ImagesToLARModel, a tool for creation of three-dimensional models from a stack of images

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Abstract

Here we will present a software for creating a three-dimensional model from a stack of images. This can be useful because of the simplicity of these type of representations. In particular a scope of use can be offered by medicine, where there is an enormous number of images but with very complex two-dimensional representations.

This work will use the LAR representation with the Julia language ([CL13]), because of its simplicity, showing how it can be used for quickly process image data.

Contents

1 Introduction

This work has the objective of transforming a two-dimensional representation of a model (based on a stack of images) into a three-dimensional representation based on the LAR schema. In particular, it will produce a single obj model which can be viewed with standard graphics software.

The biggest problem we will face is lack of memory. In fact, our aim is to get a very large stack of images (so with the maximum possible resolution) and convert them. However biomedical images used in research are very big so we cannot save them entirely in memory. The idea used here is the same of existing software based on LAR schema ([PDFJ15]) with the introduction of parallelism layer, transforming only little parts of images obtaining models to merge in final result file. A typical hardware environment for this software is a cluster of computers, where processes (which convert images portions) are distributed among different machines.

1.1 Why Julia

Ricordare che precedenti versioni erano in python
Semplicita
Efficienza
Capacita di realizzare programmi paralleli con poco sforzo

2 Software structure

2.1 Julia packages

This software will be distributed as a Julia Package. For the actual release (Julia 0.4) a package is a simple git project with the structure showed in figure 1

Source code must be in folder `src`, while in `test` folder there are module tests with a `runtests.jl` for executing them and with a `REQUIRE` file for specifying tests dependencies. For listing dependencies for the entire project, there is another REQUIRE file in main folder. As an example in figure 2 there is the REQUIRE file for `ImagesToLARModel.jl`.

After creating this structure for a project it can be pushed on a git repository and installed on Julia systems. The usual installation procedure use this syntax:

```
Pkg.add("Package-name")
```

This will check for that package in METADATA.jl repository on github where there are all official Julia package. However it is also possible to install an unofficial package (on a public git repository) using this sintax:
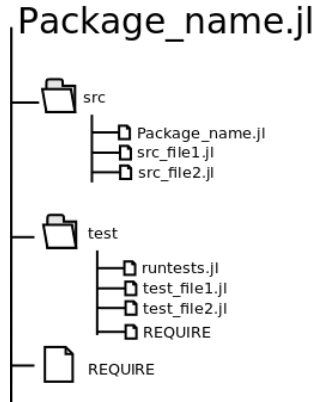
Figure 1: Julia module structure

Figure 2: REQUIRE contents for `ImagesToLARModel.jl`

```
Pkg.clone("git://repository-address.git")
```

This will install the package on your system with all the dependencies listed in RE-QUIRE file.

2.2   Architecture of ImagesToLARModel

In previous section we have seen how to create a Julia package for distribute our application. Now we focus on the structure of our application. In `src` folder we can find the following modules:

ImagesToLARModel.jl: main module for the software, it takes input parameters and start images conversion

ImagesConvertion.jl: it is called by `ImagesToLARModel.jl` module and controls the entire conversion process calling all other modules

GenerateBorderMatrix.jl: it generates the boundary operator for grid specified in input, saving it in a JSON file

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PngStack2Array3dJulia.jl: it is responsible of images loading and conversion into computable data

Lar2Julia.jl: it contains a small subset of LAR functions written in Julia language

LARUtils.jl: it contains utility functions for manipulation of LAR models

Model2Obj.jl: it contains function that manipulates obj files

larcc.py: python larcc module for boundary computation. In next releases of the software it will be rewritten in Julia language

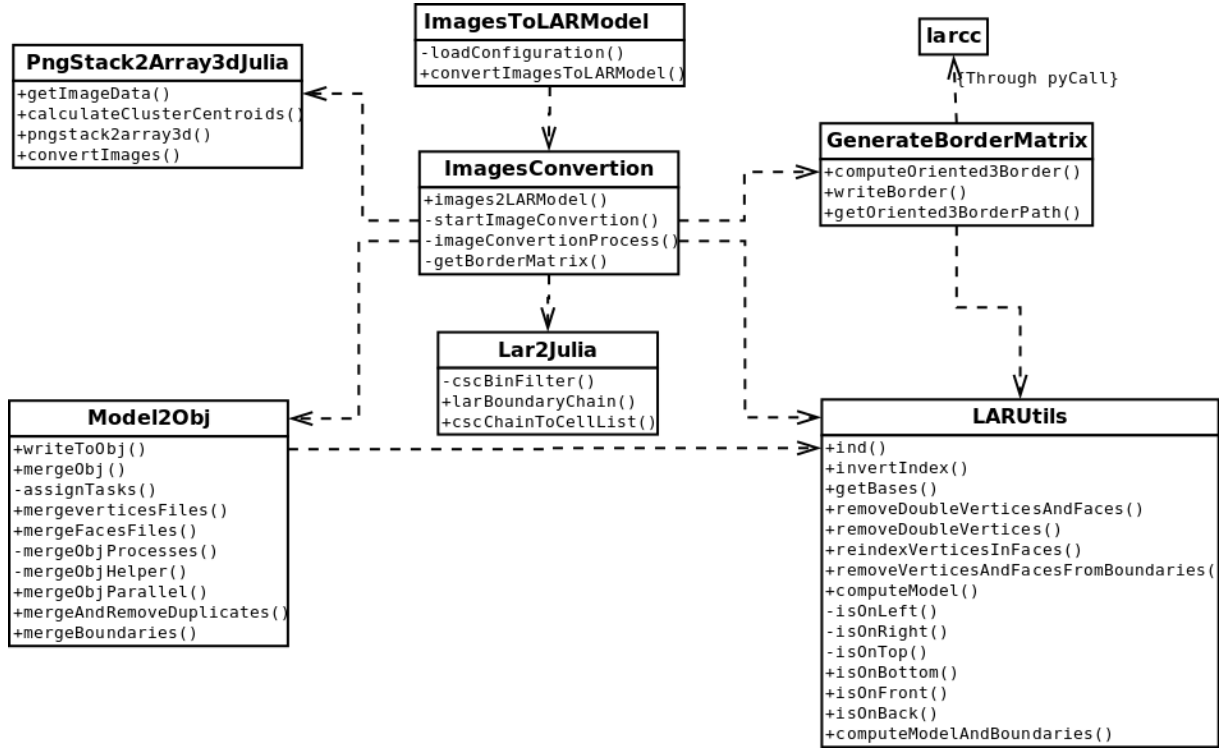In figure 3 there is a simple schema of dependencies between modules.

Figure 3: Schema of module dependencies of ImagesToLARModel

Next sections of this document will explain in details all these modules showing also the code involved in conversion

3   ImagesToLARModel

This is the main module for the application; it takes the input data and start conversion calling `ImagesConvertion.jl`.

3.1   Calling modules

As we have already said, this first module has the responsibility of starting the conversion calling all other modules in the package. In Julia calling modules requires that they are in a path specified by `LOAD_PATH` array. So at the beginning of this module we need to add this line:

⟨ *update load path* 6a ⟩ ≡

```
    push!(LOAD_PATH, Pkg.dir("ImagesToLARModel/src"))
```
        ◇

Fragment referenced in 10a.

`Pkg.dir()` function gives us the path of the Julia installation, so `Pkg.dir("ImagesToLARModel/src")` returns "⟨*Julia − path*⟩/*ImagesToLARModel*/*src*"

After this line we can now import all modules defined here and export public functions:

⟨ *modules import ImagesToLARModel* 6b ⟩ ≡

```
    import JSON
    import ImagesConvertion

    using Logging

    export convertImagesToLARModel
```

        ◇

Fragment referenced in 10a.

3.2   Input loading

Images conversion takes several parameters:

- inputDirectory: The path of the directory containing the stack of images

- outputDirectory: The path of the directory containing the output

- bestImage: Image chosen for centroid computation (see section 4)

- nx, ny, nz: Sizes of the grid chosen for image segmentation (see section 4)

- DEBUG_LEVEL: Debug level for Julia logger

- parallelMerge (experimental): Choose between sequential or parallel merge of files (see section 9)

Because of their number it has been realized a function for simply loading them from a JSON configuration file; this is the code:

⟨ *load JSON configuration* 7 ⟩ ≡

```julia
function loadConfiguration(configurationFile)
  """
  load parameters from JSON file

  configurationFile: Path of the configuration file
  """

  configuration = JSON.parse(configurationFile)

  DEBUG_LEVELS = [DEBUG, INFO, WARNING, ERROR, CRITICAL]

  try
    if configuration["parallelMerge"] == "true"
      parallelMerge = true
    else
      parallelMerge = false
    end
  catch
    parallelMerge = false
  end

  return configuration["inputDirectory"], configuration["outputDirectory"],
         configuration["bestImage"],
         configuration["nx"], configuration["ny"], configuration["nz"],
         DEBUG_LEVELS[configuration["DEBUG_LEVEL"]],
         parallelMerge

end
```
◇

Fragment referenced in 10a.

A valid JSON file has the following structure:

{
  "inputDirectory": "Path of the input directory",
  "outputDirectory": "Path of the output directory",
  "bestImage": "Name of the best image (with extension) ",
  "nx": x grid size,
  "ny": y grid size,
  "nz": border z,
  "DEBUG_LEVEL": julia Logging level (can be a number from 1 to 5)
  "parallelMerge": "true" or "false"
}

As we can see, in a valid JSON configuration file DEBUG_LEVEL can be a number from 1 to 5. Instead, when we explicitly define parameters, DEBUG_LEVEL can only be one of the following Julia constants:

- DEBUG

- INFO

- WARNING

- ERROR

- CRITICAL

3.3 Starting conversion

As we have already said, this module has the only responsibility to collect data input and starts other modules. These are the functions that start the process and the only exposed to the application users:

⟨ *Start conversion from JSON file* 8 ⟩ ≡

```
    function convertImagesToLARModel(configurationFile)
        """
        Start convertion of a stack of images into a 3D model
        loading parameters from a JSON configuration file

        configurationFile: Path of the configuration file
        """
        inputDirectory, outputDirectory, bestImage, nx, ny, nz,
            DEBUG_LEVEL, parallelMerge = loadConfiguration(open(configurationFile))
        convertImagesToLARModel(inputDirectory, outputDirectory, bestImage,
```

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```
                                    nx, ny, nz, DEBUG_LEVEL, parallelMerge)
      end
      ◇
```

Fragment referenced in 10a.

⟨ *Start manual conversion* 9 ⟩ ≡

```
      function convertImagesToLARModel(inputDirectory, outputDirectory, bestImage,
                                 nx, ny, nz, DEBUG_LEVEL = INFO, parallelMerge = false)
      """
      Start convertion of a stack of images into a 3D model

      inputDirectory: Directory containing the stack of images
      outputDirectory: Directory containing the output
      bestImage: Image chosen for centroids computation
      nx, ny, nz: Border dimensions (Possibly the biggest power of two of images dimensions)
      DEBUG_LEVEL: Debug level for Julia logger. It can be one of the following:
        - DEBUG
        - INFO
        - WARNING
        - ERROR
        - CRITICAL
      """
      # Create output directory
      try
        mkpath(outputDirectory)
      catch
      end

      Logging.configure(level=DEBUG_LEVEL)
      ImagesConvertion.images2LARModel(nx, ny, nz, bestImage,
              inputDirectory, outputDirectory, parallelMerge)
      end
      ◇
```

Fragment referenced in 10a.

ImagesToLARModel

```
"src/ImagesToLARModel.jl" 10a≡
     module ImagesToLARModel
```

⟨ *update load path* 6a ⟩

⟨ *modules import ImagesToLARModel* 6b ⟩
⟨ *load JSON configuration* 7 ⟩
⟨ *Start conversion from JSON file* 8 ⟩
⟨ *Start manual conversion* 9 ⟩
```
     end
     ◇
```

ImagesConvertion

```
"src/ImagesConvertion.jl" 10b≡
     module ImagesConvertion

     import GenerateBorderMatrix
     import PngStack2Array3dJulia
     import Lar2Julia
     import Model2Obj
     import LARUtils

     import JSON
```

```julia
using PyCall
@pyimport scipy.sparse as Pysparse

using Logging

export images2LARModel

"""
This is main module for converting a stack
of images into a 3d model
"""

function images2LARModel(nx, ny, nz, bestImage, inputDirectory, outputDirectory, parallelMerge
  """
  Convert a stack of images into a 3d model
  """

  info("Starting model creation")

  numberOfClusters = 2 # Number of clusters for
                       # images segmentation

  info("Moving images into temp directory")
  try
    mkdir(string(outputDirectory, "TEMP"))
  catch
  end

  tempDirectory = string(outputDirectory,"TEMP/")

  newBestImage = PngStack2Array3dJulia.convertImages(inputDirectory, tempDirectory, bestImage)

  imageWidth, imageHeight = PngStack2Array3dJulia.getImageData(string(tempDirectory,newBestIma
  imageDepth = length(readdir(tempDirectory))

  # Computing border matrix
  info("Computing border matrix")
  try
    mkdir(string(outputDirectory, "BORDERS"))
  catch
  end
  borderFilename = GenerateBorderMatrix.getOriented3BorderPath(string(outputDirectory, "BORDERS

  # Starting images convertion and border computation
  info("Starting images convertion")
```

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```
   startImageConvertion(tempDirectory, newBestImage, outputDirectory, borderFilename,
                        imageHeight, imageWidth, imageDepth,
                        nx, ny, nz,
                        numberOfClusters, parallelMerge)

end

function startImageConvertion(sliceDirectory, bestImage, outputDirectory, borderFilename,
                              imageHeight, imageWidth, imageDepth,
                              imageDx, imageDy, imageDz,
                              numberOfClusters, parallelMerge)
  """
  Support function for converting a stack of images into a model

  sliceDirectory: directory containing the image stack
  imageForCentroids: image chosen for centroid computation
  """

  # Create clusters for image segmentation
  info("Computing image centroids")
  debug("Best image = ", bestImage)
  centroidsCalc = PngStack2Array3dJulia.calculateClusterCentroids(sliceDirectory, bestImage, n
  debug(string("centroids = ", centroidsCalc))

  try
    mkdir(string(outputDirectory, "BORDERS"))
  catch
  end
  debug(string("Opening border file: ", "border_", imageDx, "-", imageDy, "-", imageDz, ".json
  boundaryMat = getBorderMatrix(string(outputDirectory,"BORDERS/","border_", imageDx, "-",
                                       imageDy, "-", imageDz, ".json"))
  beginImageStack = 0
  endImage = beginImageStack

  info("Converting images into a 3d model")
  tasks = Array(RemoteRef, 0)
  for zBlock in 0:(imageDepth / imageDz - 1)
    startImage = endImage
    endImage = startImage + imageDz
    info("StartImage = ", startImage)
    info("endImage = ", endImage)

    task = @spawn imageConvertionProcess(sliceDirectory, outputDirectory,
                          beginImageStack, startImage, endImage,
                          imageDx, imageDy, imageDz,
                          imageHeight, imageWidth,
```

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```
                              centroidsCalc, boundaryMat)

    push!(tasks, task)
  end

  # Waiting for tasks completion
  for task in tasks
    wait(task)
  end

  info("Merging boundaries")
  # Merge Boundaries files
  Model2Obj.mergeBoundaries(string(outputDirectory, "MODELS"),
                            imageHeight, imageWidth, imageDepth,
                            imageDx, imageDy, imageDz)

  info("Merging obj models")
  if parallelMerge
    Model2Obj.mergeObjParallel(string(outputDirectory, "MODELS"))
  else
    Model2Obj.mergeObj(string(outputDirectory, "MODELS"))
  end

end

function imageConvertionProcess(sliceDirectory, outputDirectory,
                                beginImageStack, startImage, endImage,
                                imageDx, imageDy, imageDz,
                                imageHeight, imageWidth,
                                centroids, boundaryMat)
  """
  Support function for converting a stack of image on a single
  independent process
  """

  info("Transforming png data into 3d array")
  theImage = PngStack2Array3dJulia.pngstack2array3d(sliceDirectory, startImage, endImage, cent

  centroidsSorted = sort(vec(reshape(centroids, 1, 2)))
  foreground = centroidsSorted[2]
  background = centroidsSorted[1]
  debug(string("background = ", background, " foreground = ", foreground))

  for xBlock in 0:(imageHeight / imageDx - 1)
    for yBlock in 0:(imageWidth / imageDy - 1)
      yStart = xBlock * imageDx
```

```
xStart = yBlock * imageDy
#xEnd = xStart + imageDx
#yEnd = yStart + imageDy
xEnd = xStart + imageDy
yEnd = yStart + imageDx
debug("***********")
debug(string("xStart = ", xStart, " xEnd = ", xEnd))
debug(string("yStart = ", yStart, " yEnd = ", yEnd))
debug("theImage dimensions: ", size(theImage)[1], " ", size(theImage[1])[1], " ", size(t]

# Getting a slice of theImage array

image = Array(Uint8, (convert(Int, length(theImage)), convert(Int, xEnd - xStart), conver
debug("image size: ", size(image))
for z in 1:length(theImage)
  for x in 1 : (xEnd - xStart)
    for y in 1 : (yEnd - yStart)
      image[z, x, y] = theImage[z][x + xStart, y + yStart]
    end
  end
end

nz, nx, ny = size(image)
chains3D = Array(Uint8, 0)
zStart = startImage - beginImageStack
for y in 0:(nx - 1)
  for x in 0:(ny - 1)
    for z in 0:(nz - 1)
      if(image[z + 1, x + 1, y + 1] == foreground)
        push!(chains3D, y + ny * (x + nx * z))
      end
    end
  end
end

if(length(chains3D) != 0)
  # Computing boundary chain
  debug("chains3d = ", chains3D)
  debug("Computing boundary chain")
  objectBoundaryChain = Lar2Julia.larBoundaryChain(boundaryMat, chains3D)
  debug("Converting models into obj")
  try
    mkdir(string(outputDirectory, "MODELS"))
  catch
  end
  # IMPORTANT: inverting xStart and yStart for obtaining correct rotation of the model
```

```
            models = LARUtils.computeModelAndBoundaries(imageDx, imageDy, imageDz, yStart, xStart,

            V, FV = models[1][1] # inside model
            V_left, FV_left = models[2][1]
            V_right, FV_right = models[3][1] # right boundary
            V_top, FV_top = models[4][1] # top boundary
            V_bottom, FV_bottom = models[5][1] # bottom boundary
            V_front, FV_front = models[6][1] # front boundary
            V_back, FV_back = models[7][1] # back boundary

            # Writing all models on disk
            model_outputFilename = string(outputDirectory, "MODELS/model_output_", xBlock, "-", yB
            Model2Obj.writeToObj(V, FV, model_outputFilename)

            left_outputFilename = string(outputDirectory, "MODELS/left_output_", xBlock, "-", yBlo
            Model2Obj.writeToObj(V_left, FV_left, left_outputFilename)

            right_outputFilename = string(outputDirectory, "MODELS/right_output_", xBlock, "-", yB
            Model2Obj.writeToObj(V_right, FV_right, right_outputFilename)

            top_outputFilename = string(outputDirectory, "MODELS/top_output_", xBlock, "-", yBlock
            Model2Obj.writeToObj(V_top, FV_top, top_outputFilename)

            bottom_outputFilename = string(outputDirectory, "MODELS/bottom_output_", xBlock, "-", y
            Model2Obj.writeToObj(V_bottom, FV_bottom, bottom_outputFilename)

            front_outputFilename = string(outputDirectory, "MODELS/front_output_", xBlock, "-", yB
            Model2Obj.writeToObj(V_front, FV_front, front_outputFilename)

            back_outputFilename = string(outputDirectory, "MODELS/back_output_", xBlock, "-", yBlo
            Model2Obj.writeToObj(V_back, FV_back, back_outputFilename)
          else
            debug("Model is empty")
          end
        end
      end
end

function getBorderMatrix(borderFilename)
    """
    TO REMOVE WHEN PORTING OF LARCC IN JULIA IS COMPLETED

    Get the border matrix from json file and convert it in
    CSC format
    """
    # Loading borderMatrix from json file
```

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```
      borderData = JSON.parsefile(borderFilename)
      row = Array(Int64, length(borderData["ROW"]))
      col = Array(Int64, length(borderData["COL"]))
      data = Array(Int64, length(borderData["DATA"]))

      for i in 1: length(borderData["ROW"])
        row[i] = borderData["ROW"][i]
      end

      for i in 1: length(borderData["COL"])
        col[i] = borderData["COL"][i]
      end

      for i in 1: length(borderData["DATA"])
        data[i] = borderData["DATA"][i]
      end

      # Converting csr matrix to csc
      csrBorderMatrix = Pysparse.csr_matrix((data,col,row), shape=(borderData["ROWCOUNT"],borderDa
      denseMatrix = pycall(csrBorderMatrix["toarray"],PyAny)

      cscBoundaryMat = sparse(denseMatrix)

      return cscBoundaryMat

    end
    end
    ◇
```

GenerateBorderMatrix

"src/GenerateBorderMatrix.jl" 16≡

```
    module GenerateBorderMatrix

    type MatrixObject
      ROWCOUNT
      COLCOUNT
      ROW
      COL
      DATA
    end
```

```
export computeOriented3Border, writeBorder, getOriented3BorderPath

import LARUtils
using PyCall

import JSON

@pyimport sys
unshift!(PyVector(pyimport("sys")["path"]), "") # Search for python modules in folder
# Search for python modules in package folder
unshift!(PyVector(pyimport("sys")["path"]), Pkg.dir("ImagesToLARModel/src"))
@pyimport larcc # Importing larcc from local folder

# Compute the 3-border operator
function computeOriented3Border(nx, ny, nz)
  """
  Compute the 3-border matrix using a modified
  version of larcc
  """
  V, bases = LARUtils.getBases(nx, ny, nz)
  boundaryMat = larcc.signedCellularBoundary(V, bases)
  return boundaryMat

end

function writeBorder(boundaryMatrix, outputFile)
  """
  Write 3-border matrix on json file

  boundaryMatrix: matrix to write on file
  outputFile: path of the outputFile
  """

  rowcount = boundaryMatrix[:shape][1]
  colcount = boundaryMatrix[:shape][2]

  row = boundaryMatrix[:indptr]
  col = boundaryMatrix[:indices]
  data = boundaryMatrix[:data]

  # Writing informations on file
  outfile = open(outputFile, "w")

  matrixObj = MatrixObject(rowcount, colcount, row, col, data)
  JSON.print(outfile, matrixObj)
  close(outfile)
```

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```
      end

      function getOriented3BorderPath(borderPath, nx, ny, nz)
        """
        Try reading 3-border matrix from file. If it fails matrix
        is computed and saved on disk in JSON format

        borderPath: path of border directory
        nx, ny, nz: image dimensions
        """

        filename = string(borderPath,"/border_", nx, "-", ny, "-", nz, ".json")
        if !isfile(filename)
          border = computeOriented3Border(nx, ny, nz)
          writeBorder(border, filename)
        end
        return filename

      end
      end
      ◇
```

Lar2Julia

"src/Lar2Julia.jl" 18≡

```
      module Lar2Julia

      export larBoundaryChain, cscChainToCellList

      import JSON

      using Logging

      function larBoundaryChain(cscBoundaryMat, brcCellList)
        """
        Compute boundary chains
        """

        # Computing boundary chains
        n = size(cscBoundaryMat)[1]
        m = size(cscBoundaryMat)[2]
```

```julia
    debug("Boundary matrix size: ", n, "\t", m)

    data = ones(Int64, length(brcCellList))

    i = Array(Int64, length(brcCellList))
    for k in 1:length(brcCellList)
      i[k] = brcCellList[k] + 1
    end

    j = ones(Int64, length(brcCellList))

    debug("cscChain rows length: ", length(i))
    debug("cscChain columns length: ", length(j))
    debug("cscChain data length: ", length(brcCellList))

    debug("rows ", i)
    debug("columns ", j)
    debug("data ", data)

    cscChain = sparse(i, j, data, m, 1)
    cscmat = cscBoundaryMat * cscChain
    out = cscBinFilter(cscmat)
    return out
end

function cscBinFilter(CSCm)
  k = 1
  data = nonzeros(CSCm)
  sgArray = copysign(1, data)

  while k <= nnz(CSCm)
    if data[k] % 2 == 1 || data[k] % 2 == -1
      data[k] = 1 * sgArray[k]
    else
      data[k] = 0
    end
    k += 1
  end

  return CSCm
end

function cscChainToCellList(CSCm)
  """
  Get a csc containing a chain and returns
  the cell list of the "+1" oriented faces
```

```
    """
    data = nonzeros(CSCm)
    # Now I need to remove zero element (problem with Julia nonzeros)
    nonzeroData = Array(Int64, 0)
    for n in data
      if n != 0
        push!(nonzeroData, n)
      end
    end

    cellList = Array(Int64,0)
    for (k, theRow) in enumerate(findn(CSCm)[1])
      if nonzeroData[k] == 1
        push!(cellList, theRow)
      end
    end
    return cellList
  end
end
◇
```

LARUtils

"src/LARUtils.jl" 20≡

```
    module LARUtils

    using Logging

    export ind, invertIndex, getBases, removeDoubleVerticesAndFaces, computeModel, computeModelAndI

    function ind(x, y, z, nx, ny)
        """
        Transform coordinates into linearized matrix indexes
        """
        return x + (nx + 1) * (y + (ny + 1) * (z))
    end


    function invertIndex(nx,ny,nz)
      """
      Invert indexes
      """
      nx, ny, nz = nx + 1, ny + 1, nz + 1
```

```
  function invertIndex0(offset)
      a0, b0 = trunc(offset / nx), offset % nx
      a1, b1 = trunc(a0 / ny), a0 % ny
      a2, b2 = trunc(a1 / nz), a1 % nz
      return b0, b1, b2
  end
  return invertIndex0
end


function getBases(nx, ny, nz)
  """
  Compute all LAR relations
  """

  function the3Dcell(coords)
    x,y,z = coords
    return [ind(x,y,z,nx,ny),ind(x+1,y,z,nx,ny),ind(x,y+1,z,nx,ny),ind(x,y,z+1,nx,ny),ind(x+1,y
            ind(x+1,y,z+1,nx,ny),ind(x,y+1,z+1,nx,ny),ind(x+1,y+1,z+1,nx,ny)]
  end

  # Calculating vertex coordinates (nx * ny * nz)
  V = Array{Int64}[]
  for z in 0:nz
    for y in 0:ny
      for x in 0:nx
        push!(V,[x,y,z])
      end
    end
  end

  # Building CV relationship
  CV = Array{Int64}[]
  for z in 0:nz-1
    for y in 0:ny-1
      for x in 0:nx-1
        push!(CV,the3Dcell([x,y,z]))
      end
    end
  end

  # Building FV relationship
  FV = Array{Int64}[]
  v2coords = invertIndex(nx,ny,nz)

  for h in 0:(length(V)-1)
```

```
    x,y,z = v2coords(h)

    if (x < nx) && (y < ny)
      push!(FV, [h,ind(x+1,y,z,nx,ny),ind(x,y+1,z,nx,ny),ind(x+1,y+1,z,nx,ny)])
    end

    if (x < nx) && (z < nz)
      push!(FV, [h,ind(x+1,y,z,nx,ny),ind(x,y,z+1,nx,ny),ind(x+1,y,z+1,nx,ny)])
    end

    if (y < ny) && (z < nz)
      push!(FV,[h,ind(x,y+1,z,nx,ny),ind(x,y,z+1,nx,ny),ind(x,y+1,z+1,nx,ny)])
    end

  end

  # Building VV relationship
  VV = map((x)->[x], 0:length(V)-1)

  # Building EV relationship
  EV = Array{Int64}[]
  for h in 0:length(V)-1
    x,y,z = v2coords(h)
    if (x < nx)
      push!(EV, [h,ind(x+1,y,z,nx,ny)])
    end
    if (y < ny)
      push!(EV, [h,ind(x,y+1,z,nx,ny)])
    end
    if (z < nz)
      push!(EV, [h,ind(x,y,z+1,nx,ny)])
    end
  end

  # return all basis
  return V, (VV, EV, FV, CV)
end

function lessThanVertices(v1, v2)
  """
  Utility function for comparing vertices coordinates
  """

  if v1[1] == v2[1]
    if v1[2] == v2[2]
      return v1[3] < v2[3]
```

```
      end
      return v1[2] < v2[2]
    end
    return v1[1] < v2[1]
  end
end

function removeDoubleVerticesAndFaces(V, FV, facesOffset)
  """
  Removes double vertices and faces from a LAR model

  V: Array containing all vertices
  FV: Array containing all faces
  facesOffset: offset for faces indices
  """

  newV, indices = removeDoubleVertices(V)
  reindexedFaces = reindexVerticesInFaces(FV, indices, facesOffset)
  newFV = unique(FV)

  return newV, newFV

end

function removeDoubleVertices(V)
  """
  Remove double vertices from a LAR model

  V: Array containing all vertices of the model
  """

  # Sort the vertices list and returns the ordered indices
  orderedIndices = sortperm(V, lt = lessThanVertices, alg=MergeSort)

  orderedVerticesAndIndices = collect(zip(sort(V, lt = lessThanVertices),
                                          orderedIndices))
  newVertices = Array(Array{Int}, 0)
  indices = zeros(Int, length(V))
  prevv = Nothing
  i = 1
  for (v, ind) in orderedVerticesAndIndices
    if v == prevv
      indices[ind] = i - 1
    else
      push!(newVertices, v)
      indices[ind] = i
      i += 1
```

```
      prevv = v
    end
  end
  return newVertices, indices
end

function reindexVerticesInFaces(FV, indices, offset)
  """
  Reindex vertices indices in faces array

  FV: Faces array of the LAR model
  indices: new Indices for faces
  offset: offset for faces indices
  """

  for f in FV
    for i in 1: length(f)
      f[i] = indices[f[i] - offset] + offset
    end
  end
  return FV
end

function removeVerticesAndFacesFromBoundaries(V, FV)
  """
  Remove vertices and faces duplicates on
  boundaries models

  V,FV: lar model of two merged boundaries
  """

  newV, indices = removeDoubleVertices(V)
  uniqueIndices = unique(indices)

  # Removing double faces on both boundaries
  FV_reindexed = reindexVerticesInFaces(FV, indices, 0)
  FV_unique = unique(FV_reindexed)

  FV_cleaned = Array(Array{Int}, 0)
  for f in FV_unique
    if(count((x) -> x == f, FV_reindexed) == 1)
      push!(FV_cleaned, f)
    end
  end

  # Creating an array of faces with explicit vertices
```

```julia
  FV_vertices = Array(Array{Array{Int}}, 0)

  for i in 1 : length(FV_cleaned)
    push!(FV_vertices, Array(Array{Int}, 0))
    for vtx in FV_cleaned[i]
      push!(FV_vertices[i], newV[vtx])
    end
  end

  V_final = Array(Array{Int}, 0)
  FV_final = Array(Array{Int}, 0)

  # Saving only used vertices
  for face in FV_vertices
    for vtx in face
      push!(V_final, vtx)
    end
  end

  V_final = unique(V_final)

  # Renumbering FV
  for face in FV_vertices
    tmp = Array(Int, 0)
    for vtx in face
      ind = findfirst(V_final, vtx)
      push!(tmp, ind)
    end
    push!(FV_final, tmp)
  end

  return V_final, FV_final
end

function computeModel(imageDx, imageDy, imageDz,
                      xStart, yStart, zStart,
                      facesOffset, objectBoundaryChain)
  """
  Takes the boundary chain of a part of the entire model
  and returns a LAR model

  imageDx, imageDy, imageDz: Boundary dimensions
  xStart, yStart, zStart: Offset of this part of the model
  facesOffset: Offset for the faces
  objectBoundaryChain: Sparse csc matrix containing the cells
  """
```

```
    V, bases = getBases(imageDx, imageDy, imageDz)
    FV = bases[3]

    V_model = Array(Array{Int}, 0)
    FV_model = Array(Array{Int}, 0)

    vertex_count = 1

    #b2cells = Lar2Julia.cscChainToCellList(objectBoundaryChain)
    # Get all cells (independently from orientation)
    b2cells = findn(objectBoundaryChain)[1]

    debug("b2cells = ", b2cells)

    for f in b2cells
      old_vertex_count = vertex_count
      for vtx in FV[f]
        push!(V_model, [convert(Int, V[vtx + 1][1] + xStart),
                        convert(Int, V[vtx + 1][2] + yStart),
                        convert(Int, V[vtx + 1][3] + zStart)])
        vertex_count += 1
      end

      push!(FV_model, [old_vertex_count + facesOffset, old_vertex_count + 1 + facesOffset, old_v
      push!(FV_model, [old_vertex_count + facesOffset, old_vertex_count + 3 + facesOffset, old_v
    end

  # Removing double vertices
  return removeDoubleVerticesAndFaces(V_model, FV_model, facesOffset)

end

function isOnLeft(face, V, nx, ny, nz)
  """
  Check if face is on left boundary
  """

  for(vtx in face)
    if(V[vtx + 1][2] != 0)
      return false
    end
  end
  return true

end
```

```
function isOnRight(face, V, nx, ny, nz)
   """
   Check if face is on right boundary
   """

   for(vtx in face)
     if(V[vtx + 1][2] != ny)
       return false
     end
   end
   return true

end

function isOnTop(face, V, nx, ny, nz)
   """
   Check if face is on top boundary
   """

   for(vtx in face)
     if(V[vtx + 1][3] != nz)
       return false
     end
   end
   return true
end

function isOnBottom(face, V, nx, ny, nz)
   """
   Check if face is on bottom boundary
   """

   for(vtx in face)
     if(V[vtx + 1][3] != 0)
       return false
     end
   end
   return true
end

function isOnFront(face, V, nx, ny, nz)
   """
   Check if face is on front boundary
   """
```

```
    for(vtx in face)
      if(V[vtx + 1][1] != nx)
        return false
      end
    end
    return true
end

function isOnBack(face, V, nx, ny, nz)
  """
  Check if face is on back boundary
  """

  for(vtx in face)
    if(V[vtx + 1][1] != 0)
      return false
    end
  end
  return true
end

function computeModelAndBoundaries(imageDx, imageDy, imageDz,
                    xStart, yStart, zStart,
                    objectBoundaryChain)
  """
  Takes the boundary chain of a part of the entire model
  and returns a LAR model splitting the boundaries

  imageDx, imageDy, imageDz: Boundary dimensions
  xStart, yStart, zStart: Offset of this part of the model
  objectBoundaryChain: Sparse csc matrix containing the cells
  """

  function addFaceToModel(V_base, FV_base, V, FV, face, vertex_count)
    """
    Insert a face into a LAR model

    V_base, FV_base: LAR model of the base
    V, FV: LAR model
    face: Face that will be added to the model
    vertex_count: Indices for faces vertices
    """
    new_vertex_count = vertex_count
    for vtx in FV_base[face]
      push!(V, [convert(Int, V_base[vtx + 1][1] + xStart),
                      convert(Int, V_base[vtx + 1][2] + yStart),
```

```
                    convert(Int, V_base[vtx + 1][3] + zStart)])
    new_vertex_count += 1
  end
  push!(FV, [vertex_count, vertex_count + 1, vertex_count + 3])
  push!(FV, [vertex_count, vertex_count + 3, vertex_count + 2])

  return new_vertex_count
end

V, bases = getBases(imageDx, imageDy, imageDz)
FV = bases[3]

V_model = Array(Array{Int}, 0)
FV_model = Array(Array{Int}, 0)

V_left = Array(Array{Int},0)
FV_left = Array(Array{Int},0)

V_right = Array(Array{Int},0)
FV_right = Array(Array{Int},0)

V_top = Array(Array{Int},0)
FV_top = Array(Array{Int},0)

V_bottom = Array(Array{Int},0)
FV_bottom = Array(Array{Int},0)

V_front = Array(Array{Int},0)
FV_front = Array(Array{Int},0)

V_back = Array(Array{Int},0)
FV_back = Array(Array{Int},0)

vertex_count_model = 1
vertex_count_left = 1
vertex_count_right = 1
vertex_count_top = 1
vertex_count_bottom = 1
vertex_count_front = 1
vertex_count_back = 1

#b2cells = Lar2Julia.cscChainToCellList(objectBoundaryChain)
# Get all cells (independently from orientation)
b2cells = findn(objectBoundaryChain)[1]

debug("b2cells = ", b2cells)
```

```
  for f in b2cells
    old_vertex_count_model = vertex_count_model
    old_vertex_count_left = vertex_count_left
    old_vertex_count_right = vertex_count_right
    old_vertex_count_top = vertex_count_top
    old_vertex_count_bottom = vertex_count_bottom
    old_vertex_count_front = vertex_count_front
    old_vertex_count_back = vertex_count_back

    # Choosing the right model for vertex
    if(isOnLeft(FV[f], V, imageDx, imageDy, imageDz))
      vertex_count_left = addFaceToModel(V, FV, V_left, FV_left, f, old_vertex_count_left)
    elseif(isOnRight(FV[f], V, imageDx, imageDy, imageDz))
      vertex_count_right = addFaceToModel(V, FV, V_right, FV_right, f, old_vertex_count_right)
    elseif(isOnTop(FV[f], V, imageDx, imageDy, imageDz))
      vertex_count_top = addFaceToModel(V, FV, V_top, FV_top, f, old_vertex_count_top)
    elseif(isOnBottom(FV[f], V, imageDx, imageDy, imageDz))
      vertex_count_bottom = addFaceToModel(V, FV, V_bottom, FV_bottom, f, old_vertex_count_bot
    elseif(isOnFront(FV[f], V, imageDx, imageDy, imageDz))
      vertex_count_front = addFaceToModel(V, FV, V_front, FV_front, f, old_vertex_count_front)
    elseif(isOnBack(FV[f], V, imageDx, imageDy, imageDz))
      vertex_count_back = addFaceToModel(V, FV, V_back, FV_back, f, old_vertex_count_back)
    else
      vertex_count_model = addFaceToModel(V, FV, V_model, FV_model, f, old_vertex_count_model)
    end

  end

  # Removing double vertices
  return [removeDoubleVerticesAndFaces(V_model, FV_model, 0)],
  [removeDoubleVerticesAndFaces(V_left, FV_left, 0)],
  [removeDoubleVerticesAndFaces(V_right, FV_right, 0)],
  [removeDoubleVerticesAndFaces(V_top, FV_top, 0)],
  [removeDoubleVerticesAndFaces(V_bottom, FV_bottom, 0)],
  [removeDoubleVerticesAndFaces(V_front, FV_front, 0)],
  [removeDoubleVerticesAndFaces(V_back, FV_back, 0)]
end
end
◇
```

Model2Obj

"src/Model2Obj.jl" 31≡

```julia
module Model2Obj

import LARUtils

using Logging

export writeToObj, mergeObj, mergeObjParallel

function writeToObj(V, FV, outputFilename)
  """
  Take a LAR model and write it on obj file

  V: array containing vertices coordinates
  FV: array containing faces
  outputFilename: prefix for the output files
  """

  if (length(V) != 0)
    outputVtx = string(outputFilename, "_vtx.stl")
    outputFaces = string(outputFilename, "_faces.stl")

    fileVertex = open(outputVtx, "w")
    fileFaces = open(outputFaces, "w")

    for v in V
      write(fileVertex, "v ")
      write(fileVertex, string(v[1], " "))
      write(fileVertex, string(v[2], " "))
      write(fileVertex, string(v[3], "\n"))
    end

    for f in FV

      write(fileFaces, "f ")
      write(fileFaces, string(f[1], " "))
      write(fileFaces, string(f[2], " "))
      write(fileFaces, string(f[3], "\n"))
    end

    close(fileVertex)
    close(fileFaces)

  end

end
```

```
function mergeObj(modelDirectory)
  """
  Merge stl files in a single obj file

  modelDirectory: directory containing models
  """

  files = readdir(modelDirectory)
  vertices_files = files[find(s -> contains(s,string("_vtx.stl")), files)]
  faces_files = files[find(s -> contains(s,string("_faces.stl")), files)]
  obj_file = open(string(modelDirectory,"/","model.obj"),"w") # Output file

  vertices_counts = Array(Int64, length(vertices_files))
  number_of_vertices = 0
  for i in 1:length(vertices_files)
    vtx_file = vertices_files[i]
    f = open(string(modelDirectory, "/", vtx_file))
    debug("Opening ", vtx_file)

    # Writing vertices on the obj file
    for ln in eachline(f)
      write(obj_file, ln)
      number_of_vertices += 1
    end
    # Saving number of vertices
    vertices_counts[i] = number_of_vertices
    close(f)
  end

  for i in 1 : length(faces_files)
    faces_file = faces_files[i]
    f = open(string(modelDirectory, "/", faces_file))
    debug("Opening ", faces_file)
    for ln in eachline(f)
      splitted = split(ln)
      write(obj_file, "f ")
      if i > 1
        write(obj_file, string(parse(splitted[2]) + vertices_counts[i - 1], " "))
        write(obj_file, string(parse(splitted[3]) + vertices_counts[i - 1], " "))
        write(obj_file, string(parse(splitted[4]) + vertices_counts[i - 1]))
      else
        write(obj_file, string(splitted[2], " "))
        write(obj_file, string(splitted[3], " "))
        write(obj_file, splitted[4])
      end
```

```
      write(obj_file, "\n")
    end
    close(f)
  end
  close(obj_file)

  # Removing all tmp files
  for vtx_file in vertices_files
    rm(string(modelDirectory, "/", vtx_file))
  end

  for fcs_file in faces_files
    rm(string(modelDirectory, "/", fcs_file))
  end

end

function assignTasks(startInd, endInd, taskArray)
  """
  This function choose the first files to merge
  creating a tree where number of processes is maximized

  startInd: starting index for array subdivision
  endInd: end index for array subdivision
  taskArray: array containing indices of files to merge for first
  """
  if (endInd - startInd == 2)
    push!(taskArray, startInd)
  elseif (endInd - startInd < 2)
    if (endInd % 4 != 0 && startInd != endInd)
      # Stop recursion on this branch
      push!(taskArray, startInd)
    end
    # Stop recursion doing nothing
  else
    assignTasks(startInd, startInd + trunc((endInd - startInd) / 2), taskArray)
    assignTasks(startInd + trunc((endInd - startInd) / 2) + 1, endInd, taskArray)
  end
end

function mergeVerticesFiles(file1, file2, startOffset)
  """
  Support function for merging two vertices files.
  Returns the number of vertices of the merged file

  file1: path of the first file
```

```
    file2: path of the second file
    startOffset: starting face offset for second file
    """

    f1 = open(file1, "a")

    f2 = open(file2)
    debug("Merging ", file2)
    number_of_vertices = startOffset
    for ln in eachline(f2)
      write(f1, ln)
      number_of_vertices += 1
    end
    close(f2)

    close(f1)

    return number_of_vertices
  end


  function mergeFacesFiles(file1, file2, facesOffset)
    """
    Support function for merging two faces files

    file1: path of the first file
    file2: path of the second file
    facesOffset: offset for faces
    """

    f1 = open(file1, "a")

    f2 = open(file2)
    for ln in eachline(f2)
      splitted = split(ln)
      write(f1, "f ")
      write(f1, string(parse(splitted[2]) + facesOffset, " "))
      write(f1, string(parse(splitted[3]) + facesOffset, " "))
      write(f1, string(parse(splitted[4]) + facesOffset, "\n"))
    end
    close(f2)

    close(f1)
  end

  function mergeObjProcesses(fileArray, facesOffset = Nothing)
```

```julia
  """
  Merge files on a single process

  fileArray: Array containing files that will be merged
  facesOffset (optional): if merging faces files, this array contains
    offsets for every file
  """

  if(contains(fileArray[1], string("_vtx.stl")))
    # Merging vertices files
    offsets = Array(Int, 0)
    push!(offsets, countlines(fileArray[1]))
    vertices_count = mergeVerticesFiles(fileArray[1], fileArray[2], countlines(fileArray[1]))
    rm(fileArray[2]) # Removing merged file
    push!(offsets, vertices_count)
    for i in 3: length(fileArray)
      vertices_count = mergeVerticesFiles(fileArray[1], fileArray[i], vertices_count)
      rm(fileArray[i]) # Removing merged file
      push!(offsets, vertices_count)
    end
    return offsets
  else
    # Merging faces files
    mergeFacesFiles(fileArray[1], fileArray[2], facesOffset[1])
    rm(fileArray[2]) # Removing merged file
    for i in 3 : length(fileArray)
      mergeFacesFiles(fileArray[1], fileArray[i], facesOffset[i - 1])
      rm(fileArray[i]) # Removing merged file
    end
  end
end

function mergeObjHelper(vertices_files, faces_files)
  """
  Support function for mergeObj. It takes vertices and faces files
  and execute a single merging step

  vertices_files: Array containing vertices files
  faces_files: Array containing faces files
  """
  numberOfImages = length(vertices_files)
  taskArray = Array(Int, 0)
  assignTasks(1, numberOfImages, taskArray)

  # Now taskArray contains first files to merge
  numberOfVertices = Array(Int, 0)
```

```
    tasks = Array(RemoteRef, 0)
    for i in 1 : length(taskArray) - 1
      task = @spawn mergeObjProcesses(vertices_files[taskArray[i] : (taskArray[i + 1] - 1)])
      push!(tasks, task)
      #append!(numberOfVertices, mergeObjProcesses(vertices_files[taskArray[i + 1]
    end

    # Merging last vertices files
    task = @spawn mergeObjProcesses(vertices_files[taskArray[length(taskArray)] : end])
    push!(tasks, task)
    #append!(numberOfVertices, mergeObjProcesses(vertices_files[taskArray[length(taskArray)] : e

    for task in tasks
      append!(numberOfVertices, fetch(task))
    end

    debug("NumberOfVertices = ", numberOfVertices)

    # Merging faces files
    tasks = Array(RemoteRef, 0)
    for i in 1 : length(taskArray) - 1

      task = @spawn mergeObjProcesses(faces_files[taskArray[i] : (taskArray[i + 1] - 1)],
                                        numberOfVertices[taskArray[i] : (taskArray[i + 1] - 1)])
      push!(tasks, task)

      #mergeObjProcesses(faces_files[taskArray[i] : (taskArray[i + 1] - 1)],
      #                  numberOfVertices[taskArray[i] : (taskArray[i + 1] - 1)])
    end

    #Merging last faces files
    task = @spawn mergeObjProcesses(faces_files[taskArray[length(taskArray)] : end],
                                      numberOfVertices[taskArray[length(taskArray)] : end])

    push!(tasks, task)
    #mergeObjProcesses(faces_files[taskArray[length(taskArray)] : end],
    #                  numberOfVertices[taskArray[length(taskArray)] : end])

    for task in tasks
      wait(task)
    end

end

function mergeObjParallel(modelDirectory)
```

```
    """
    Merge stl files in a single obj file using a parallel
    approach. Files will be recursively merged two by two
    generating a tree where number of processes for every
    step is maximized
    Actually use of this function is discouraged. In fact
    speedup is influenced by disk speed. It could work on
    particular systems with parallel accesses on disks

    modelDirectory: directory containing models
    """

    files = readdir(modelDirectory)

    # Appending directory path to every file
    files = map((s) -> string(modelDirectory, "/", s), files)

    # While we have more than one vtx file and one faces file
    while(length(files) != 2)
      vertices_files = files[find(s -> contains(s,string("_vtx.stl")), files)]
      faces_files = files[find(s -> contains(s,string("_faces.stl")), files)]

      # Merging files
      mergeObjHelper(vertices_files, faces_files)

      files = readdir(modelDirectory)
      files = map((s) -> string(modelDirectory, "/", s), files)
    end

    mergeVerticesFiles(files[2], files[1], 0)
    mv(files[2], string(modelDirectory, "/model.obj"))
    rm(files[1])

end

function mergeAndRemoveDuplicates(firstPath, secondPath)
    """
    Merge two boundary files removing common faces between
    them

    firstPath, secondPath: Prefix of paths to merge
    """

    firstPathV = string(firstPath, "_vtx.stl")
    firstPathFV = string(firstPath, "_faces.stl")
```

```julia
secondPathV = string(secondPath, "_vtx.stl")
secondPathFV = string(secondPath, "_faces.stl")

if(isfile(firstPathV) && isfile(secondPathV))

  V = Array(Array{Int}, 0)
  FV = Array(Array{Int}, 0)

  offset = 0

  # First of all open files and retrieve LAR models

  f1_V = open(firstPathV)
  f1_FV = open(firstPathFV)

  for ln in eachline(f1_V)
    splitted = split(ln)
    push!(V, [parse(splitted[2]), parse(splitted[3]), parse(splitted[4])])
    offset += 1
  end

  for ln in eachline(f1_FV)
    splitted = split(ln)
    push!(FV, [parse(splitted[2]), parse(splitted[3]), parse(splitted[4])])
  end

  close(f1_V)
  close(f1_FV)

  f2_V = open(secondPathV)
  f2_FV = open(secondPathFV)

  for ln in eachline(f2_V)
    splitted = split(ln)
    push!(V, [parse(splitted[2]), parse(splitted[3]), parse(splitted[4])])
  end

  for ln in eachline(f2_FV)
    splitted = split(ln)
    push!(FV, [parse(splitted[2]) + offset, parse(splitted[3]) + offset, parse(splitted[4]) +
  end

  close(f2_V)
  close(f2_FV)

  V_final, FV_final = LARUtils.removeVerticesAndFacesFromBoundaries(V, FV)
```

```
      # Writing model to file
      rm(firstPathV)
      rm(firstPathFV)
      rm(secondPathV)
      rm(secondPathFV)
      writeToObj(V_final, FV_final, firstPath)
    end
end

function mergeBoundariesProcess(modelDirectory, startImage, endImage,
                                imageDx, imageDy,
                                imageWidth, imageHeight)
  """
  Helper function for mergeBoundaries.
  It is executed on different processes

  modelDirectory: Directory containing model files
  startImage: Block start image
  endImage: Block end image
  imageDx, imageDy: x and y sizes of the grid
  imageWidth, imageHeight: Width and Height of the image
  """
  for xBlock in 0:(imageHeight / imageDx - 1)
    for yBlock in 0:(imageWidth / imageDy - 1)

      # Merging right Boundary
      firstPath = string(modelDirectory, "/right_output_", xBlock, "-", yBlock, "_", startImag
      secondPath = string(modelDirectory, "/left_output_", xBlock, "-", yBlock + 1, "_", start
      mergeAndRemoveDuplicates(firstPath, secondPath)

      # Merging top boundary
      firstPath = string(modelDirectory, "/top_output_", xBlock, "-", yBlock, "_", startImage,
      secondPath = string(modelDirectory, "/bottom_output_", xBlock, "-", yBlock, "_", endImag
      mergeAndRemoveDuplicates(firstPath, secondPath)

      # Merging front boundary
      firstPath = string(modelDirectory, "/front_output_", xBlock, "-", yBlock, "_", startImag
      secondPath = string(modelDirectory, "/back_output_", xBlock + 1, "-", yBlock, "_", start
      mergeAndRemoveDuplicates(firstPath, secondPath)
    end
  end
end

function mergeBoundaries(modelDirectory,
                         imageHeight, imageWidth, imageDepth,
```

```
                                 imageDx, imageDy, imageDz)
    """
    Merge boundaries files. For every cell of size
    (imageDx, imageDy, imageDz) in the model grid,
    it merges right faces with next left faces, top faces
    with the next cell bottom faces, and front faces
    with the next cell back faces

    modelDirectory: directory containing models
    imageHeight, imageWidth, imageDepth: images sizes
    imageDx, imageDy, imageDz: sizes of cells grid
    """

    beginImageStack = 0
    endImage = beginImageStack

    tasks = Array(RemoteRef, 0)
    for zBlock in 0:(imageDepth / imageDz - 1)
      startImage = endImage
      endImage = startImage + imageDz
      task = @spawn mergeBoundariesProcess(modelDirectory, startImage, endImage,
                              imageDx, imageDy,
                              imageWidth, imageHeight)
      push!(tasks, task)
    end

    # Waiting for tasks
    for task in tasks
      wait(task)
    end
  end
  end
  ◇
```

PngStack2Array3dJulia

"src/PngStack2Array3dJulia.jl" 40≡

```
    module PngStack2Array3dJulia

    export calculateClusterCentroids, pngstack2array3d, getImageData, convertImages

    using Images # For loading png images
    using Colors # For grayscale images
```

```julia
using PyCall # For including python clustering
using Logging
@pyimport scipy.ndimage as ndimage
@pyimport scipy.cluster.vq as cluster

NOISE_SHAPE_DETECT=10

function getImageData(imageFile)
  """
  Get width and heigth from a png image
  """

  input = open(imageFile, "r")
  data = readbytes(input, 24)

  if (data[2:4] != [80, 78, 71] && data[13:16] != [73, 72, 68, 82])
    error("This is not a png image")
  end

  w = data[17:20]
  h = data[21:24]

  width = reinterpret(Int32, reverse(w))[1]
  height = reinterpret(Int32, reverse(h))[1]

  close(input)

  return width, height
end

function calculateClusterCentroids(path, image, numberOfClusters = 2)
  """
  Loads an image and calculate cluster centroids for segmentation

  path: Path of the image folder
  image: name of the image
  numberOfClusters: number of desidered clusters
  """
  imageFilename = string(path, image)

  img = imread(imageFilename) # Open png image with Julia Package

  rgb_img = convert(Image{ColorTypes.RGB}, img)
  gray_img = convert(Image{ColorTypes.Gray}, rgb_img)
  imArray = raw(gray_img)
```

```
  imageWidth = size(imArray)[1]
  imageHeight = size(imArray)[2]

  # Getting pixel values and saving them with another shape
  image3d = Array(Array{Uint8,2}, 0)

  # Inserting page on another list and reshaping
  push!(image3d, imArray)
  pixel = reshape(image3d[1], (imageWidth * imageHeight), 1)

  # Segmenting image using kmeans
  # https://en.wikipedia.org/wiki/Image_segmentation#Clustering_methods

  centroids,_ = cluster.kmeans(pixel, numberOfClusters)

  return centroids

end


function pngstack2array3d(path, minSlice, maxSlice, centroids)
  """
  Import a stack of PNG images into a 3d array

  path: path of images directory
  minSlice and maxSlice: number of first and last slice
  centroids: centroids for image segmentation
  """

  # image3d contains all images values
  image3d = Array(Array{Uint8,2}, 0)

  debug("maxSlice = ", maxSlice, " minSlice = ", minSlice)
  files = readdir(path)

  for slice in minSlice : (maxSlice - 1)
    debug("slice = ", slice)
    imageFilename = string(path, files[slice + 1])
    debug("image name: ", imageFilename)
    img = imread(imageFilename) # Open png image with Julia Package

    # Converting image in grayscale
    rgb_img = convert(Image{ColorTypes.RGB}, img)
    gray_img = convert(Image{ColorTypes.Gray}, rgb_img)
    imArray = raw(gray_img) # Putting pixel values into RAW 3d array
    debug("imArray size: ", size(imArray))
```

```julia
      # Inserting page on another list and reshaping
      push!(image3d, imArray)

   end

   # Removing noise using a median filter and quantization
   for page in 1:length(image3d)

      # Denoising
      image3d[page] = ndimage.median_filter(image3d[page], NOISE_SHAPE_DETECT)

      # Image Quantization
      debug("page = ", page)
      debug("image3d[page] dimensions: ", size(image3d[page])[1], "\t", size(image3d[page])[2])
      pixel = reshape(image3d[page], size(image3d[page])[1] * size(image3d[page])[2] , 1)
      qnt,_ = cluster.vq(pixel,centroids)

      # Reshaping quantization result
      centers_idx = reshape(qnt, size(image3d[page],1), size(image3d[page],2))
      #centers_idx = reshape(qnt, size(image3d[page]))

      # Inserting quantized values into 3d image array
      tmp = Array(Uint8, size(image3d[page],1), size(image3d[page],2))

      for j in 1:size(image3d[1],2)
        for i in 1:size(image3d[1],1)
          tmp[i,j] = centroids[centers_idx[i,j] + 1]
        end
      end

      image3d[page] = tmp

   end

   return image3d
end

function convertImages(inputPath, outputPath, bestImage)
   """
   Get all images contained in inputPath directory
   saving them in outputPath directory in png format.
   If images have one of two odd dimensions, they will be resized
   and if folder contains an odd number of images another one will be
   added
```

```
inputPath: Directory containing input images
outputPath: Temporary directory containing png images
bestImage: Image chosen for centroids computation

Returns the new name for the best image
"""

imageFiles = readdir(inputPath)
numberOfImages = length(imageFiles)
outputPrefix = ""
for i in 1: length(string(numberOfImages)) - 1
  outputPrefix = string(outputPrefix,"0")
end

newBestImage = ""
imageNumber = 0
for imageFile in imageFiles
  img = imread(string(inputPath, imageFile))

  # resizing images if they do not have even dimensions
  dim = size(img)
  if(dim[1] % 2 != 0)
    debug("Image has odd x; resizing")
    xrange = 1: dim[1] - 1
  else
    xrange = 1: dim[1]
  end

  if(dim[2] % 2 != 0)
    debug("Image has odd y; resizing")
    yrange = 1: dim[2] - 1
  else
    yrange = 1: dim[2]
  end

  img = subim(img, xrange, yrange)

  outputFilename = string(outputPath, outputPrefix[length(string(imageNumber)):end], imageNu
  imwrite(img, outputFilename)

  # Searching the best image
  if(imageFile == bestImage)
    newBestImage = string(outputPrefix[length(string(imageNumber)):end], imageNumber,".png")
  end

  imageNumber += 1
```

```
      end

      # Adding another image if they are odd
      if(numberOfImages % 2 != 0)
        debug("Odd images, adding one")
        bestImage = imread(string(outputPath, "/", newBestImage))
        imArray = zeros(Uint8, size(bestImage))
        img = grayim(imArray)
        outputFilename = string(outputPath, "/", outputPrefix[length(string(imageNumber)):end], ima
        imwrite(img, outputFilename)
      end

    return newBestImage
  end
  end
  ◇
```

10.1 Installing the library

11 Conclusions

11.1 Results

11.2 Further improvements

References

[CL13]   CVD-Lab, *Linear algebraic representation*, Tech. Report 13-00, Roma Tre University, October 2013.

[PDFJ15] Alberto Paoluzzi, Antonio DiCarlo, Francesco Furiani, and Miroslav Jirik, *Cad models from medical images using lar*, Computer-Aided Design and Applications **13** (2015), To appear.

A Utility functions

B Tests

Generation of the border matrix

"test/generateBorderMatrix.jl" 45≡

```julia
push!(LOAD_PATH, "../../")
import GenerateBorderMatrix
import JSON
using Base.Test

function testComputeOriented3Border()
    """
    Test function for computeOriented3Border
    """
    boundaryMatrix = GenerateBorderMatrix.computeOriented3Border(2,2,2)

    rowcount = boundaryMatrix[:shape][1]
    @test rowcount == 36
    colcount = boundaryMatrix[:shape][2]
    @test colcount == 8
    row = boundaryMatrix[:indptr]
    @test row == [0,1,2,3,4,5,7,8,9,11,12,13,15,17,18,19,20,22,23,24,26,27,29,30,32,34,35,37,39,4
    col = boundaryMatrix[:indices]
    @test col == [0,0,0,1,1,0,1,1,2,0,2,2,3,1,3,2,3,3,2,3,0,4,4,4,1,5,5,4,5,5,2,6,4,6,6,3,7,5,7,0
    data = boundaryMatrix[:data]
    @test data == [-1,1,-1,-1,1,1,-1,1,-1,-1,1,-1,-1,-1,1,1,-1,1,-1,-1,1,-1,1,-1,1,1,-1,1,1

end

function testWriteBorder()
    """
    Test for writeBorder
    """
    boundaryMatrix = GenerateBorderMatrix.computeOriented3Border(2,2,2)
    filename = "borderFile"

    GenerateBorderMatrix.writeBorder(boundaryMatrix, filename)
    @test isfile(filename)

    # Loading borderMatrix from json file
    borderData = JSON.parsefile(filename)
    row = Array(Int64, length(borderData["ROW"]))
    col = Array(Int64, length(borderData["COL"]))
    data = Array(Int64, length(borderData["DATA"]))

    @test borderData["ROW"] == [0,1,2,3,4,5,7,8,9,11,12,13,15,17,18,19,20,22,23,24,26,27,29,30,3
    @test borderData["COL"] == [0,0,0,1,1,0,1,1,2,0,2,2,3,1,3,2,3,3,2,3,0,4,4,4,1,5,5,4,5,5,2,6,
    @test borderData["DATA"] == [-1,1,-1,-1,1,1,-1,1,-1,-1,1,-1,-1,-1,1,1,-1,1,-1,-1,1,-1,1,-1,1

    rm(filename)
```

```
end

function executeAllTests()
  @time testComputeOriented3Border()
  @time testWriteBorder()
  println("Tests completed.")
end

executeAllTests()

◇
```

Conversion of a png stack to a 3D array

```
"test/pngStack2Array3dJulia.jl" 47≡
    push!(LOAD_PATH, "../../")
    import PngStack2Array3dJulia
    using Base.Test

    function testGetImageData()
      """
      Test function for getImageData
      """

      width, height = PngStack2Array3dJulia.getImageData("images/0.png")

      @test width == 50
      @test height == 50

    end

    function testCalculateClusterCentroids()
      """
      Test function for calculateClusterCentroids
      """
      path = "images/"
      image = 0
      centroids = PngStack2Array3dJulia.calculateClusterCentroids(path, image, 2)

      expected = [0, 253]
      centroids = vec(reshape(centroids, 1, 2))

      @test sort(centroids) == expected
```

```
end

function testPngstack2array3d()
  """
  Test function for pngstack2array3d
  """
  path = "images/"
  minSlice = 0
  maxSlice = 4
  centroids = PngStack2Array3dJulia.calculateClusterCentroids(path, 0, 2)
  image3d = PngStack2Array3dJulia.pngstack2array3d(path, minSlice, maxSlice, centroids)

  @test size(image3d)[1] == 5
  @test size(image3d[1])[1] == 50
  @test size(image3d[1])[2] == 200

end

function executeAllTests()
  @time testCalculateClusterCentroids()
  @time testPngstack2array3d()
  @time testGetImageData()
  println("Tests completed.")
end

executeAllTests()

◇
```

Test for LAR utilities

"test/LARUtils.jl" 48≡
```
push!(LOAD_PATH, "../../")
import LARUtils
using Base.Test

function testInd()
  """
  Test function for ind
  """

  nx = 2
  ny = 2
```

```
  @test LARUtils.ind(0, 0, 0, nx, ny) == 0
  @test LARUtils.ind(1, 1, 1, nx, ny) == 13
  @test LARUtils.ind(2, 5, 4, nx, ny) == 53
  @test LARUtils.ind(1, 1, 1, nx, ny) == 13
  @test LARUtils.ind(2, 7, 1, nx, ny) == 32
  @test LARUtils.ind(1, 0, 3, nx, ny) == 28
end

function executeAllTests()
  @time testInd()
  println("Tests completed.")
end

executeAllTests()

◇
```