    ' --query Reservations[*].Instances[*].PublicIpAddress',...
                    ' --profile gmtto.control'],...
                    self.awspath,self.instance_id);
      [status,public_ip_] = system(cmd);
      if status~=0
          error('Getting AWS machine public IP failed!')
      end
      self.public_ip = strtrim(public_ip_);
      fprintf('\n ==> machine is up and running @%s\n',self.public_ip)
      Defines:
      public_ip, used in chunks 27 and 33b.
      Uses awspath 29a and instance_id 29a.
```

Once the instance is running, ZeroMQ connects the client to the server port of ZeroMQ on the AWS instance:

```
33b  <broker client: setup ZMQ connection 33b>≡ (36a)
      self.socket = zmq.core.socket(self.ctx, 'ZMQ_REQ');
      status = zmq.core.setsockopt(self.socket,'ZMQ_RCVTIMEO',60e3);
      if status<0
          error('broker:zmqRcvTimeOut','Setting ZMQ_RCVTIMEO failed!')
      end
      status = zmq.core.setsockopt(self.socket,'ZMQ_SNDTIMEO',60e3);
      if status<0
          error('broker:zmqSndTimeOut','Setting ZMQ_SNDTIMEO failed!')
      end
      address = sprintf('tcp://%s:3650',self.public_ip);
      zmq.core.connect(self.socket, address);
      fprintf('@(broker)> %s connected at %s\n',class(self),address)
```

Uses public_ip 33a.

The allocated ZeroMQ resources are released with:

```
33c  <release ressources 33c>≡ (27)
      function delete(self)
          fprintf('@(broker)> Deleting %s\n',class(self))
          terminate_instance(self)
          zmq.core.close(self.socket);
          zmq.core.ctx_shutdown(self.ctx);
          zmq.core.ctx_term(self.ctx);
      end
```

Uses terminate_instance 31c.

Two static methods are defined. *getBroker* instantiates and retrieves the broker object. There can be only one broker object per Matlab session.

```

34  <instanciation and retrieval 34>≡ (27)
    function self = getBroker(varargin)
    % getBroker Get a pointer to the broker object
    %
    % agent = ceo.broker.getBroker() % Launch an AWS instance and returns
    % a pointer to the broker object
    % agent = ceo.broker.getBroker('awspath','path_to_aws_cli') % Launch
    % an AWS instance using the given AWS CLI path and returns a pointer to
    % the broker object
    % agent =
    % ceo.broker.getBroker('instance_id','the_id_of_AWS_instance_to_start')
    % Launch the AWS instance 'instance_id' and returns a pointer to the broker object

    persistent this
    if isempty(this)
        fprintf('~~~~~')
        fprintf('\n SIMCEO CLIENT!\n')
        fprintf('~~~~~\n')
        this = ceo.broker(varargin{:});
    end
    self = this;
end

```

Defines:

getBroker, used in chunks 35 and 36.

sendrecv sends a request to the server and returns the server reply:

```
35  <request and reply 35>≡ (27)
    function jmsg = sendrecv(send_msg)
        tid = tic;
        self = ceo.broker.getBroker();
        jsend_msg = saveubjson('',send_msg);
        zmq.core.send( self.socket, uint8(jsend_msg) );
        rcev_msg = -1;
        count = 0;
        while all(rcev_msg<0) && (count<15)
            rcev_msg = zmq.core.recv( self.socket , 2^24);
            if count>0
                fprintf('@(broker)> sendrecv: Server busy (call #%d)!\n',15-count)
            end
            count = count + 1;
        end
        if count==15
            set_param(gcs,'SimulationCommand','stop')
        end
        jmsg = loadubjson(char(rcev_msg),'SimplifyCell',1);
        if ~isstruct(jmsg) && strcmp(char(jmsg),'The server has failed!')
            disp('Server issue!')
            set_param(gcs,'SimulationCommand','stop')
        end
        self.elapsedTime = self.elapsedTime + toc(tid);
    end
```

Defines:

`sendrecv`, used in chunks 42–44.

Uses `getBroker` 34 and `self.elapsedTime` 29a.

resetZMQ resets the ZeroMQ socket

```
36a  <reset ZMQ socket 36a>≡ (27)
      function resetZMQ()
          self = ceo.broker.getBroker();
          if self.zmqReset
              [~,aws_instance_state] = system(...
                  sprintf(['%s ec2 describe-instances --instance-ids %s',...
                      ' --output text',...
                      ' --query Reservations[*].Instances[*].State.Name ',...
                      '--profile gmtto.control'],...
                      self.awspath, self.instance_id));
              if any(strcmp(strtrim(aws_instance_state),{'shutting-down','terminated'}))
                  run_instance(self)
              end
              zmq.core.close(self.socket);
              <broker client: setup ZMQ connection 33b>
          end
          self.zmqReset = false;
      end
      function setZmqResetFlag(val)
          self = ceo.broker.getBroker();
          self.zmqReset = val;
      end
  end
```

Uses *awspath* 29a, *getBroker* 34, *instance.id* 29a, *run_instance* 30a, and *zmqReset* 29a.

Time spent communicating:

```
36b  <time spent 36b>≡ (27)
      function timeSpent()
          self = ceo.broker.getBroker();
          fprintf('@(broker)> Time spent communicating with the server: %.3fs\n',...
              self.elapsedTime)
          self.elapsedTime = 0;
      end
```

Uses *getBroker* 34 and *self.elapsedTime* 29a.

5.2 The dealer class

The *dealer* class contains the messages that are sent by the different functions of the S-function. Each CEO block instantiates a *dealer* class and tailors the messages in the initialization of the block mask. It also holds the number of inputs and outputs of the block as well as the dimensions of the inputs and outputs.

```
37  <dealer.m 37>≡
    classdef dealer < handle

        properties
            n_in
            n_in_ceo
            dims_in
            n_out
            n_out_ceo
            dims_out
            start
            update
            outputs
            terminate
            init
            sampleTime
            enabled
            triggered
            tag
        end

        properties (Dependent)
            currentTime
            class_id
        end

        properties (Access=private)
            p_currentTime
            p_class_id
            tid
        end

        methods

            <dealer public methods 38>

        end

        methods (Access=private)
```

<dealer private methods 42>

```
end
end
```

There are five messages that corresponds to 4 four S-function routines:

```
38  <dealer public methods 38>≡ (37) 39>
    function self = dealer(class_id,tag)

        self.p_class_id = class_id;
        self.tag = strrep(tag,char(10),' ');
        proto_msg = struct('currentTime',[],...
                           'class_id',self.p_class_id,...
                           'method_id','',...
                           'tag',self.tag,...
                           'args',struct('args',[]));

        % Start
        self.start      = proto_msg;
        self.start.method_id = 'Start';
        % InitializeConditions
        self.init        = proto_msg;
        self.init .method_id = 'InitializeConditions';
        % Outputs
        self.update      = proto_msg;
        self.update.method_id = 'Update';
        self.outputs     = proto_msg;
        self.outputs.method_id = 'Outputs';
        % Terminate
        self.terminate = proto_msg;
        self.terminate.method_id = 'Terminate';

        self.enabled = true;
        self.triggered = true;
    end
```

Both, the *currentTime* and the *class_id* properties trigger an update of all the messages:

```
39  <dealer public methods 38>+≡ (37) <38 40a>
    function val = get.class_id(self)
        val = self.p_class_id;
    end
    function set.class_id(self,val)
        self.p_class_id = val;
        self.start.class_id = val;
        self.init.class_id = val;
        self.update.class_id = val;
        self.outputs.class_id = val;
        self.terminate.class_id = val;
    end
    function val = get.currentTime(self)
        val = self.p_currentTime;
    end
    function set.currentTime(self,val)
        self.p_currentTime = val;
        self.start.currentTime = val;
        self.init.currentTime = val;
        self.update.currentTime = val;
        self.outputs.currentTime = val;
        self.terminate.currentTime = val;
    end
end
```

5.2.1 Public methods

The properties of the blocks inputs and outputs are set with:

```
40a <dealer public methods 38>+≡ (37) <39 40b>
function IO_setup(self,block)
    block.NumInputPorts = self.n_in;
    for k_in=1:self.n_in
        block.InputPort(k_in).Dimensions = self.dims_in{k_in};
        block.InputPort(k_in).DatatypeID = 0; % double
        block.InputPort(k_in).Complexity = 'Real';
        block.InputPort(k_in).SamplingMode = 'sample';
        block.InputPort(k_in).DirectFeedthrough = true;
    end
    block.NumOutputPorts = self.n_out;
    for k_out=1:self.n_out
        block.OutputPort(k_out).Dimensions = self.dims_out{k_out};
        block.OutputPort(k_out).DatatypeID = 0; % double
        block.OutputPort(k_out).Complexity = 'Real';
        block.OutputPort(k_out).SamplingMode = 'sample';
    end
    block.SampleTimes = self.sampleTime;
end
```

Defines:

IO_setup, used in chunk 46.

The names of the output ports are set with:

```
40b <dealer public methods 38>+≡ (37) <40a 41a>
function output_names(self,port_handle)
    for k_out=1:self.n_out
        set(port_handle.Outport(k_out), ...
            'SignalNameFromLabel', self.outputs.args.outputs{k_out})
    end
end
```

Defines:

output_names, used in chunk 46.

The *deal* method sends the message to the CEO server, waits for the server replies and process the reply.

```
41a  <dealer public methods 38>+≡ (37) <40b 41b>
      function deal(self,block,tag)
        self.currentTime = {block.currentTime};
        switch tag
          case 'start'
            deal_start(self);
          case 'init'
            deal_init(self);
          case 'inputs'
            deal_inputs(self, block);
          case 'outputs'
            deal_outputs(self, block);
          case 'IO'
            deal_inputs(self, block);
            deal_outputs(self, block);
          case 'terminate'
            deal_terminate(self);
          otherwise
            fprintf(['@(dealer)> deal: Unknown tag;',...
                    ' valid tags are: start, init, IO and terminate!'])
        end
      end
```

Defines:

deal, used in chunks 46–48.

Uses *deal_init* 42, *deal_inputs* 43, *deal_outputs* 44, *deal_start* 42, and *deal_terminate* 42.

The messages are concatenated into a single json file with:

```
41b  <dealer public methods 38>+≡ (37) <41a
      function dump(self)
        s = struct('start',    self.start,...
                   'init',     self.init,...
                   'update',    self.update,...
                   'outputs',   self.outputs,...
                   'terminate', self.terminate);
        [status,message,messageid] = mkdir('JSON',gcs);
        if status<1
          error(messageid,message)
        end
        dirpath = fullfile('JSON',gcs);
        filename = [strrep(get_param(gcb,'Name'),char(10),' '),'.json'];
        savejson('',s,fullfile(dirpath,filename));
      end
```

Defines:

dump, used in chunk 42.

5.2.2 Private methods

```
42  <dealer private methods 42>≡ (37) 43▷
    function deal_start(self)
        ceo.broker.resetZMQ()
        jmsg = ceo.broker.sendrecv(self.start);
        self.class_id = char(jmsg);
        fprintf('@(%s)> Object created!\n',self.tag)
        self.tid = tic;
    end

    function deal_init(self)
        ceo.broker.sendrecv(self.init);
        fprintf('@(%s)> Object calibrated!\n',self.tag)
        self.tid = tic;
    end

    function deal_terminate(self)
        toc(self.tid)
        jmsg = ceo.broker.sendrecv(self.terminate);
        dump(self)
        fprintf('@(%s)> %s\n',self.tag,jmsg)
        ceo.broker.setZmqResetFlag(true)
        ceo.broker.timeSpent()
    end
end
```

Defines:

- deal_init, used in chunk 41a.
- deal_start, used in chunk 41a.
- deal_terminate, used in chunk 41a.

Uses dump 41b and sendrecv 35.

deal_inputs reads the block inputs and affects the input data to the corresponding field in the update message:

```

43  <dealer private methods 42>+≡ (37) <42 44>
    function deal_inputs(self, block)
        n = self.n_in - self.n_in_ceo;
        if n>0
            self.enabled = block.InputPort(1).Data;
            self.triggered = block.InputPort(2).Data;
        end
        if self.enabled
            if self.n_in_ceo>0
                fields = fieldnames(self.update.args.inputs_args);
                for k_in=1:self.n_in_ceo
                    self.update.args.inputs_args.(fields{k_in+n}) = ...
                        reshape(block.InputPort(k_in).Data,1,[]);
                end
            end
            ceo.broker.sendrecv(self.update);
        end
    end
end

```

Defines:

`deal_inputs`, used in chunk 41a.

Uses `sendrecv` 35.

deal_outputs affects the inputs from the CEO server to the corresponding data field of the block outputs:

```

44  <dealer private methods 42>+≡ (37) <43
    function deal_outputs(self, block)
        if self.n_out>0
            if self.enabled && self.triggered
                outputs_msg = ceo.broker.sendrecv(self.outputs);
                try
                    fields = fieldnames(outputs_msg);
                catch ME
                    disp('ERROR in output_msg:')
                    disp(outputs_msg)
                    rethrow(ME)
                end
                for k_out=1:self.n_out
                    data = outputs_msg.(fields{k_out});
                    if isempty(data)
                        data = NaN(size(block.OutputPort(k_out).Data));
                    end
                    if iscell(data)
                        data = cellfun(@(x) double(x), data{1});
                    else
                        data = double(data);
                    end
                    block.OutputPort(k_out).Data = data;
                end
            else
                for k_out=1:self.n_out
                    block.OutputPort(k_out).Data = zeros(1,block.OutputPort(k_out).Dimensions);
                end
            end
        end
    end
end

```

Defines:

`deal_outputs`, used in chunk 41a.

Uses `sendrecv` 35.

5.3 The loadprm function

```
45a <liftprm.m 45a>≡
function args = liftprm(prm_src)
if isstruct(prm_src)
    args = prm_src;
elseif ischar(prm_src)
    [~,~,ext] = fileparts(prm_src);
    switch ext
        case '.ubj'
            args = loadubjson(prm_src,'simplifyCell',1);
        case '.json'
            args = loadjson(prm_src,'simplifyCell',1);
        otherwise
            error('simceo:loadprm:file_error','Unrecognized file type! Valid file extensions are .ubj or .json')
    end
else
    error('simceo:loadprm:type_error','Input must be either a structure or a filename!')
end
```

5.4 The SCEO S-function

```
45b <SCEO.m 45b>≡
function SCEO(block)

setup(block);

<SCEO setup 46>

<SCEO Start 47a>

<SCEO Outputs 47b>

<SCEO Terminate 48>
```

5.4.1 setup

```

46  <SCEO setup 46>≡ (45b)
    function setup(block)

        msg_box    = get(gcbh,'UserData');
        fprintf('__ %s: SETUP __\n',msg_box.tag)
        % Register number of ports
        %block.NumInputPorts = 0;

        % Setup port properties to be inherited or dynamic
        %block.SetPreCompInpPortInfoToDynamic;
        %block.SetPreCompOutPortInfoToDynamic;

        IO_setup(msg_box, block)

        % Register sample times
        % [0 offset]          : Continuous sample time
        % [positive_num offset] : Discrete sample time
        %
        % [-1, 0]              : Inherited sample time
        % [-2, 0]              : Variable sample time
        %block.SampleTimes = [1 0];

        % Specify the block simStateCompliance. The allowed values are:
        % 'UnknownSimState', < The default setting; warn and assume DefaultSimState
        % 'DefaultSimState', < Same sim state as a built-in block
        % 'HasNoSimState',   < No sim state
        % 'CustomSimState',  < Has GetSimState and SetSimState methods
        % 'DisallowSimState' < Error out when saving or restoring the model sim state
        block.SimStateCompliance = 'DefaultSimState';

        %% -----
        %% The MATLAB S-function uses an internal registry for all
        %% block methods. You should register all relevant methods
        %% (optional and required) as illustrated below. You may choose
        %% any suitable name for the methods and implement these methods
        %% as local functions within the same file. See comments
        %% provided for each function for more information.
        %% -----

        block.RegBlockMethod('Start', @Start);
        block.RegBlockMethod('Outputs', @Outputs);      % Required
        block.RegBlockMethod('Update', @Update);
        block.RegBlockMethod('Terminate', @Terminate); %
        block.RegBlockMethod('PostPropagationSetup', @PostPropagationSetup);

```

```

block.RegBlockMethod('InitializeConditions', @InitializeConditions);
%end setup

function PostPropagationSetup(block)
msg_box = get(gcbh,'UserData');
fprintf('__ %s: PostPropagationSetup __\n',msg_box.tag)
output_names(msg_box,get(gcbh, 'PortHandles'))

function InitializeConditions(block)
msg_box = get(gcbh,'UserData');
fprintf('__ %s: InitializeConditions __\n',msg_box.tag)
deal(msg_box,block,'init')

```

Uses deal 41a, IO_setup 40a, and output_names 40b.

5.4.2 Start

47a $\langle SCEO \text{ Start } 47a \rangle \equiv$ (45b)

```

function Start(block)

msg_box = get(gcbh,'UserData');
fprintf('__ %s: START __\n',msg_box.tag)
deal(msg_box,block,'start')
%set(gcbh,'UserData',msg_box)
%end Start

```

Uses deal 41a.

5.4.3 Outputs

47b $\langle SCEO \text{ Outputs } 47b \rangle \equiv$ (45b)

```

function Outputs(block)

msg_box = get(gcbh,'UserData');
%fprintf('__ %s: OUTPUTS __\n',msg_box.class_id)
deal(msg_box,block,'IO')

%end Outputs

```

Uses deal 41a.

5.4.4 Terminate

48 $\langle SCEO \text{ Terminate } 48 \rangle \equiv$ (45b)

```
function Update(block)

    %msg_box    = get(gcbh,'UserData');
    %deal(msg_box,block,'inputs')

%end Update

function Terminate(block)

msg_box = get(gcbh,'UserData');
deal(msg_box,block,'terminate')
%set(gcbh,'UserData',[])
%end Terminate
```

Uses deal 41a.

5.5 The block masks

5.5.1 Optical Path

```
49  <OpticalPath.md 49>≡
    # Optical Path

    ## Guide Star Tab

    ##### Zenith angle

    The guide star zenith angle, in arcsecond, given with respect to
    the telescope optical axis.

    ##### Azimuth angle

    The guide star azimuth angle in degree.

    ##### Photometry

    The guide star photometry to choose from.
    This will set the wavelength, the spectral bandwidth and the magnitude zero
    point.

    The table below gives the values of those:
```

	V	R	I	J	H	K	Ks
-----	-----	-----	-----	-----	-----	-----	-----
λ [μm]	0.550	0.640	0.790	1.215	1.654	2.179	2.157
$\Delta\lambda$ [μm]	0.090	0.150	0.150	0.260	0.290	0.410	0.320
Zero point [m ⁻² .s ⁻¹]	8.97E9	10.87E9	7.34E9	5.16E9	2.99E9	1.90E9	1.49E9
-----	-----	-----	-----	-----	-----	-----	-----

```
    ##### Magnitude

    The guide star magnitude used to derive the number of photon taking
    into account the guide star photometry.

    ##### \# of rays per lenslet

    The \# of rays per lenslet corresponds to the number of rays used
    for ray tracing through the telescope.
    It has different meanings depending on the value of Sensor (See below).

    ### Sensor
```

The type of `sensor`:

- * 'None': No `sensor` is used;
the \# of rays per lenslet corresponds to the number of rays
across the telescope diameter,
- * 'Imaging': The `sensor` creates an image at the focal plane of the telescope;
the \# of rays per lenslet corresponds to the number of rays
across the diameter of the imaging lens,
- * 'ShackHartmann': A shack-Hartmann model where the wavefront of the guide star is
propagated from the telescope exit pupil to the focal plane of the lenslet array
using Fourier optics propagation;
the \# of rays per lenslet corresponds to the number of rays across one lenslet,
- * 'GeometricShackHartmann': A shack-Hartmann model where the centroids are derived
from the finite difference of the wavefront averaged on the lenslets;
the \# of rays per lenslet corresponds to the number of rays across one lenslet.
- * 'TT7': A shack-Hartmann model where the centroids are derived
from the finite difference of the wavefront averaged on each segment of the GMT;
the \# of rays per lenslet corresponds to the number of rays across the telescope diameter

Source FWHM

The full width at half maximum of the source intensity profile assuming a Gaussian intensity.
The FWHM is given in units of pixel before binning.

Propagate through the atmosphere

If checked, the guide star is propagated through the atmosphere using the model defined in

Sample Time

The sampling time of the block outputs.

Sensor Tab

\# of lenslet

The linear size of the lenslet array.

lenslet size

The physical length of one lenslet project on M1 in meter.

camera resolution

The detector resolution of the optical `sensor` in pixel.

Intensity threshold

The threshold on the lenslet integrated flux. Any lenslet, whose fraction of integrated in

Pixel scale

The angular size of a pixel of the detector in arcsec.

It is given by

$$\frac{\lambda}{d} \left(\frac{b}{a} \right)$$

where both a and b are integers.

b is set by adjusting the binning factor and a is set by adjusting the sampling fa

Field-of-view

The field-of-view of the wavefront [sensor](#) in arcsec.

Exposure time

The detector exposure time. A value of -1 will set it to the same value that the exposure

Exposure start

Start of the exposure delay time.

Outputs Tab

Star

Each output is derived on the telescope full pupil and/or on each segment.

Wavefront error rms

The RMS of the guide star wavefront in micron.

Piston

The piston component of the guide star wavefront in micron.

Tip-tilt

The tip-tilt component of the guide star wavefront in arcsec.

Sensor

EE80

The 80% encircled energy diameter in pixel.

Commands: Load calibration from file

The name of the file where the calibration matrices are saved to.

If the file already exists on the CEO server, the calibration matrices are loaded from the file.

Commands: Calibration inputs

A ShackHartmann or GeometricShackHartmann [sensor](#) can return an estimate of the mirror commands based on its measurements.

The mirror commands are given by the matrix multiplication of

the inverse of the poke matrix and the [sensor](#) measurements.

To generate the poke matrix, CEO needs to know which modes to calibrate

from which mirror ('M1' or 'M2') and what stroke to apply to these modes.

The available mirror modes are:

- * 'segment tip-tilt': to calibrate the tip (Rx) and tilt (Ry) of each segment,
- * 'Txyz': to calibrate the translation of each segment along its x, y and z axis,
- * 'Rxyz': to calibrate the rotation of each segment along its x, y and z axis,
- * 'zernike': to calibrate the Zernike modes of each segment,
- * 'bending modes': to calibrate the bending modes of M1.

For example:

* to calibrate M2 segment tip-tilt, the calibration inputs argument is

```
''matlab
struct('M2_TT',struct('mirror','M2','mode','segment tip-tilt','stroke',1e-6))
''
```

where 'M2_TT' is the name of the output port consisting of the 14 tip and tilts,

* to calibrate all M1 modes and to concatenate all the modes into a single calibration matrix

```
''matlab
struct('M1_RTBM',[struct('mirror','M1','mode','Rxyz','stroke',1e-6),...
                    struct('mirror','M1','mode','Txyz','stroke',1e-6),...
                    struct('mirror','M1','mode','bending modes','stroke',1e-6)])
''
```

Commands: Command vector length

The length of the different command vector defined with calibration inputs.

For the examples in Calibration inputs, the length of the command vector are 14 for M2_TT

Modes Rz and Tz for segment #1 of M1 are un-observable by the WFS.

Only mode Rz for segment #1 of M2 is un-observable by the WFS.

For M2_TT, the output vector has the following structure: $[R_{xy}^1, R_{xy}^2, R_{xy}^3, R_{xy}^4]$
 For M1_RTBM, the output vector is: $[R_{xyz}, T_{xyz}, BM]$ with $(R_{xyz} \equiv X, T_{xyz} \equiv Y)$

Commands: SVD truncation

The number of eigen values, from the singular value decomposition of the calibration matrix.
 If the calibration is loaded from a previously saved file, the threshold is re-applied and

Commands: Decoupling segments

If checked, eaach segment is controlled independently from the others,
 the lenslets that span across two segments are rejected and there are 7 command matrices i
 Otherwise M1 and M2 mirrors are controlled in the same way that non segmented mirrors.

Uses sensor 14b.

5.5.2 GMT Mirror

53 $\langle GMTMirror.md \ 53 \rangle \equiv$
 # GMT Mirror

Mirror

Either the primary M1 or the secondary M2 mirror.

Mirror commands

The mirrors accept two types of intputs:

Txyz and Rxyz rigid body

A 7×6 matrix concatenating row wise the vectors $[Tx, Ty, Tz, Rx, Ry, Rz]$ of segments 1

Mirror mode coefficients

The coefficients of the segments modal basis that is used to shape the segments.
 It is a $7 \times n_{mode}$ matrix of either bending mode for M1 or Zernike coefficients for

6 The CEO server

The CEO daemon is start at boot time with the *CEO.sh* shell script. It must be placed in the `/etc/init.d` directory.

```
54 <CEO.sh 54>≡
    #!/bin/bash -e

    DAEMON="/usr/bin/env LD_LIBRARY_PATH=/usr/local/cuda/lib64 PYTHONPATH=/home/ubuntu/CEO/pyt
    daemon_OPT=""
    DAEMONUSER="root"
    daemon_NAME="ceo_server"
    PIDFILE=/var/run/$daemon_NAME.pid

    PATH="/sbin:/bin:/usr/sbin:/usr/bin" #Ne pas toucher

    #test -x $DAEMON || exit 0

    . /lib/lsb/init-functions

    d_start () {
        log_daemon_msg "Starting system $daemon_NAME Daemon"
        start-stop-daemon --background --name $daemon_NAME --start --quiet --make-pidfile
        log_end_msg $?
    }

    d_stop () {
        log_daemon_msg "Stopping system $daemon_NAME Daemon"
        start-stop-daemon --name $daemon_NAME --stop --retry 5 --quiet --pidfile "$PIDFILE"
        log_end_msg $?
    }

    case "$1" in

        start|stop)
            d_${1}
            ;;

        restart|reload|force-reload)
            d_stop
            d_start
            ;;

        force-stop)
            d_stop
            killall -q $daemon_NAME || true
            sleep 2
    esac
```

```

        killall -q -9 $daemon_NAME || true
        ;;

status)
    status_of_proc "$daemon_NAME" "$DAEMON" "system-wide $daemon_NAME" && exit
    ;;
*)
    echo "Usage: /etc/init.d/$daemon_NAME {start|stop|force-stop|restart|reload}"
    exit 1
    ;;

esac
exit 0

```

Uses `etc 29a`.

7 Index

awspath: [27](#), [29a](#), [30b](#), [30c](#), [31a](#), [31b](#), [31c](#), [32b](#), [32c](#), [33a](#), [36a](#)
deal: [41a](#), [46](#), [47a](#), [47b](#), [48](#)
deal_init: [41a](#), [42](#)
deal_inputs: [41a](#), [43](#)
deal_outputs: [41a](#), [44](#)
deal_start: [41a](#), [42](#)
deal_terminate: [41a](#), [42](#)
dump: [41b](#), [42](#)
etc: [27](#), [29a](#), [30b](#), [31b](#), [54](#)
exposure_start: [16a](#)
exposure_time: [16a](#)
getBroker: [34](#), [35](#), [36a](#), [36b](#)
idx: [14b](#), [16a](#)
instance_end_state: [27](#), [29b](#), [31c](#)
instance_id: [27](#), [29a](#), [29b](#), [30b](#), [30c](#), [31a](#), [31b](#), [31c](#), [32b](#), [32c](#), [33a](#), [36a](#)
IO_setup: [40a](#), [46](#)
output_names: [40b](#), [46](#)
propagateThroughAtm: [16a](#)
public_ip: [27](#), [33a](#), [33b](#)
run_instance: [29b](#), [30a](#), [36a](#)
self.elapsedTime: [29a](#), [35](#), [36b](#)
sendrecv: [35](#), [42](#), [43](#), [44](#)
sensor: [14b](#), [16a](#), [17c](#), [18a](#), [18b](#), [22](#), [49](#)
src: [16a](#), [17c](#), [18b](#), [22](#)
start_instance: [29b](#), [32a](#)
terminate_instance: [31c](#), [33c](#)
zmqReset: [27](#), [29a](#), [36a](#)

8 List of code chunks

<branding instance [31a](#)>
<broker [8a](#)>
<broker client [29a](#)>
<broker client: AWS instance launch [29b](#)>
<broker client: setup ZMQ connection [33b](#)>
<broker get item [10a](#)>
<broker run [8b](#)>
<broker run details [9a](#)>
<broker.m [27](#)>
<CalibrationMatrix [24](#)>
<CEO.sh [54](#)>
<dealer private methods [42](#)>
<dealer public methods [38](#)>

- ⟨dealer.m 37⟩
- ⟨getting the public IP 33a⟩
- ⟨GMTMirror.md 53⟩
- ⟨instanciation and retrieval 34⟩
- ⟨launch AWS AMI 30a⟩
- ⟨launching an instance 30b⟩
- ⟨liftprm.m 45a⟩
- ⟨OpticalPath.md 49⟩
- ⟨release ressources 33c⟩
- ⟨request and reply 35⟩
- ⟨reset ZMQ socket 36a⟩
- ⟨S-function 11a⟩
- ⟨SAtmosphere 14a⟩
- ⟨SCEO Outputs 47b⟩
- ⟨SCEO setup 46⟩
- ⟨SCEO Start 47a⟩
- ⟨SCEO Terminate 48⟩
- ⟨SCEO.m 45b⟩
- ⟨Sensor abstract class 26⟩
- ⟨setting up cloudwatch 31b⟩
- ⟨SGMT 11b⟩
- ⟨SGMT Start message 12a⟩
- ⟨simceo.py 5⟩
- ⟨SOpticalPath 14b⟩
- ⟨SOpticalPath InitializeConditions message 19⟩
- ⟨SOpticalPath Outputs message 17d⟩
- ⟨SOpticalPath Start message 15⟩
- ⟨SOpticalPath Terminate message 16b⟩
- ⟨SOpticalPath Update message 12c⟩
- ⟨start AWS instance 32a⟩
- ⟨starting an instance 32b⟩
- ⟨terminate AWS instance 31c⟩
- ⟨time spent 36b⟩
- ⟨waiting for initialization 30c⟩
- ⟨waiting for the running state 32c⟩