

# IN480 Larstruct Module

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# Introduction

This module of LAR-CC library deals with the hierarchical structures with LAR. Hierarchical models of complex assemblies are generated by an aggregation of subassemblies, each one defined in a local coordinates's system, and relocated by affine transformations of coordinates.

In this module there are:

- The **Affine transformations** whom are based on elementary matrices for affine transformations of vectors in any dimensional vector space, including translation, scaling and rotation;
- The **Struct iterable class**, starting from an array representable geometric object, generates a new object representing the initial one in an alternative way, by means of specific fields attribution, e.g. body, box, etc..
- The **structure to LAR conversion** is based on functions for the embedding of two-dimensional LAR model into 3D space. It removes duplicate faces, vertices and cells of geometric objec

In the next sections the main functions of the module will be shown through the API. For each function will be proposed the codes' conversion from Python to Julia language, a parallelization frame, some unit tests and the study of the execution times.

# 1 API

- **larApply**(Matrix)(Tuple)→ Tuple

Through the affine matrix given in input, it performs an affine transformation and returns in output a tuple containing two arrays: the list of the transformed coordinates of the vertices and a cells vector.

- **evalStruct**(Struct)→ Array

It analyzes the elements contained in the Struct object and returns an array containing the main data structures. Each structure is described by an array containing two arrays: the list of the transformed coordinates of the vertices and a cells vector.

- **vcode**(Int)(Array)→String

It approximates each element of the data structure to which it is applied. The approximation occurs with precision given by the integer given in input. The transformed data structure is returned in output as a string.

- **struct2lar**(Struct)→ Array

It converts an object of type Struct in a pair (Vertices,Cells) containing the array of the coordinates of the vertices (of any the objects present) and a cells vector (without duplicates of vertices).

- **larRemoveVertices**(Array, Array)→ (Array,Array)

It takes in input an array of vertices an the array of cells and removes any duplicates from them.

- **larEmbed**(Int)(Tuple)→ Tuple

If allows to immerse a k-dimensional geometric object into an n-dimensional space with  $n > k$ , or to pull it back to its representation in a space of dimension n starting from its representation in a space of dimension  $k > n$ . Namely, given in input n and the tuple T representing the geometric object in a space of dimension k the function will return the representation of the object T in a space of dimension  $k + n$ . Note that the value of n can be negative. In order to understand the rational behind this function, it is enough to think about the application of 3D transformations to a two-dimensional LAR model, in this case it needs to be embedded in a 3D space adding one more coordinate to its vertices.

- **larBoundary**(Struct)→ (Array,Array,Array)

It apply struct2lar to the input. If the output has dimension 3, the function returns a tuple containing 3 outputs, otherwise it returns a string containing an error message.

- **embedStruct(Int)(Struct)→ Struct**

It returns a copy of the geometrical object of dimension k represented by the structure in input. The dimension of the copy will be equal to that of the original one plus the value of the integer n given in input.

## Local Functions

- **checkStruct(Array)→ Int**
- **traversal(Matrix,Array,Struct,Array)→ Array**
- **fixedPrec(Int)→ String**
- **removeDups(Array)→ Array**

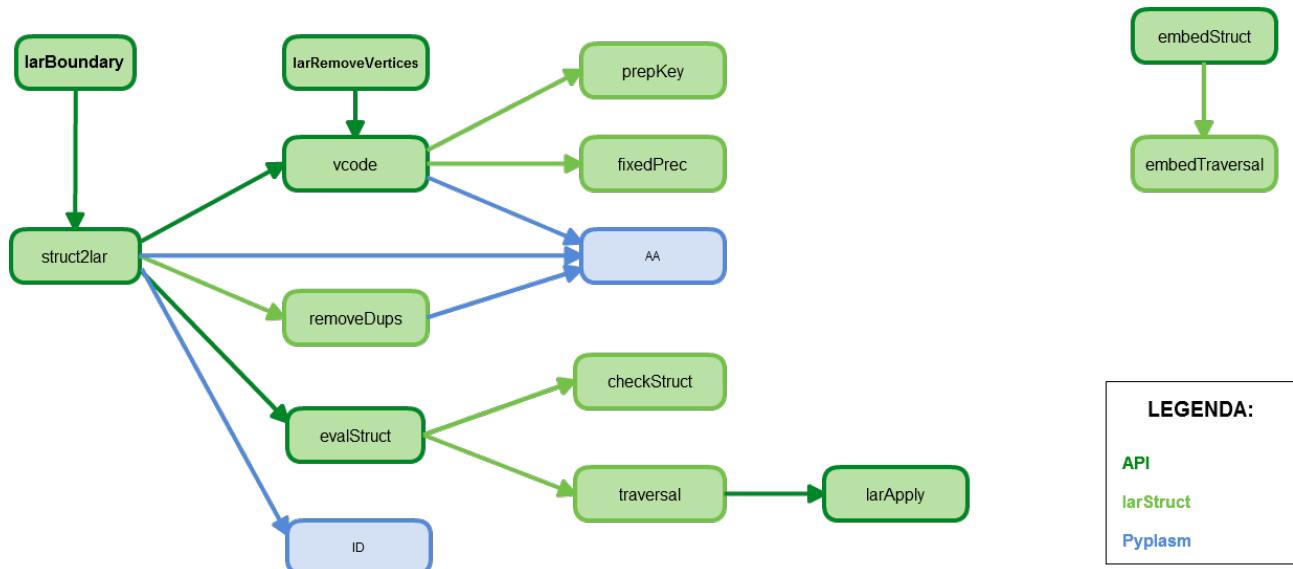


Figure 1: larStruct API

This module is divided into three sections: “**Implementation**”, “**Examples**” and “**Conclusion**”.

The section “Implementation” contains for each function four sub-sections. The sub-section “**Conversion**” shows the conversion of some of the most important functions of the module from Python to Julia language. The sub-section “**Parallelization**” is based on the use of the following Julia’s macros to parallelize the code:

- **@everywhere**: can be used to directly define a function on all processes
- **@parallel**: can be used to run a for loop on any number of processes
- **@sync**: wait until all dynamically-enclosed uses of @async, @spawn, @spawnat and @parallel are complete
- **@async**: wraps an expression in a Task and adds it to the local machine’s scheduler queue. Additionally it adds the task to the set of items that the nearest enclosing @sync waits for.

The Parallel computing is performed on 4 simultaneous processes in a personal computer running the command

```
addprocs(3)
```

within Julia console. Alternatively the parallelization can be performed running on the shell the command

```
julia -p 3
```

Parallel computing is performed also on 30 simultaneous processes running the command

```
addprocs(29)
```

within Julia console (in “Tesla”) or running on the shell the command

```
julia -p 29
```

The main tasks in the sub-section “**Unit-Test**” are carried out via the use of a particular Julia module, named **Base.Test**. The latter provides simple unit testing functionality. Unit testing is a way to see if your code is correct by checking that the results are what you expect. It can be helpful to ensure your code still works after you make changes, and can be used when developing as a way of specifying the behaviors your code should have when complete. To perform a simple unit testing, you need first to import the “Base.Test” package typing the following command within the Julia console:

```
using Base.Test
```

Then the test can be performed with the `@test()` macro.

The sub-section “Result” are divided into two parts: in the first part there are the plots representing the execution time of the underlying function performed on a personal computer with 4 processors. The magnitude of the input is increased by means of the function “Lar-Cuboids” (which is imported by the “largrid” module):

```
using PyCall
@pyimport larlib as lar
l=[]
for i in range(0,3)
    p=PyObject(lar.larCuboids([10^i,10^i]))
    push!(l,Tuple	append!([map(collect,PyObject(p[1]))],[PyObject(p[2])])))
    p=PyObject(lar.larCuboids([2*10^i,2*10^i]))
    push!(l,Tuple-append!([map(collect,PyObject(p[1]))],[PyObject(p[2])])))
    p=PyObject(lar.larCuboids([5*10^i,5*10^i]))
    push!(l,Tuple-append!([map(collect,PyObject(p[1]))],[PyObject(p[2])])))
end
```

The function used to compute the execution time is:

```
function Time(f,args)
    @elapsed f(args...)
    t=[]
    for i in range(1,10)
        push!(t,@elapsed f(args...))
    end
    m=mean(t)
    return m
end
```

The macro `@elapsed` is used to evaluates the execution time of the function given in input, discarding the resulting value, and returning just the amount of seconds elapsed to run the function. The time is expressed as a floating-point number.

The second part of the subsection “Result” contains the plot of the underlying function performance, run on “Tesla” with 30 processors, where the input magnitude is increased via the following function:

```
function addn2D(n,model)
    body=[]
    for i in range(1,n)
        el=[]
        matrix=rand(1:3)
        if matrix==1
            x=rand(1:10)/10
            y=rand(1:10)/10
            append!(el,larApply(t(x,y))(model))
            append!(body,[el])
        elseif matrix ==2
```

```

x=rand(1:10)/10
y=rand(1:10)/10
append!(el,larApply(s(x,y))(model))
append!(body,[el])
elseif matrix ==3
    x=rand(1:10)
    append!(el,larApply(r(pi/x))(model))
    append!(body,[el])
end
end
a=Struct(body)
return a
end

```

To generate the plots you need to import “Plots” and “Distributions” packages typing the following commands within the Julia console:

- `using Plots`
- `using Distributions`

## 2 Implementation

### 2.1 checkStruct

#### 2.1.1 Conversion

Python

```
def checkStruct(lst):
    obj = lst[0]
    if(isinstance(obj,tuple) or isinstance(obj,list)):
        dim = len(obj[0][0])
    elif isinstance(obj,Model):
        dim = obj.n
    elif isinstance(obj,Mat):
        dim = obj.shape[0]-1
    elif isinstance(obj,Struct):
        dim = len(obj.box[0])
    return dim
```

Julia

```
function checkStruct(lst)
    obj = lst[1]
    if isa(obj,Matrix)
        dim=size(obj)[1]-1
    elseif(isa(obj,Tuple) || isa(obj,Array))
        dim=length(obj[1][1])
    elseif isa(obj,Struct)
        dim=length(obj.box[1])
    end
    return dim
end
```

#### 2.1.2 Parallelization

```
function pcheckStruct(lst)
    obj = lst[1]
    if isa(obj,Matrix)
        dim=size(obj)[1]-1
    elseif(isa(obj,Tuple) || isa(obj,Array))
        dim=length(obj[1][1])
    elseif isa(obj,pStruct)
        dim=length(obj.box[1])
    end
    return dim
end
```

### 2.1.3 Unit-Test

```
@testset "checkStruct Tests" begin
    list=[[0.575,-0.175],[0.575,0.175],[0.925,-0.175],[0.925,0.175]],[[0,1,2,3]])
@test checkStruct(list)==length(list[1][1][1])
@test typeof(checkStruct(list))==Int
end
```

## 2.2 larApply

### 2.2.1 Conversion

The function larApply returns as output an affine trasformation of the input object and it is based on the following affine matrices:

#### Rotation

##### Python

```
def r(*args):
    args = list(args)
    n = len(args)
    if n == 1: # rotation in 2D
        angle = args[0]; cos = COS(angle); sin = SIN(angle)
        mat = scipy.identity(3)
        mat[0,0] = cos;    mat[0,1] = -sin;
        mat[1,0] = sin;    mat[1,1] = cos;
    if n == 3: # rotation in 3D
        mat = scipy.identity(4)
        angle = VECTNORM(args); axis = UNITVECT(args)
        cos = COS(angle); sin = SIN(angle)
        if axis[1]==axis[2]==0.0: # rotation about x
            mat[1,1] = cos;    mat[1,2] = -sin;
            mat[2,1] = sin;    mat[2,2] = cos;
        elif axis[0]==axis[2]==0.0: # rotation about y
            mat[0,0] = cos;    mat[0,2] = sin;
            mat[2,0] = -sin;   mat[2,2] = cos;
        elif axis[0]==axis[1]==0.0: # rotation about z
            mat[0,0] = cos;    mat[0,1] = -sin;
            mat[1,0] = sin;    mat[1,1] = cos;
        else: # general 3D rotation
            I = scipy.identity(3) ; u = axis
            Ux = scipy.array([
                [0,           -u[2],      u[1]],
                [u[2],         0,       -u[0]],
                [-u[1],        u[0],      0]])
            UU = scipy.array([
                [u[0]*u[0],    u[0]*u[1],    u[0]*u[2]],
                [u[1]*u[0],    u[1]*u[1],    u[1]*u[2]],
                [u[2]*u[0],    u[2]*u[1],    u[2]*u[2]])]
            mat[:3,:3] = cos*I + sin*Ux + (1.0-cos)*UU
    return mat.view(Mat)
```

##### Julia

```
@everywhere function r(args...)
    args = collect(args)
    n = length(args)
    if n == 1 # rotation in 2D
        angle = args[1]; COS = cos(angle); SIN = sin(angle)
        mat = eye(3)
        mat[1,1] = COS;    mat[1,2] = -SIN;
        mat[2,1] = SIN;    mat[2,2] = COS;
    end
    if n == 3 # rotation in 3D
        mat = eye(4)
        angle = norm(args); axis = normalize(args)
        COS = cos(angle); SIN= sin(angle)
        if axis[2]==axis[3]==0.0 # rotation about x
            mat[2,2] = COS;    mat[2,3] = -SIN;
            mat[3,2] = SIN;    mat[3,3] = COS;
        elseif axis[1]==axis[3]==0.0 # rotation about y
            mat[1,1] = COS;    mat[1,3] = SIN;
            mat[3,1] = -SIN;   mat[3,3] = COS;
        elseif axis[1]==axis[2]==0.0 # rotation about z
            mat[1,1] = SIN;    mat[1,2] = -SIN;
            mat[2,1] = COS;    mat[2,2] = COS;
        else
            I=eye(3); u=axis
            UX=[0 -u[3] u[2] ; u[3] 0 -u[1] ; -u[2] u[1] 1]
            UU =[u[1]*u[1] u[1]*u[2] u[1]*u[3];
                  u[2]*u[1] u[2]*u[2] u[2]*u[3];
                  u[3]*u[1] u[3]*u[2] u[3]*u[3]]
            mat[1:3,1:3]=COS*I+SIN*UX+(1.0-COS)*UU
        end
    end
    return mat
end
```

#### Translation

##### Python

```
def t(*args):
    d = len(args)
    mat = scipy.identity(d+1)
    for k in range(d):
        mat[k,d] = args[k]
    return mat.view(Mat)
```

##### Julia

```
@everywhere function t(args...)
    d=length(args)
    mat=eye(d+1)
    for k in range(1,d)
        mat[k,d+1]=args[k]
    end
    return mat
end
```

## Scaling

### Python

```
def s(*args):
    d = len(args)
    mat = scipy.identity(d+1)
    for k in range(d):
        mat[k,k] = args[k]
    return mat.view(Mat)
```

### Julia

```
@everywhere function s(args...)
    d=length(args)
    mat=eye(d+1)
    for k in range(1,d)
        mat[k,k]=args[k]
    end
    return mat
end
```

### Python

```
def larApply(affineMatrix);
    def larApply0(model):
        if isinstance(model,Model):
            V = scipy.dot(array([v+[1.0] for v in model.verts]),affineMatrix.T).tolist()
            V = [v[:-1] for v in V]
            CV = copy.copy(model.cells)
            return Model((V,CV))
        elif isinstance(model,tuple) or isinstance(model,list):
            if len(model)==2: V,CV = model
            elif len(model)==3: V,CV,FV = model
            V=scipy.dot([list(v)+[1.0]for v in V],affineMatrix.T).tolist()
            if len(model)==2: return [v[:-1] for v in V],CV
            elif len(model)==3: return [v[:-1] for v in V],CV,FV
        return larApply0
```

### Julia

```
function larApply(affineMatrix)
    function larApply0(model)
        if length(model)==2
            V,CV=model
        elseif length(model)==3
            V,CV,FV = model
        end
        V1=Array{Float64}[]
        for (k,v) in enumerate(V)
            append!(v,[1.0])
            push!(V1,vec((v')*transpose(affineMatrix)))
            pop!(V[k])
            pop!(V1[k])
        end
        if length(model)==2
            return V1,CV
        elseif length(model)==3
            return V1,CV,FV
        end
    end
```

```

end
return larApply0
end

```

### 2.2.2 Parallelization

The affine transformation matrices are the same as in the sequential case.

```

@everywhere function plarApply(affineMatrix)
    function plarApply0(model)
        if length(model)==2
            V,CV=deepcopy(model)
        elseif length(model)==3
            V,CV,FV = deepcopy(model)
        end
        V1=Array{Float64}[]
        V1=@sync @parallel (append!)for v in V
            append!(v,[1.0])
            [collect(vec((v')*transpose(affineMatrix)))]
        end
        for v in V1
            pop!(v)
        end
        if length(model)==2
            return fetch(V1),CV
        elseif length(model)==3
            return V1,CV,FV
        end
    end
    return plarApply0
end

```

### 2.2.3 Unit-Test

|              |
|--------------|
| Serial Tests |
|--------------|

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]]
cubes=[[0,0,0],[0,0,1],[0,1,0],[0,1,1],[1,0,0],[1,0,1],[1,1,0],[1,1,1]],[[0,1,2,3,4,5,6,7]]

@testset "larApply Tests" begin
    @testset "2D" begin
        @testset "larApply Translation 2D" begin
            @test typeof(larApply(t(-0.5,-0.5))(square))==Tuple{Array{Array{Float64,N} where N,1}, Array{Array{Int64,1},1}}
            @test larApply(t(-0.5,-0.5))(square)==([-0.5,-0.5],[-0.5,0.5],[0.5,-0.5],[0.5,0.5]), [[0,1,2,3]])
        end
    end

```

```

@testset "larApply Scaling 2D" begin
    @test typeof(larApply(s(-0.5,-0.5))(square))==Tuple{Array{Array{Float64,N} where N,1},
    Array{Array{Int64,1},1}}
    @test larApply(s(-0.5,-0.5))(square)==([[0.0,0.0],[0.0,-0.5],[-0.5,0.0],[-0.5,-0.5]],
    [[0,1,2,3]])
end

@testset "larApply Rotation 2D" begin
    @test typeof(larApply(r(0))(square))==Tuple{Array{Array{Float64,N} where N,1},
    Array{Array{Int64,1},1}}
    @test larApply(r(0))(square)==square
end
end

@testset "3D" begin
    @testset "larApply Translation 3D" begin
        @test typeof(larApply(t(-0.5,-0.5,-0.5))(cubes))==Tuple{Array{Array{Float64,N}
        where N,1},Array{Array{Int64,1},1}}
        @test larApply(t(-0.5,-0.5,-0.5))(cubes)==([[-0.5,-0.5,-0.5],[-0.5,-0.5,0.5],
        [-0.5,0.5,-0.5],
        [-0.5,0.5,0.5],[0.5,-0.5,-0.5],[0.5,-0.5,0.5],[0.5,0.5,-0.5],[0.5,0.5,0.5]],
        [[0,1,2,3,4,5,6,7]])
    end

    @testset "larApply Scaling 3D" begin
        @test typeof(larApply(s(-0.5,-0.5,-0.5))(cubes))==Tuple{Array{Array{Float64,N}
        where N,1},Array{Array{Int64,1},1}}
        @test larApply(s(-0.5,-0.5,-0.5))(cubes)==([[0.0,0.0,0.0],[0.0,0.0,-0.5],[0.0,-0.5,0.0],
        [0.0,-0.5,-0.5],[-0.5,0.0,0.0],[-0.5,0.0,-0.5],[-0.5,-0.5,0.0],[-0.5,-0.5,-0.5]],
        [[0,1,2,3,4,5,6,7]])
    end

    @testset "larApply Rotation 3D" begin
        @test typeof(larApply(r(pi,0,0))(cubes))==Tuple{Array{Array{Float64,N} where N,1},
        Array{Array{Int64,1},1}}
        @test isapprox(larApply(r(pi,0,0))(cubes)[1],[[0.0,0.0,0.0],[0.0,-1.22465e-16,-1.0],
        [0.0,-1.0,1.22465e-16],[0.0,-1.0,-1.0],[1.0,0.0,0.0],[1.0,-1.22465e-16,-1.0],
        [1.0,-1.0,1.22465e-16],[1.0,-1.0,-1.0]])
    end
end
end

```

### Parallel Tests

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]]
cubes=[[0,0,0],[0,0,1],[0,1,0],[0,1,1],[1,0,0],[1,0,1],[1,1,0],[1,1,1]],[[0,1,2,3,4,5,6,7]]
@testset "plarApply Tests" begin
    @testset "2D" begin
        @testset "plarApply Translation 2D" begin

```

```

@test typeof(plarApply(t(-0.5,-0.5))(square))==Tuple{Array{Array{Float64,1},1},
Array{Array{Int64,1},1}}
@test plarApply(t(-0.5,-0.5))(square)==([-0.5,-0.5],[-0.5,0.5],[0.5,-0.5],[0.5,0.5]),
[[0,1,2,3]])
end
@testset "plarApply Scaling 2D" begin
@test typeof(plarApply(s(-0.5,-0.5))(square))==Tuple{Array{Array{Float64,1},1},
Array{Array{Int64,1},1}}
@test plarApply(s(-0.5,-0.5))(square)==([0.0,0.0],[0.0,-0.5],[-0.5,0.0],
[-0.5,-0.5]),[[0,1,2,3]])
end
@testset "plarApply Rotation 2D" begin
@test typeof(plarApply(r(0))(square))==Tuple{Array{Array{Float64,1},1},
Array{Array{Int64,1},1}}
@test plarApply(r(0))(square)==square
end
end
@testset "3D" begin
@testset "plarApply Translation 3D" begin
@test typeof(plarApply(t(-0.5,-0.5,-0.5))(cubes))==Tuple{Array{Array{Float64,1},1},
Array{Array{Int64,1},1}}
@test plarApply(t(-0.5,-0.5,-0.5))(cubes)==([-0.5,-0.5,-0.5],[-0.5,-0.5,0.5],[-0.5,0.5,-0.5],
[-0.5,0.5,0.5],[0.5,-0.5,-0.5],[0.5,-0.5,0.5],[0.5,0.5,-0.5],[0.5,0.5,0.5]),[[0,1,2,3,4,5,6,7]])
end
@testset "plarApply Scaling 3D" begin
@test typeof(plarApply(s(-0.5,-0.5,-0.5))(cubes))==Tuple{Array{Array{Float64,1},1},
Array{Array{Int64,1},1}}
@test plarApply(s(-0.5,-0.5,-0.5))(cubes)==([0.0,0.0,0.0],[0.0,0.0,-0.5],[0.0,-0.5,0.0],
[0.0,-0.5,-0.5],[-0.5,0.0,0.0],[-0.5,0.0,-0.5],[-0.5,-0.5,0.0],[-0.5,-0.5,-0.5]),
[[0,1,2,3,4,5,6,7]])
end
@testset "plarApply Rotation 3D" begin
@test typeof(plarApply(r(pi,0.0,0.0))(cubes))==Tuple{Array{Array{Float64,1},1},
Array{Array{Int64,1},1}}
@test isapprox(plarApply(r(pi,0,0))(cubes)[1],[0.0,0.0,0.0],[0.0,-1.22465e-16,-1.0],
[0.0,-1.0,-1.22465e-16],[0.0,-1.0,-1.0],
[1.0,0.0,0.0],[1.0,-1.22465e-16,-1.0],[1.0,-1.0,1.22465e-16],[1.0,-1.0,-1.0])
end
end
end

```

## 2.2.4 Results

### Execution time on PC

```

times=[]
ptimes=[]
append!(times,Time(larApply(t(-0.5,-0.5)),[l[i]]) for i in range(1,length(l)))
append!(ptimes,Time(plarApply(t(-0.5,-0.5)),[l[i]]) for i in range(1,length(l)))

```

```

plot(times,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Serial"])
plot(ptimes,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Parallel"])

```

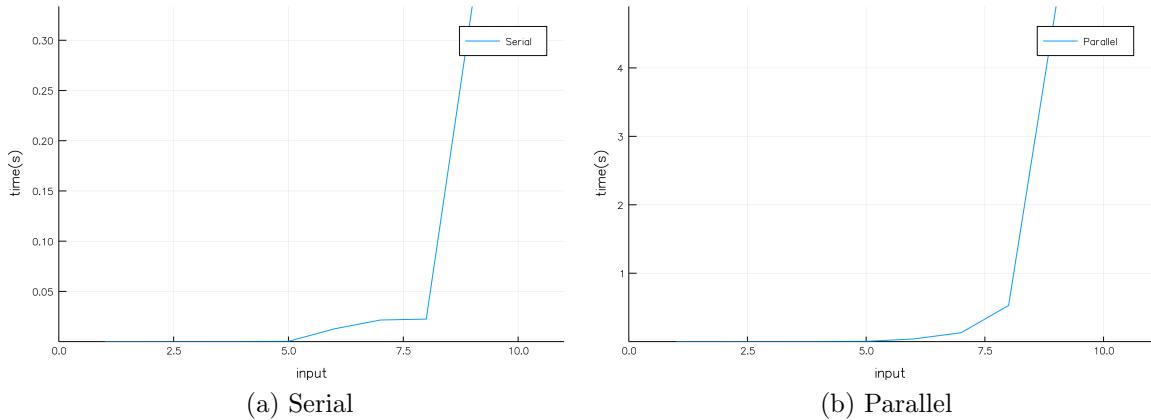


Figure 2: Execution time of function larApply

### Compare

```

plot([times,ptimes],xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",
label=["Serial","Parallel"])

```

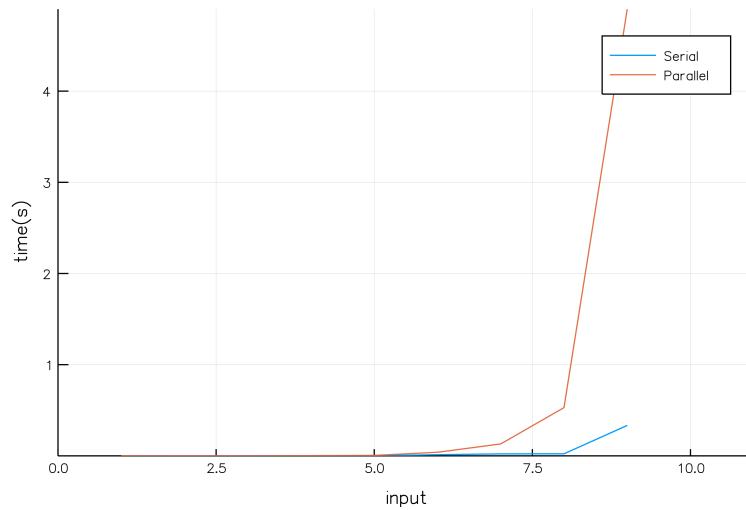


Figure 3: Compare Parallel and Serial execution time of function larApply

## 2.3 box

### 2.3.1 Conversion

#### Python

```
def box(model):
    if isinstance(model,Mat): return []
    elif isinstance(model,Struct):
        dummyModel = copy.deepcopy(model)
        dummyModel.body = [term if (not isinstance(term,Struct))
    else [term.box,[[0,1]]] for term in model.body]
    listOfModels = evalStruct( dummyModel )
    theMin,theMax = box(listOfModels[0])
    for theModel in listOfModels[1:]:
        modelMin, modelMax = box(theModel)
        theMin = [val if val<theMin[k] else theMin[k] for k,val in enumerate(modelMin)]
        theMax = [val if val>theMax[k] else theMax[k] for k,val in enumerate(modelMax)]
    return [theMin,theMax]
elif isinstance(model,Model):
    V = model.verts
elif (isinstance(model,tuple) or isinstance(model,list)) and (len(model)==2 or len(model)==3):
    V = model[0]
coords = TRANS(V)
theMin = [min(coord) for coord in coords]
theMax = [max(coord) for coord in coords]
return [theMin,theMax]
```

#### Julia

```
function box(model)
    if isa(model,Matrix)
        return []
    elseif isa(model,Struct)
        dummyModel=deepcopy(model)
        dummyModel.body=Any[]
        for term in model.body
            if isa(term,Struct)
                push!(dummyModel.body,[term.box,[0,1]])
            else
                push!(dummyModel.body,term)
            end
        end
    end
    listOfModels=evalStruct(dummyModel)
    theMin,theMax=box(listOfModels[1])
    for theModel in listOfModels[2:end]
        modelMin,modelMax= box(theModel)
        for (k,val) in enumerate(modelMin)
            if val < theMin[k]
                theMin[k]=val
            end
        end
    end
    return [theMin,theMax]
end
```

```

        end
    end
    for (k,val) in enumerate(modelMax)
        if val > theMax[k]
            theMax[k]=val
        end
    end
    return Array[theMin,theMax]
elseif (isa(model,Tuple)||isa(model,Array)) &&(length(model)==2||length(model)==3)
    V=model[1]
    theMin=[]
    theMax=[]
    for j in range(1,length(V[1]))
        Min=V[1][j]
        Max=V[1][j]
        for i in range(1,length(V))
            Min=min(Min,V[i][j])
            Max=max(Max,V[i][j])
        end
        push!(theMin,Min)
        push!(theMax,Max)
    end
    return Array[theMin,theMax]
end
end

```

### 2.3.2 Parallelization

```

function pbox(model)
    if isa(model,Matrix)
        return []
    elseif isa(model,pStruct)
        dummyModel=deepcopy(model)
        dummyModel.body=Any[]
        @sync for term in model.body
            if isa(term,pStruct)
                push!(dummyModel.body,[term.box,[0,1]])
            else
                push!(dummyModel.body,term)
            end
        end
        listOfModels=pevalStruct(dummyModel)
        theMin,theMax=pbox(listOfModels[1])
        @sync for theModel in listOfModels[2:end]
            modelMin,modelMax= pbox(theModel)
            @async begin
                for (k,val) in enumerate(modelMin)
                    if (val < theMin[k])

```

```

        theMin[k]=val
    end
end
for (k,val) in enumerate(modelMax)
    if (val > theMax[k])
        theMax[k]=val
    end
end
end
end
return Array[theMin,theMax]
elseif (isa(model,Tuple) ||isa(model,Array))&&(length(model)==2 || length(model)==3)
V=model[1]
theMin=[]
theMax=[]
@sync for j in range(1,length(V[1]))
    Min=V[1][j]
    Max=V[1][j]
    for i in range(1,length(V))
        Min=min(Min,V[i][j])
        Max=max(Max,V[i][j])
    end
    @async begin
        push!(theMin,Min)
        push!(theMax,Max)
    end
end
return Array[theMin,theMax]
end
end

```

### 2.3.3 Unit-Test

These Unit-Test can be runned after the definition of the Struct type on the Section 2.5

|              |
|--------------|
| Serial Tests |
|--------------|

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]])

cubess=[[0,0,0],[0,0,1],[0,1,0],[0,1,1],[1,0,0],[1,0,1],[1,1,0],[1,1,1]],[[[0],[1],[2],[3],[4],[5],[6],[7]],[[0,1],[2,3],[4,5],[6,7],[0,2],[1,3],[4,6],[5,7],[0,4],[1,5],[2,6],[3,7]],[[0,1,2,3],[4,5,6,7],[0,1,4,5],[2,3,6,7],[0,2,4,6],[1,3,5,7]],[[0,1,2,3,4,5,6,7]]])

@testset "box Tests" begin
    @testset "box Tests 2D" begin
        @test typeof(box(square))==Array{Array,1}
        @test length(box(square))==2
    end
end

```

```

@test length(box(square)[1])==2
end

@testset "box Tests 3D" begin
@test typeof(box(cubes))==Array{Array,1}
@test length(box(cubes))==2
@test length(box(cubes)[1])==3
end
end

```

### Parallel Tests

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]])

cubes=[[0,0,0],[0,0,1],[0,1,0],[0,1,1],[1,0,0],[1,0,1],[1,1,0],[1,1,1]],[[[0],[1],[2],[3],[4],[5],[6],[7]],[[0,1],[2,3],[4,5],[6,7],[0,2],[1,3],[4,6],[5,7],[0,4],[1,5],[2,6],[3,7]],[[0,1,2,3],[4,5,6,7],[0,1,4,5],[2,3,6,7],[0,2,4,6],[1,3,5,7]],[[0,1,2,3,4,5,6,7]]]

@testset "pbox Tests" begin
@testset "pbox Tests 2D" begin
@test typeof(pbox(square))==Array{Array,1}
@test length(pbox(square))==2
@test length(pbox(square)[1])==2
end

@testset "pbox Tests 3D" begin
@test typeof(pbox(cubes))==Array{Array,1}
@test length(pbox(cubes))==2
@test length(pbox(cubes)[1])==3
end
end

```

#### 2.3.4 Results

##### Execution time on PC

```

times=[]
ptimes=[]
input=[]

for i in range(1,length(l))
    push!(input,Struct([repeat([l[i]],outer=i)...]))
end
append!(times,Time(box,[input[i]]) for i in range(1,length(input)))
append!(ptimes,Time(pbox,[input[i]]) for i in range(1,length(input)))

```

```

plot(times,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Serial"])
plot(ptimes,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Parallel"])

```

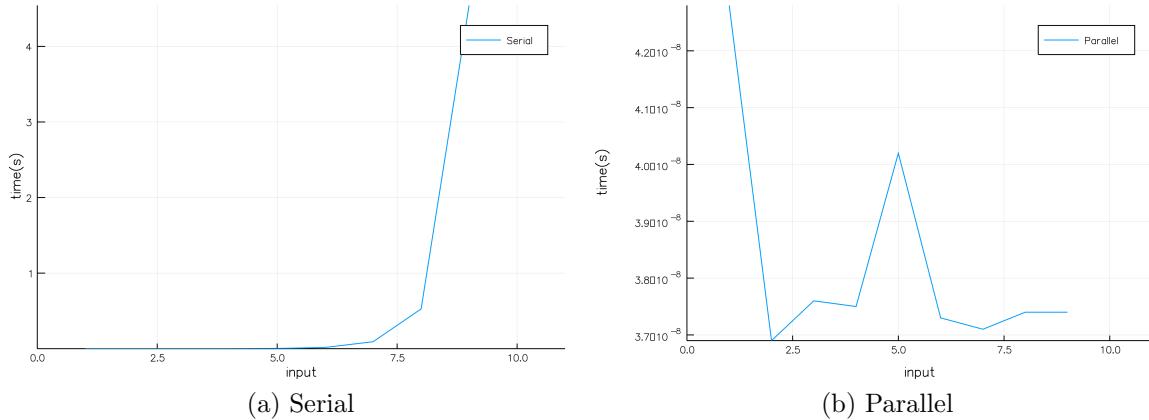


Figure 4: Execution time of function box

### Compare

```

plot([times,ptimes],xlabel="input",xlims=(0,length(ptimes)+2),ylabel="time(s)",
label=["Serial","Parallel"])

```

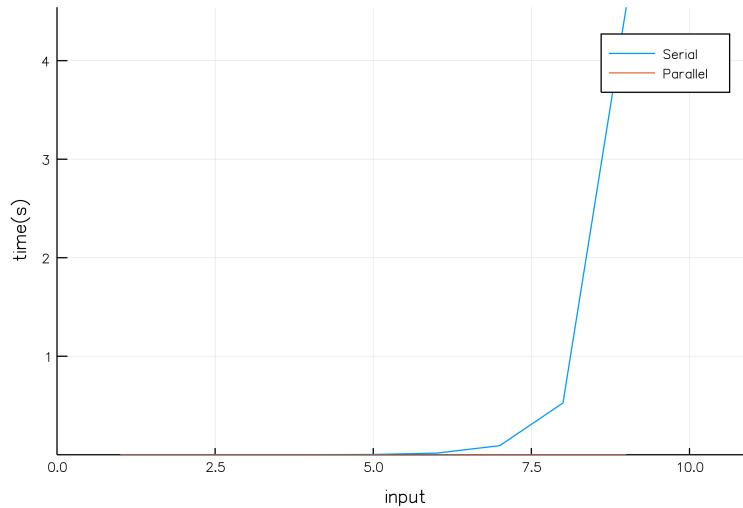


Figure 5: Compared execution time of function box

## Execution time on Tesla

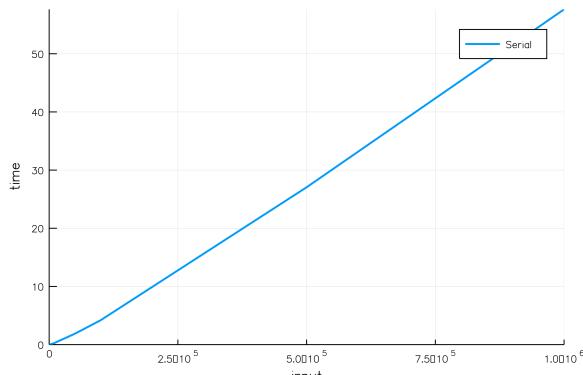
```

input =input =[1,10,20,50,10^2,5*10^2,2*10^3]
function timeFstruct(f::Function,pf::Function,model,input)
    t=Array{Float64}(length(input))
    pt=Array{Float64}(length(input))
    for i in range(1,length(input))
        structo=addn2D(input[i],model)
        pstructo=pStruct(structo.body)
        f(structo)
        pf(pstructo)
        t[i]=@elapsed f(structo)
        pt[i]=@elapsed pf(pstructo)
    end
    return t,pt
end

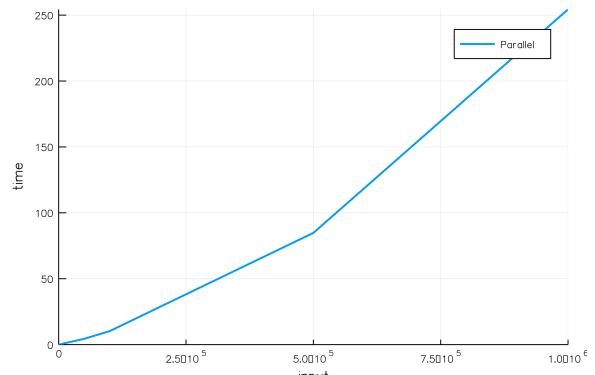
y,yp=timeFstruct(box,pbox,square,input)

p=plot(y,xaxis="input",yaxis="time",xlims=(0,length(input)+1),ylims=(0,maximum(y)+0.5),
label=["Serial"],lw=2)
pp=plot(yp,xaxis="input",yaxis="time",xlims=(0,length(input)+1),ylims=(0,maximum(y)+0.5),
label=["Parallel"],lw=2)

```



(a) Serial



(b) Parallel

Figure 6: Execution time of function box on Tesla

## Compare

```
yc=[y,yp]
pc=plot(y,xaxis="input",yaxis="time",xlims=(0,length(input)+1),ylims=(0,maximum(y)+0.5),
label=["Serial" "Parallel"],lw=2)
```

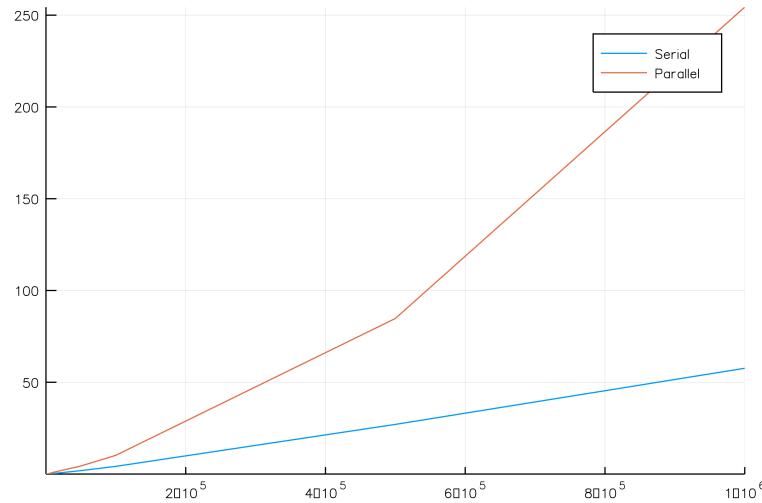


Figure 7: Compared Execution time of function box on Tesla

## 2.4 traversal

### 2.4.1 Conversion

#### Python

```
def traversal(CTM, stack, obj, scene=[]):
    for i in range(len(obj)):
        if isinstance(obj[i], Model):
            scene += [larApply(CTM)(obj[i])]
        elif(isinstance(obj[i], tuple) or isinstance(obj[i], list)) and (len(obj[i]==2 or len(obj[i])==3):
            scene += [larApply(CTM)(obj[i])]
        elif isinstance(obj[i], Mat):
            CTM = scipy.dot(CTM, obj[i])
        elif isinstance(obj[i], Struct):
            stack.append(CTM)
            traversal(CTM, stack, obj[i], scene)
            CTM = stack.pop()
    return scene
```

#### Julia

```
function traversal(CTM, stack, obj, scene[])
    for i in range(1, len(obj))
        if isa(obj.body[i], Matrix)
            CTM = CTM * obj.body[i]
        elseif (isa(obj.body[i], Tuple) || isa(obj.body[i], Array)) &&
            (length(obj.body[i]) == 2 || length(obj.body[i]) == 3)
            l=larApply(CTM)(obj.body[i])
            push!(scene,l)
        elseif isa(obj.body[i], Struct)
            push!(stack, CTM)
            traversal(CTM, stack, obj.body[i], scene)
            CTM = pop!(stack)
        end
    end
    return scene
end
```

### 2.4.2 Parallelization

```
@everywhere function ptraversal(CTM, stack, obj, scene[])
    @sync for i in range(1, len(obj))
        if isa(obj.body[i], Matrix)
            CTM = CTM*obj.body[i]
        elseif (isa(obj.body[i], Tuple) || isa(obj.body[i], Array)) &&
```

```

(length(obj.body[i])==2||length(obj.body[i])==3)
    l=plarApply(CTM)(obj.body[i])
    push!(scene,l)
elseif isa(obj.body[i],pStruct)
    push!(stack,CTM)
    ptraversal(CTM,stack,obj.body[i],scene)
    CTM = pop!(stack)
end
end
return scene
end

```

### 2.4.3 Unit-Test

These tests can be runned after the definition of the Struct type on the section 2.5

#### Serial Tests

```

square=[[0, 0], [0, 1], [1, 0], [1, 1]], [[0, 1, 2, 3]])
structure=Struct([square])
d=checkStruct(structure.body)

@testset "traversal Tests" begin
    @test length(traversal(eye(d+1),[],structure,[]))==length(structure.body)
    @test typeof(traversal(eye(d+1),[],structure,[]))==Array{Any,1}
end

```

#### Parallel Tests

```

square=[[0, 0], [0, 1], [1, 0], [1, 1]], [[0, 1, 2, 3]])
structure=pStruct([square])
d=pcheckStruct(structure.body)

@testset "ptraversal Tests" begin
    @test length(ptraversal(eye(d+1),[],structure,[]))==length(structure.body)
    @test typeof(ptraversal(eye(d+1),[],structure,[]))==Array{Any,1}
end

```

### 2.4.4 Results

#### Execution time on PC

```

times=[]
ptimes=[]
input=[]
dim=[]

```

```

for i in range(1,length(l)-1)
    push!(input,Struct([repeat([l[i]],outer=i)...]))
end

append!(dim,checkStruct(input[i].body) for i in range(1,length(input)))

for i in range(1,length(input))
    args=(eye(dim[i]+1),[],input[i],[])
    append!(times,Time(traversal,(args...)))
end
for i in range(1,length(input))
    args=(eye(dim[i]+1),[],input[i],[])
    append!(ptimes,Time(ptraversal,(args...)))
end

plot(times,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Serial"])
plot(ptimes,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Parallel"])

```

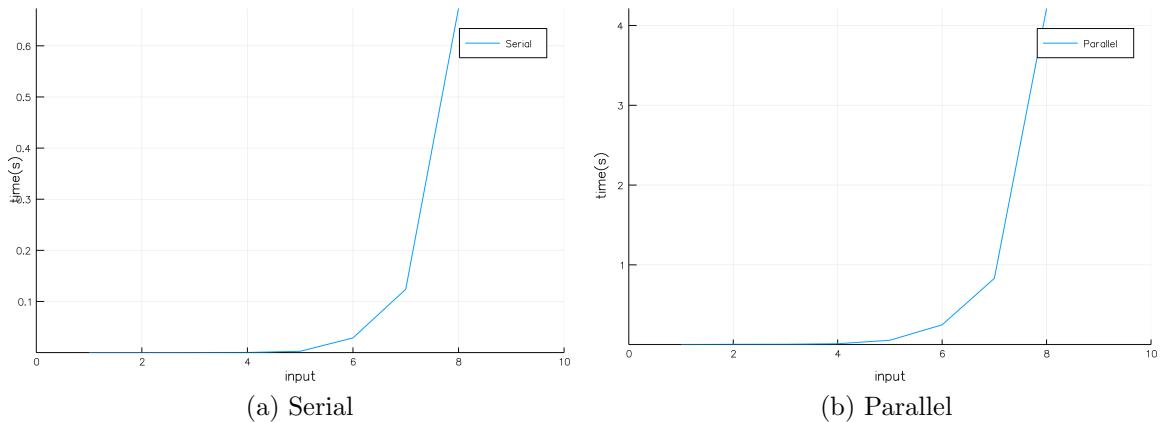


Figure 8: Execution time of function traversal

## Compare

```
plot([times,ptimes], xlabel="input", xlims=(0,length(ptimes)+2), ylabel="time(s)",  
label=["Serial","Parallel"])
```

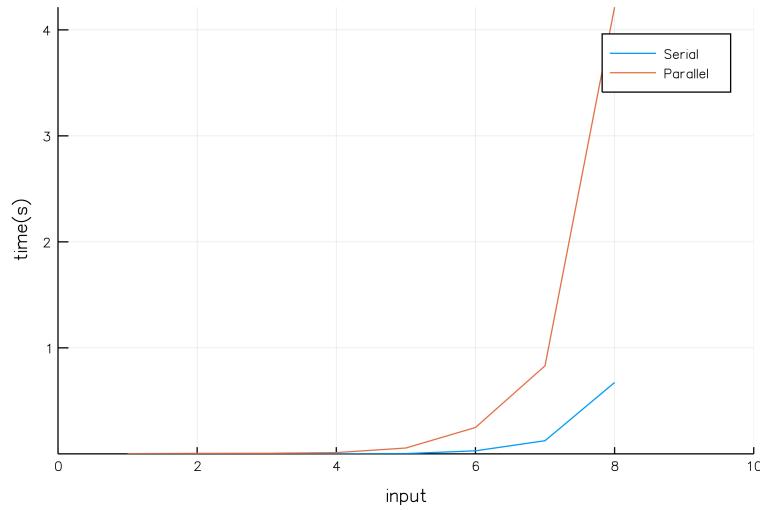


Figure 9: Compared execution time of function traversal

## Execution time on Tesla

```
input=[1,10,20,50,10^2,2*10^2,5*10^2,10^3,2*10^3]  
  
function timeTraversal(model,input)  
    t=Array{Float64}(length(input))  
    pt=Array{Float64}(length(input))  
    for i in range(1,length(input))  
        structo=addn2D(input[i],model)  
        pstructo=pStruct(structo.body)  
        dim=checkStruct(structo.body)  
        traversal(eye(dim+1),[],structo,[])  
        ptraversal(eye(dim+1),[],pstructo,[])  
        pt[i]=@elapsed ptraversal(eye(dim+1),[],pstructo,[])  
        t[i]=@elapsed traversal(eye(dim+1),[],structo,[])  
    end  
    return t,pt  
end  
  
y,yp=timeTraversal(square,input)
```

```

p=plot(y,xaxis="input",yaxis="time",xlims=(0,length(input)+1),ylims=(0,maximum(y)+0.5),
       label=["Serial"],lw=2)
pp=plot(yp,xaxis="input",yaxis="time",xlims=(0,length(input)+1),
        ylims=(0,maximum(y)+0.5),label=["Parallel"],lw=2)

```

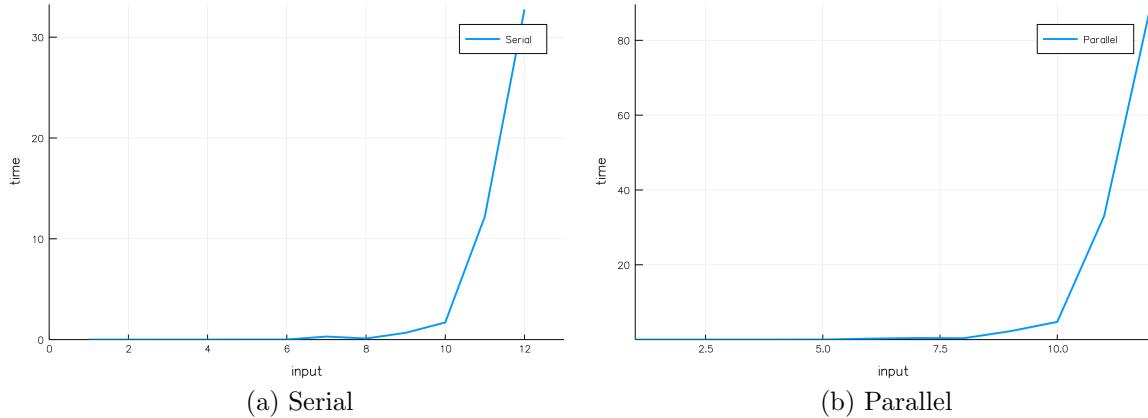


Figure 10: Execution time of function traversal on Tesla

### Compare

```
yc=[y,yp]
pc=plot(yc,label=["Serial" "Parallel"])
```

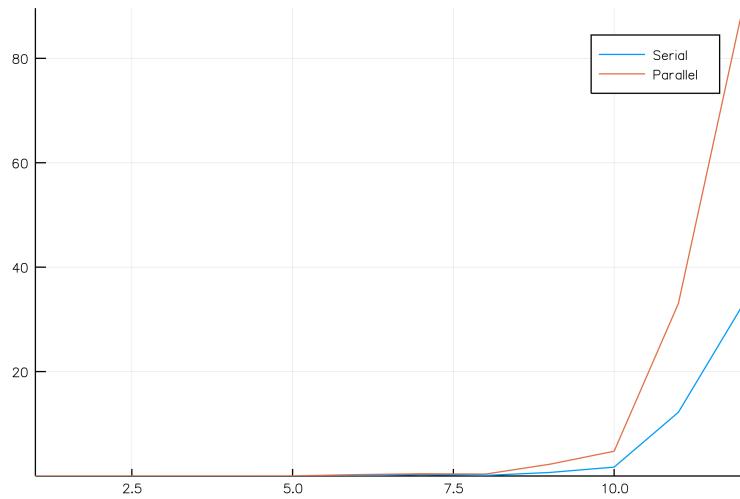


Figure 11: Compared execution time of function traversal on Tesla

## 2.5 Struct

### 2.5.1 Conversion

evalStruct

Python

```
def evalStruct(struct):
    dim = checkStruct(struct.body)
    CTM, stack = scipy.identity(dim+1), []
    scene = traversal(CTM, stack, struct, [])
    return scene
```

Julia

```
function evalStruct(self)
    dim = checkStruct(self.body)
    CTM, stack = eye(dim+1), []
    scene = traversal(CTM, stack, self, [])
    return scene
end
```

Python

```
class Struct:
    def __init__(self,data=None,name=None,category=None):
        if data==None or data==[ ]:
            self.body = [ ]
        else:
            #self.body = [item for item in data if item != None]
            self.body = [item for item in data]
            self.box = box(self)
            self.dim = len(self.box[0])
        if name != None:
            self.name = str(name)
        else:
            self.name = str(id(self))
        if category != None:
            self.category = str(category)
        else:
            self.category = "feature"
    def __name__(self):
        return self.name
    def __category__(self):
        return self.category
    def __iter__(self):
        return iter(self.body)
    def __len__(self):
        return len(list(self.body))
    def __getitem__(self,i):
        return list(self.body)[i]
    def __setitem__(self,i,value):
        self.body[i] = value
    def __print__(self):
        return "<Struct name: %s>" % self.__name__()
    def __repr__(self):
        return "<Struct name: %s>" % self.__name__()
```

```

def set_name(self,name):
    self.name = str(name)
def clone(self,i=0):
    from copy import deepcopy
    newObj = deepcopy(self)
    if i != 0: newObj.name = self.name + "_" + str(i)
    return newObj
def set_category(self,category):
    self.category = str(category)

```

## Julia

```

type Struct
    body::Array
    box
    name::AbstractString
    dim
    category::AbstractString
    function Struct()
        self=new([],Nullable{Any}, "new", Nullable{Any}, "feature")
        self.name=string(object_id(self))
        return self
    end
    function Struct(data::Array)
        self=Struct()
        self.body=data
        self.box=box(self)
        self.dim=length(self.box[1])
        return self
    end
    function Struct(data::Array, name)
        self=Struct()
        self.body=[item for item in data]
        self.box=box(self)
        self.dim=length(self.box[1])
        self.name=string(name)
        return self
    end
    function Struct(data::Array, name, category)
        self=Struct()
        self.body=[item for item in data]
        self.box=box(self)
        self.dim=length(self.box[1])
        self.name=string(name)
        self.category=string(category)
        return self
    end
end

```

```

function name(self::Struct)
    return self.name
end
function category(self::Struct)
    return self.category
end
function len(self::Struct)
    return length(self.body)
end
function getitem(self::Struct,i::Int)
    return self.body[i]
end
function setitem(self::Struct,i,value)
    self.body[i]=value
end
function pprint(self::Struct)
    return "<Struct name: $(self.__name__())"
end
function set_name(self::Struct,name)
    self.name=string(name)
end
function clone(self::Struct,i=0)
    newObj=deepcopy(self)
    if i!=0
        newObj.name=$(self.__name__())_$(string(i))"
    end
    return newObj
end
function set_category(self::Struct,category)
    self.category=string(category)
end

```

### 2.5.2 Parallelization

```

function pevalStruct(self)
    dim = pcheckStruct(self.body)
    CTM, stack = eye(dim+1), []
    scene = ptraversal(CTM, stack, self, [])
return scene
end

```

```

@everywhere type pStruct
    body::Array
    box
    name::AbstractString
    dim

```

```

category::AbstractString
function pStruct()
    self=new([],Nullable{Any}, "new", Nullable{Any}, "feature")
    self.name=string(object_id(self))
    return self
end
function pStruct(data::Array)
    self=pStruct()
    self.body=data
    self.box=pbox(self)
    self.dim=length(self.box[1])
    return self
end
function pStruct(data::Array,name)
    self=pStruct()
    self.body=[item for item in data]
    self.box=pbox(self)
    self.dim=length(self.box[1])
    self.name=string(name)
    return self
end
function pStruct(data::Array,name,category)
    self=pStruct()
    self.body=[item for item in data]
    self.box=pbox(self)
    self.dim=length(self.box[1])
    self.name=string(name)
    self.category=string(category)
    return self
end
end
function name(self::pStruct)
    return self.name
end
function category(self::pStruct)
    return self.category
end
function len(self::pStruct)
    return length(self.body)
end
function getitem(self::pStruct,i::Int)
    return self.body[i]
end
function setitem(self::pStruct,i,value)
    self.body[i]=value
end
function pprint(self::pStruct)
    return "<Struct name: $(self.__name__())"
end

```

```

function set_name(self::pStruct,name)
    self.name=string(name)
end
function clone(self::pStruct,i=0)
    newObj=deepcopy(self)
    if i!=0
        newObj.name="$(self.__name__())_$(string(i))"
    end
    return newObj
end
function set_category(self::pStruct,category)
    self.category=string(category)
end

```

### 2.5.3 Unit-Test

|              |
|--------------|
| Serial Tests |
|--------------|

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]]

@testset "Struct Tests" begin
    @test Struct([square]).body==[square]
    @test Struct([square]).dim==length(square[1][1])
    @test Struct([square]).box==[[0,0],[1,1]]
end

```

|                |
|----------------|
| Parallel Tests |
|----------------|

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]]

@testset "pStruct Tests" begin
    @test pStruct([square]).body==[square]
    @test pStruct([square]).dim==length(square[1][1])
    @test pStruct([square]).box==[[0,0],[1,1]]
    @test pStruct([square]).category=="feature"
    @test pStruct([square],"quadrato").name=="quadrato"
end

```

### 2.5.4 Results

#### Execution time on PC

```

times=[]
ptimes=[]

append!(times,Time(Struct,[[l[i]]])) for i in range(1,length(l)) )
append!(ptimes,Time(pStruct,[[l[i]]])) for i in range(1,length(l)-1))

```

```

plot(times,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Serial"])
plot(ptimes,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Parallel"])

```

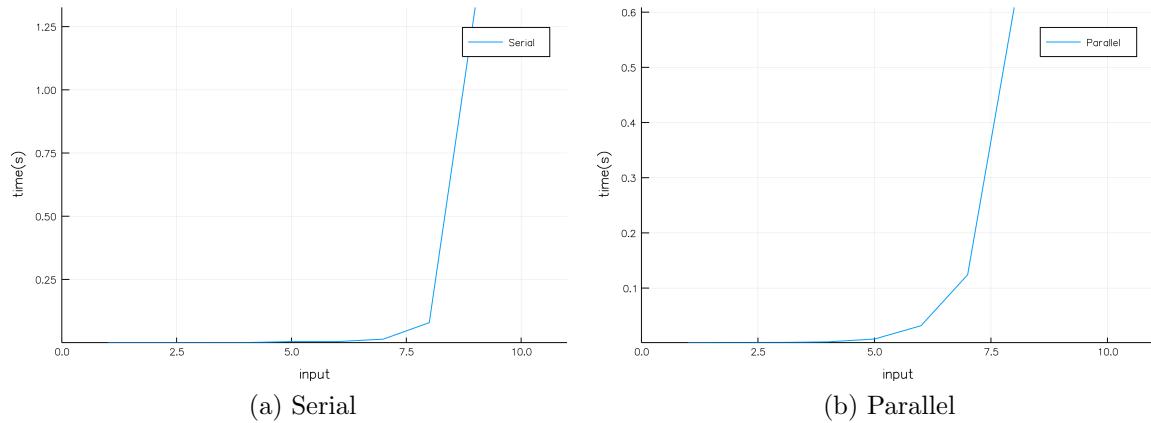


Figure 12: Execution time of function Struct

### Compare

```

plot([times,ptimes],xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",
label=["Serial","Parallel"])

```

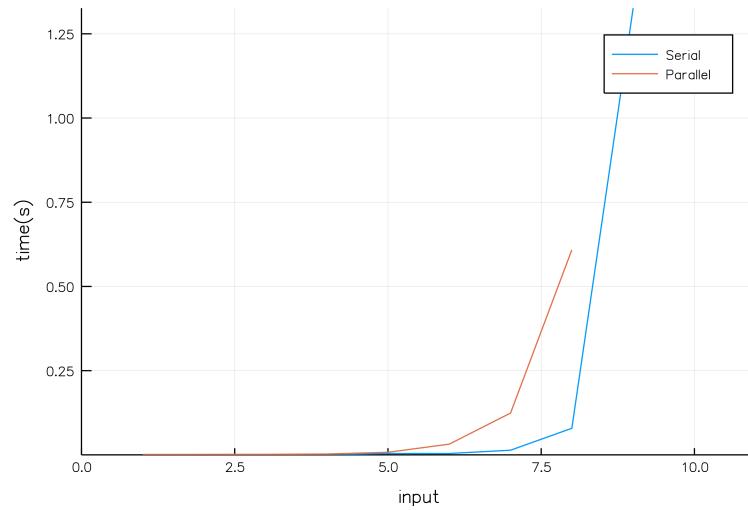


Figure 13: Compared execution time of function Struct

## Execution time on Tesla

```

input=[1,10,20,50,10^2,2*10^2,5*10^2,10^3,2*10^3]
function timeStruct(model,input)
    t=Array{Float64}(length(input))
    pt=Array{Float64}(length(input))
    for i in range(1,length(input))
        structo=addn2D(input[i],model)
        Struct(structo.body)
        pStruct(structo.body)
        t[i]=@elapsed Struct(structo.body)
        pt[i]=@elapsed pStruct(structo.body)
    end
    return t,pt
end

y,yp=timeStruct(square,input)
p=plot(y,xaxis="input",yaxis="time",xlims=(0,length(input)+1),
       ylims=(0,maximum(y)+0.5), label=["Serial"],lw=2)

pp=plot(yp,xaxis="input",yaxis="time",xlims=(0,length(input)+1),
       ylims=(0,maximum(y)+0.5),label=["Parallel"],lw=2)

```

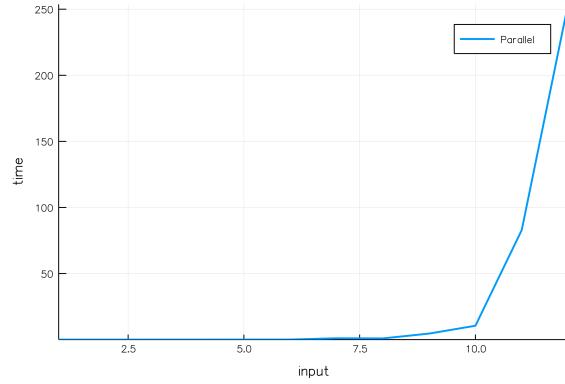
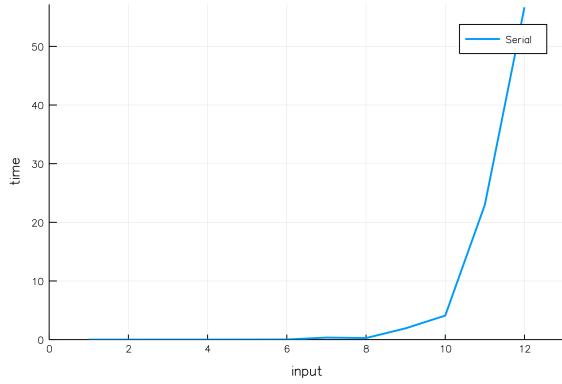


Figure 14: Execution time of function Struct on Tesla

## Compare

```
yc=[y,yp]
pc=plot(yc,label=["Serial" "Parallel"])
```

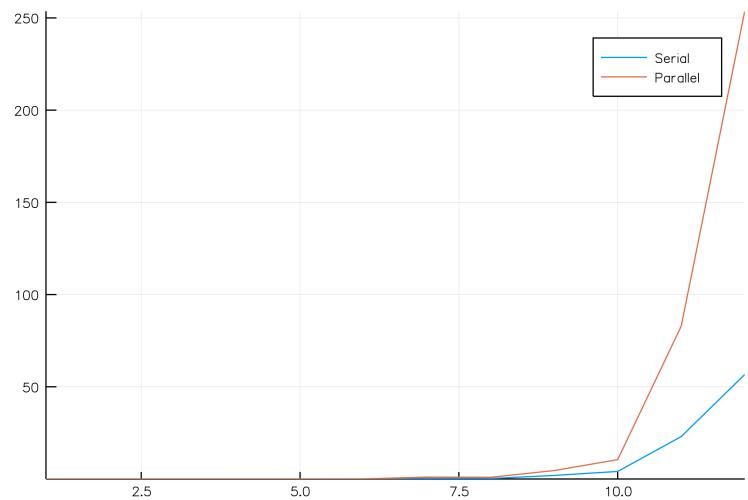


Figure 15: Compared execution time of function Struct on Tesla

## 2.6 embedTraversal

### 2.6.1 Conversion

#### Python

```
def embedTraversal(cloned, obj,n,suffix):
    for i in range(len(obj)):
        if isinstance(obj[i],Model):
            cloned.body += [obj[i]]
        elif (isinstance(obj[i],tuple) or isinstance(obj[i],list)) and (len(obj[i])==2):
            V,EV = obj[i]
            V = [v+n*[0.0] for v in V]
            cloned.body += [(V,EV)]
        elif (isinstance(obj[i],tuple) or isinstance(obj[i],list)) and (len(obj[i])==3):
            V,FV,EV = obj[i]
            V = [v+n*[0.0] for v in V]
            cloned.body += [(V,FV,EV)]
        elif isinstance(obj[i],Mat):
            mat = obj[i]
            d,d = mat.shape
            newMat = scipy.identity(d+n*1)
            for h in range(d-1):
                for k in range(d-1):
                    newMat[h,k] = mat[h,k]
            newMat[h,d-1+n*1] = mat[h,d-1]
            cloned.body += [newMat.view(Mat)]
        elif isinstance(obj[i],Struct):
            newObj = Struct()
            newObj.box = hstack((obj[i].box, [n*[0],n*[0]]))
            newObj.name = obj[i].name+suffix
            newObj.category = obj[i].category
            cloned.body +=[embedTraversal(newObj, obj[i], n, suffix)]
    return cloned
```

#### Julia

```
function embedTraversal(cloned,obj,n,suffix)
    for i in range(1,len(obj))
        if isa(obj.body[i],Matrix)
            mat=obj.body[i]
            d,d=size(mat)
            newMat=eye(d+n*1)
            for h in range(1,d-1)
                for k in range(1,d-1)
                    newMat[h,k]=mat[h,k]
                end
                newMat[h,d-1+n*1]=mat[h,d-1]
            end
            append!(cloned.body,newMat)
```

```

elseif (isa(obj.body[i], Tuple) || isa(obj.body[i], Array))&&length(obj.body[i])==3
    V,FV,EV=obj.body[i]
    dimadd=fill([0.0],n)
    for k in dimadd
        for v in V
            append!(v,k)
        end
    end
    append!(cloned.body, [(V,FV,EV)])
elseif (isa(obj.body[i], Tuple) || isa(obj.body[i], Array))&&length(obj.body[i])==2
    V,EV=deepcopy(obj.body[i])
    dimadd=fill([0.0],n)
    for k in dimadd
        for v in V
            append!(v,k)
        end
    end
    append!(cloned.body, [(V,EV)])
elseif isa(obj.body[i], Struct)
    newObj=Struct()
    newObj.box=hcat((obj.body[i].box,[fill([0],n),fill([0],n)]))
    newObj.category=obj.body[i].category
    append!(cloned.body,embedTraversal(newObj,obj.body[i],n,suffix))
end
end
return cloned
end

```

## 2.6.2 Parallelization

```

@everywhere function pembedTraversal(cloned,obj,n,suffix)
    for i in range(1,len(obj))
        if (isa(obj.body[i], Matrix) || isa(obj.body[i], SharedArray))
            mat=obj.body[i]
            d,d=size(mat)
            newMat=eye(d+n*1)
            @sync begin
                for h in range(1,d-1)
                    @async begin
                        for k in range(1,d-1)
                            newMat[h,k]=mat[h,k]
                        end
                    end
                    newMat[h,d-1+n*1]=mat[h,d-1]
                end
            end
            append!(cloned.body,newMat)
        elseif (isa(obj.body[i], Tuple) || isa(obj.body[i], Array))&& length(obj.body[i])==2
            V,EV=deepcopy(obj.body[i])

```

```

dimadd=fill([0.0],n)
@sync begin
    for k in dimadd
        @async begin
            for v in V
                append!(v,k)
            end
        end
    end
end
append!(cloned.body,[(V,EV)])
elseif (isa(obj.body[i],Tuple) || isa(obj.body[i],Array))&&length(obj.body[i])==3
    V,FV,EV=obj.body[i]
    dimadd=fill([0.0],n)
    @sync begin
        for k in dimadd
            @async begin
                for v in V
                    append!(v,k)
                end
            end
        end
    end
end
append!(cloned.body,[(V,FV,EV)])
elseif isa(obj.body[i],pStruct)
    newObj=pStruct()
    @async begin
        newObj.box=hcat((obj.body[i].box,[fill([0],n),fill([0],n)]))
        newObj.category=obj.body[i].category
        append!(cloned.body,embedTraversal(newObj,obj.body[i],n,suffix))
    end
end
end
return cloned
end

```

### 2.6.3 Unit-Test

|              |
|--------------|
| Serial Tests |
|--------------|

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]]
x=Struct([square])

@testset "embedTraversal Tests" begin
    @test length(embedTraversal(deepcopy(x),deepcopy(x),1,"New").body[2][1][1])==
        length(x.body[1][1][1])+1
    #in this case n=1, but generally:
    # length(length(embedTraversal(x,x,1,"New"))=length(x.body[1][1][1])+n
    @test length(embedTraversal(deepcopy(x),deepcopy(x),3,"New").body[2][1][1])==

```

```

length(x.body[1][1][1])+3
@test typeof(embedTraversal(deepcopy(x),deepcopy(x),1,"New"))==Struct
end

```

### Parallel Tests

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]]
x=pStruct([square])

@testset "pembedTraversal Tests" begin
@test length(pembedTraversal(deepcopy(x),deepcopy(x),1,"New").body[2][1][1])==
length(x.body[1][1][1])+1
#in this case n=1, but generally:
#length(length(embedTraversal(x,x,1,"New"))=length(x.body[1][1][1])+n
@test length(pembedTraversal(deepcopy(x),deepcopy(x),3,"New").body[2][1][1])==
length(x.body[1][1][1])+3
@test typeof(pembedTraversal(deepcopy(x),deepcopy(x),1,"New"))==pStruct
end

```

## 2.6.4 Results

### Execution time on Tesla

```

input=[1,10,20,50,10^2,2*10^2,5*10^2,10^3,2*10^3]
function timeEmbedTraversal(model,input)
    t=Array{Float64}(length(input))
    pt=Array{Float64}(length(input))
    for i in range(1,length(input))
        structo=addn2D(input[i],model)
        pstructo=pStruct(structo.body)
        cloned=Struct()
        cloned.box=hcat((structo.box,[fill([0],10),fill([0],10)]))
        cloned.name=string(object_id(cloned))
        cloned.category=structo.category
        cloned.dim=structo.dim+10
        pcloned=pStruct()
        pcloned.box=hcat((pstructo.box,[fill([0],10),fill([0],10)]))
        pcloned.name=string(object_id(pcloned))
        pcloned.category=pstructo.category
        pcloned.dim=pstructo.dim+10
        embedTraversal(cloned,structo,10,"New")
        pembedTraversal(pcloned,pstructo,10,"New")
        t[i]=@elapsed embedTraversal(cloned,structo,10,"New")
        pt[i]=@elapsed pembedTraversal(pcloned,pstructo,10,"New")
    end
    return t,pt
end
y,yp=timeEmbedTraversal(square,input)

```

```

p=plot(input,y,xaxis="input",yaxis="time",xlims=(0,length(input)+1),
       ylims=(0,maximum(y)+0.5), label=["Serial"],lw=2)
pp=plot(input,yp,xaxis="input",yaxis="time",xlims=(0,length(input)+1),
        ylims=(0,maximum(y)+0.5),label=["Parallel"],lw=2)

```

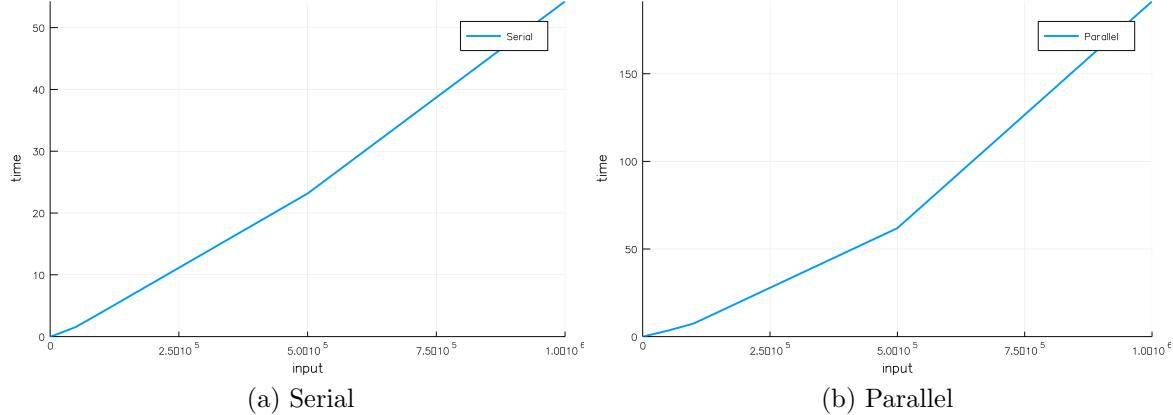


Figure 16: Execution time of function embedTraversal on Tesla

### Compare

```
yc=[y,yp]
pc=plot(input,yc,label=["Serial" "Parallel"])
```

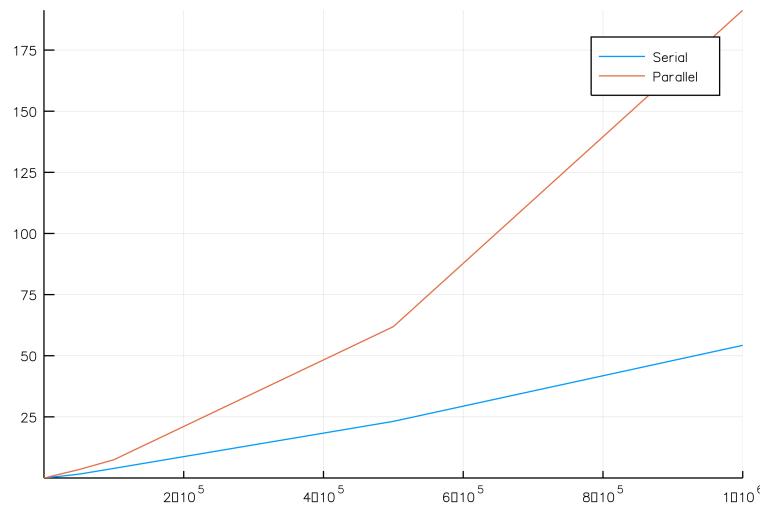


Figure 17: Compared execution time of function embedtraversal on Tesla

## 2.7 embedStruct

### 2.7.1 Conversion

Python

```
def embedStruct(n):
    def embedStruct0(struct,suffix="New"):
        if n==0:
            return struct, len(struct.box[0])
        cloned = Struct()
        cloned.box = hstack((struct.box, [n*[0],n*[0]])).tolist()
        cloned.name = str(id(cloned)) #struct.name+suffix
        cloned.category = struct.category
        cloned.dim = struct.dim + n
        cloned = embedTraversal(cloned,struct,n,suffix)
        return cloned
    return embedStruct0
```

Julia

```
function embedStruct(n)
    function embedStruct0(self,suffix="New")
        if n==0
            return self, length(self.box[1])
        end
        cloned=Struct()
        cloned.box=hcat((self.box,[fill([0],n),fill([0],n)]))
        cloned.name=string(object_id(cloned))
        cloned.category=self.category
        cloned.dim=self.dim+n
        cloned=embedTraversal(cloned,self,n,suffix)
        return cloned
    end
    return embedStruct0
end
```

### 2.7.2 Parallelization

```
@everywhere function pembedStruct(n)
    function pembedStruct0(self,suffix="New")
        if n==0
            return self, length(self.box[1])
        end
        cloned=pStruct()
```

```

cloned.box=hcat((self.box,[fill([0],n),fill([0],n)]))
cloned.name=string(object_id(cloned))
cloned.category=self.category
cloned.dim=self.dim+n
cloned=pembedTraversal(cloned,self,n,suffix)
    return cloned
end
return pembedStruct0
end

```

### 2.7.3 Unit-Test

#### Serial Tests

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]]
x=Struct([square])

@testset "embedStruct Tests" begin
@test length(embedStruct(1)(x).body[1][1][1])==length(x.body[1][1][1])+1
#in this case n = 1, but generally:
#length(embedStruct(n)(x).body[1][1][1])=length(x.body[1][1][1])+n
@test length(embedStruct(3)(x).body[1][1][1])==length(x.body[1][1][1])+3
@test typeof(embedStruct(1)(x))==Struct
end

```

#### Parallel Tests

```

square=[[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]]
x=pStruct([square])

@testset "pembedStruct Tests" begin
@test length(pembedStruct(1)(x).body[1][1][1])==length(x.body[1][1][1])+1
#in this case n = 1, but generally:
#length(embedStruct(n)(x).body[1][1][1])=length(x.body[1][1][1])+n
@test length(pembedStruct(3)(x).body[1][1][1])==length(x.body[1][1][1])+3
@test typeof(pembedStruct(1)(x))==pStruct
end

```

## 2.7.4 Results

### Execution time on Tesla

```

input=[1,10,20,50,10^2,2*10^2,5*10^2,10^3,2*10^3]

function timeEmbedStruct(n,model,input)
    t=Array{Float64}(length(input))
    pt=Array{Float64}(length(input))
    for i in range(1,length(input))
        structo=addn2D(input[i],model)
        pstructo=pStruct(structo.body)
        embedStruct(n)(structo)
        pembedStruct(n)(pstructo)
        t[i]=@elapsed embedStruct(n)(structo)
        pt[i]=@elapsed pembedStruct(n)(pstructo)
    end
    return t,pt
end
y,yp=timeEmbedStruct(10,square,input)

p=plot(input,y,xaxis="input",yaxis="time",xlims=(0,length(input)+1),
       ylims=(0,maximum(y)+0.5), label=["Serial"],lw=2)
pp=plot(input,yp,xaxis="input",yaxis="time",xlims=(0,length(input)+1),
       ylims=(0,maximum(y)+0.5),label=["Parallel"],lw=2)

```

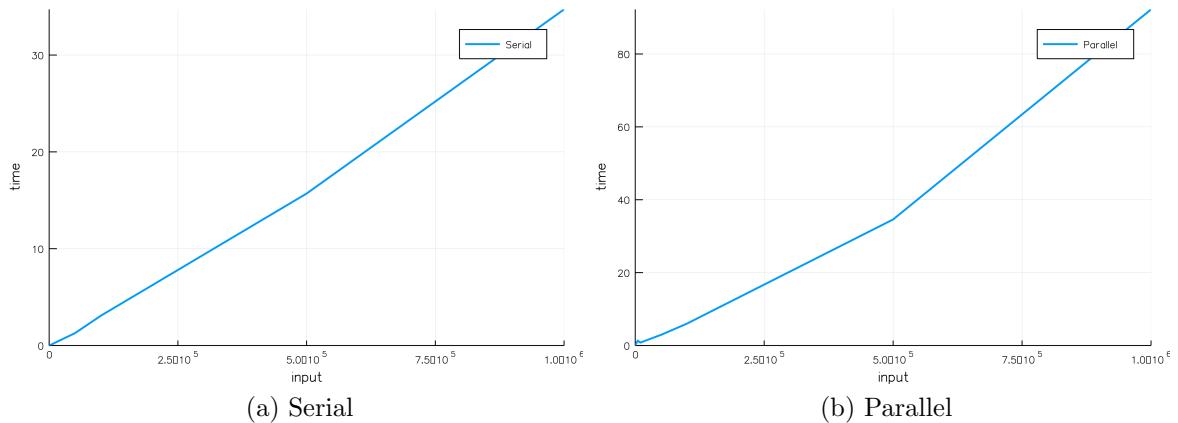


Figure 18: Execution time of function embedStruct on Tesla

## Compare

```
yc=[y,yp]
pc=plot(input,yc,label=["Serial" "Parallel"])
```

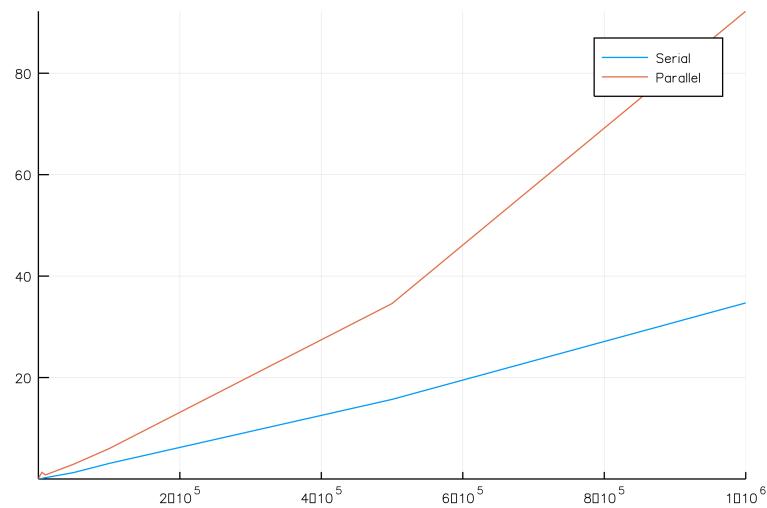


Figure 19: Compared execution time of function embedtraversal on Tesla

## 2.8 removeDups

### 2.8.1 Conversion

#### Python

```
def removeDups (CW):
    CW = list(set(AA(tuple)(CW)))
    CWS = list(set(AA(tuple)(AA(sorted)(CW))))
    no_duplicates = defaultdict(list)
    for f in CWS: no_duplicates[f] = []
    for f in CW:
        no_duplicates[tuple(sorted(f))] += [f]
    CW = [f[0] for f in no_duplicates.values()]
    return CW
```

#### Julia

```
function removeDups(CW)
    CW=collect(Set(CW))
    CWS=collect(map(sort,CW))
    no_duplicates=Dict()
    for f in CWS
        no_duplicates[f] = []
    end
    for f in CW
        no_duplicates[sort(f)]=[f]
    end
    CW=[f[1] for f in values(no_duplicates)]
    return CW
end
```

### 2.8.2 Parallelization

```
function premoveDups(CW)
    CW=collect(Set(CW))
    CWS=collect(@sync pmap(sort,CW))
    no_duplicates=Dict()
    @parallel for f in CWS
        no_duplicates[f] = []
    end
    @parallel for f in CW
        no_duplicates[sort(f)]=[f]
    end
    @parallel for f in values(no_duplicates)
        append!(CW,f[1])
    end
    return CW
end
```

## 2.8.3 Unit-Test

### Serial Tests

```
CW1=[[0,1,2,3],[4,5,6,7],[0,1,4,5],[2,3,6,7],[0,2,4,6],[1,3,5,7],[4,5,6,7],[8,9,10,11],  
[4,5,8,9],[6,7,10,11],[4,6,8,10],[5,7,9,11]]  
CW2=[[0,1,2,3],[4,5,6,7],[8,9,10,11],[12,13,14,15],[16,17,18,19]]
```

```
@testset "removeDups Tests" begin  
    @testset "removeDups 3D" begin  
        @test length(removeDups(CW1))<= length(CW1)  
        @test typeof(removeDups(CW1))==Array{Array{Int64,1},1}  
    end  
    @testset "removeDups 2D" begin  
        @test length(removeDups(CW2))<= length(CW2)  
        @test typeof(removeDups(CW2))==Array{Array{Int64,1},1}  
    end  
end
```

### Parallel Tests

```
CW1=[[0,1,2,3],[4,5,6,7],[0,1,4,5],[2,3,6,7],[0,2,4,6],[1,3,5,7],[4,5,6,7],[8,9,10,11],  
[4,5,8,9],[6,7,10,11],[4,6,8,10],[5,7,9,11]]  
CW2=[[0,1,2,3],[4,5,6,7],[8,9,10,11],[12,13,14,15],[16,17,18,19]]
```

```
@testset "premoveDups Tests" begin  
    @testset "premoveDups 3D" begin  
        @test length(premoveDups(CW1))<= length(CW1)  
        @test typeof(premoveDups(CW1))==Array{Array{Int64,1},1}  
    end  
    @testset "premoveDups 2D" begin  
        @test length(premoveDups(CW2))<= length(CW2)  
        @test typeof(premoveDups(CW2))==Array{Array{Int64,1},1}  
    end  
end
```

## 2.8.4 Results

### Execution time on PC

```
input=[]  
times=[]  
ptimes=[]  
  
append!(input,l[i][1] for i in range(1,length(l)))  
append!(times,Time(removeDups,[input[i]])) for i in range(1,length(input)))  
append!(ptimes,Time(premoveDups,[input[i]])) for i in range(1,length(input)))
```

```

plot(times,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Serial"])
plot(ptimes,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Parallel"])

```

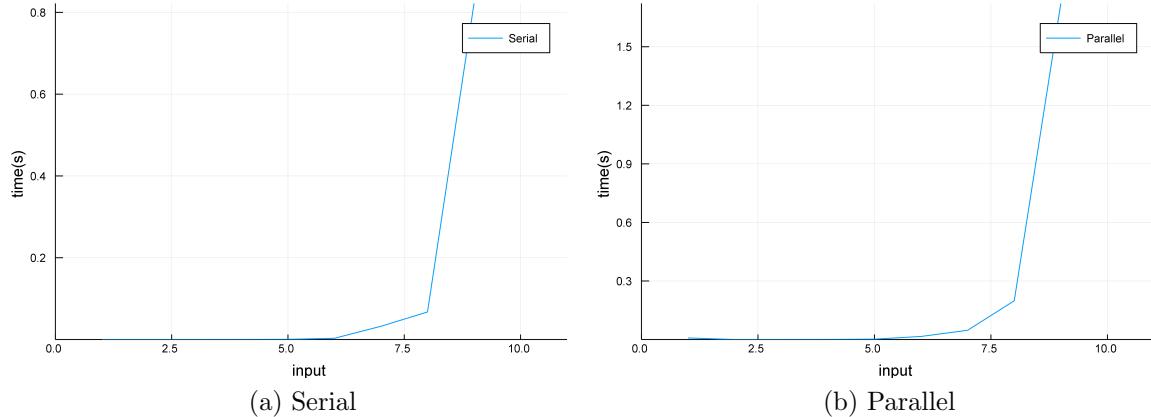


Figure 20: Execution time of function removeDups

Compare

```

plot([times,ptimes],xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",
label=["Serial","Parallel"])

```

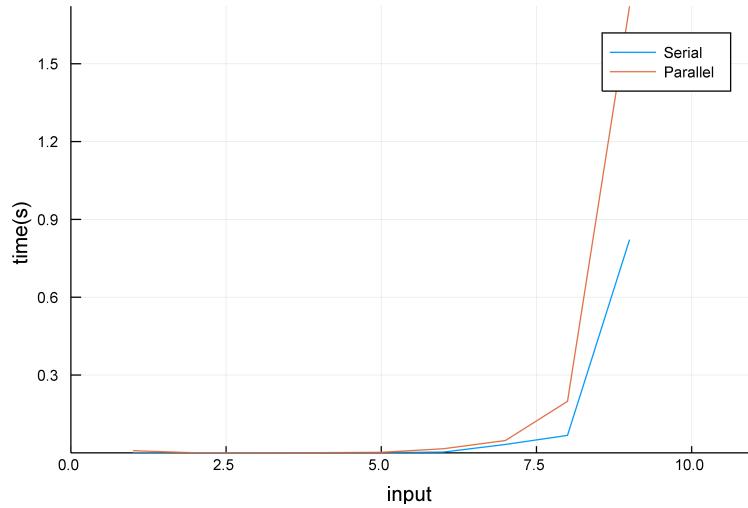


Figure 21: Compared execution time of function removeDups

## 2.9 struct2lar

### 2.9.1 Conversion

fixedPrec

Python

```
def fixedPrec(PRECISION):
    def fixedPrec0(value):
        out = round(value*10**PRECISION)/10**PRECISION
        if out == -0.0: out = 0.0
        return str(out)
    return fixedPrec0
```

Julia

```
@everywhere function fixedPrec(PRECISION)
    function fixedPrec0(value)
        out=round.(value,PRECISION)
        if out== -0.0
            out=0.0
        end
        return string(out)
    end
    return fixedPrec0
end
```

vcode

Python

```
def vcode (PRECISION=4):
    def vcode0 (vect):
        return prepKey(AA(fixedPrec(PRECISION))(vect))
    return vcode0
```

Julia

```
@everywhere function vcode(PRECISION=4)
    function vcode0(vect)
        return fixedPrec(PRECISION)(vect)
    end
    return vcode0
end
```

Python

```
def struct2lar(structure,metric=ID):
    listOfModels = evalStruct(structure)
    vertDict = dict()
    index,defaultValue,CW,W,FW = -1,-1,[],[],[]
    for model in listOfModels:
        if isinstance(model,Model):
            V= model.verts
            FV=model.cells
        elif (isinstance(model,tuple) or isinstance(model,list)):
            if len(model)==2:
                V,FV=model
                dim=len(model)
            elif len(model)==3:
                V,FV,EV,dim=model,len(model)
                for k,incell in enumerate(EV):
                    outcell = []
                    for v in incell:
                        key = vcode(4)(V[v])
                        if vertDict.get(key,defaultValue) == defaultValue:
                            index += 1
```

```

        vertDict[key] = index
        outcell += [index]
        W += [eval(key)]
    else:
        outcell += [vertDict[key]]
    FW += [outcell]
for k,incell in enumerate(FV):
    outcell = []
    for v in incell:
        key = vcode(4)(V[v])
        if vertDict.get(key,defaultValue) == defaultValue:
            index += 1
            vertDict[key] = index
            outcell += [index]
            W += [eval(key)]
        else:
            outcell += [vertDict[key]]
    CW += [outcell]
if ((isinstance(model,tuple) or isinstance(model,list))and len(model)==2) or
((isinstance(model,Model)and model.n==2)):
    if len(CW[0])==2:
        CW = list(set(AA(tuple)(AA(sorted)(CW))))
    else: CW = removeDups(CW)
    return metric(W),CW
if ((isinstance(model,tuple) or isinstance(model,list))and len(model)==3):
    FW = list(set(AA(tuple)(AA(sorted)(FW))))
    CW = removeDups(CW)
    return metric(W),CW,FW

```

### Julia

```

function struct2lar(structure)
    listOfModels=evalStruct(structure)
    vertDict= Dict()
    index,defaultValue,CW,W,FW = -1,-1,[],[],[]
    for model in listOfModels
        if length(model)==2
            V,FV=model
        elseif length(model)==3
            V,FV,EV=model
        end
        for (k,incell) in enumerate(FV)
            outcell=[ ]
            for v in incell
                key=vcode(4)(V[v+1])
                if get(vertDict,key,defaultValue)==defaultValue
                    index =index+1
                    vertDict[key]=index
                    append!(outcell,index)

```

```

        append!(W,[eval(parse(key))])
    else
        append!(outcell,vertDict[key])
    end
end
append!(CW,[outcell])
end
if length(model)==3
    for (k,incell) in enumerate(FV)
        outcell=[]
        for v in incell
            key=vcode(4)(V[v+1])
            if get(vertDict,key,defaultValue)==defaultValue
                index =index+1
                vertDict[key]=index
                append!(outcell,[index])
                append!(W,[eval(parse(key))])
            else
                append!(outcell,vertDict[key])
            end
        end
        append!(FW,[outcell])
    end
end
end
if length(listOfModels[end])==2
    if length(CW[1])==2
        CW=map(Tuple,map(sort,CW))
    else
        CW=removeDups(CW)
    end
    return W,CW
end
if length(listOfModels[end])==3
    FW=map(Tuple,map(sort,FW))
    CW=removeDups(CW)
    return W,CW,FW
end
end

```

## 2.9.2 Parallelization

```

@everywhere function pstruct2lar(structure)
    listOfModels=pevalStruct(structure)
    vertDict= Dict()
    index,defaultValue,CW,W,FW = -1,-1,[],[],[]
    for model in listOfModels

```

```

if length(model)==2
    V,FV=model
elseif lenght(model)==3
    V,FV,EV=model
end
@sync begin
    for (k,incell) in enumerate(FV)
        outcell=[]
        @async begin
            for v in incell
                key=vcode(4)(V[v+1])
                if get(vertDict,key,defaultValue)==defaultValue
                    index =index+1
                    vertDict[key]=index
                    append!(outcell,index)
                    append!(W,[eval(parse(key))])
                else
                    append!(outcell,vertDict[key])
                end
            end
        end
        append!(CW,[outcell])
    end
end
if length(model)==3
    @sync begin
        for (k,incell) in enumerate(FV)
            outcell=[]
            @async begin
                for v in incell
                    key=vcode(4)(V[v+1])
                    if get(vertDict,key,defaultValue)==defaultValue
                        index =index+1
                        vertDict[key]=index
                        append!(outcell,[index])
                        append!(W,[eval(parse(key))])
                    else
                        append!(outcell,vertDict[key])
                    end
                end
            end
            append!(FW,[outcell])
        end
    end
end
if length(listOfModels[end])==2
    if length(CW[1])==2
        CW=pmap(Tuple,pmap(sort,CW))

```

```

    else
        CW=premoveDups(CW)
    end
    return W,CW
end
if length(listOfModels[end])==3
    FW=pmap(Tuple,pmap(sort,FW))
    CW=premoveDups(CW)
    return W,CW,FW
end
end

```

### 2.9.3 Unit-Test

#### Serial Tests

```

@testset "struct2lar Tests" begin
square=[[0, 0],[0,1],[1,0],[1,1],[[0,1,2,3]]]
table=larApply(t(-0.5,-0.5))(square)
structure=Struct([repeat([table,r(pi/2)],outer=2)...])
@testset "struct2lar 2D" begin
    @test typeof(struct2lar(structure))==Tuple{Array{Any,1},Array{Array{Any,1},1}}
    @test length(struct2lar(structure)[1][1])==2
end
BV=[[0,1,2,3],[4,5,6,7],[0,1,4,5],[2,3,6,7],[0,2,4,6],[1,3,5,7]]
V=[[0,0,0],[0,0,1],[0,1,0],[0,1,1],[1,0,0],[1,0,1],[1,1,0],[1,1,1]]
block=[V,BV]
structure=Struct(repeat([block,t(1,0,0)],outer=2))
@testset "struct2lar 3D" begin
    @test typeof(struct2lar(structure))==Tuple{Array{Any,1},Array{Array{Any,1},1}}
    @test length(struct2lar(structure)[1][1])==3
end
end

```

#### Parallel Tests

```

@testset "pstruct2lar Tests" begin
square=[[0,0],[0,1],[1,0],[1,1],[[0,1,2,3]]]
table=plarApply(t(-0.5,-0.5))(square)
structure=pStruct([repeat([table,r(pi/2)],outer=2)...])

@testset "pstruct2lar 2D" begin
    @test typeof(pstruct2lar(structure))==Tuple{Array{Any,1},Array{Any,1}}
    @test length(pstruct2lar(structure)[1][1])==2
end

```

```

BV=[[0,1,2,3],[4,5,6,7],[0,1,4,5],[2,3,6,7],[0,2,4,6],[1,3,5,7]]
V=[[0,0,0],[0,0,1],[0,1,0],[0,1,1],[1,0,0],[1,0,1],[1,1,0],[1,1,1]]
block=[V,BV]
structure=pStruct(repeat([block,t(1,0,0)],outer=2));

@testset "pstruct2lar 3D" begin
@test typeof(pstruct2lar(structure))==Tuple{Array{Any,1},Array{Any,1}}
@test length(pstruct2lar(structure)[1][1])==3
end
end

```

## 2.9.4 Results

### Execution time on PC

```

times=[]
ptimes=[]
input=[]

for i in range(1,length(l)-1)
    push!(input,Struct([repeat([l[i]],outer=i)...]))
end
append!(times,Time(struct2lar,[input[i]]) for i in range(1,length(input)))
append!(ptimes,Time(pstruct2lar,[input[i]]) for i in range(1,length(input)))

plot(times,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Serial"])
plot(ptimes,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Parallel"])

```

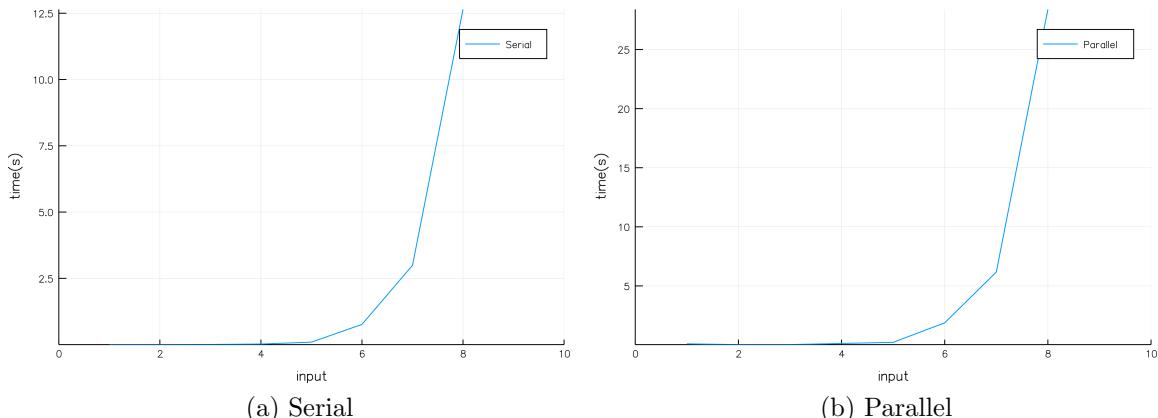


Figure 22: Execution time of function struct2lar

## Compare

```
plot([times,ptimes],xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",  
label=["Serial","Parallel"])
```

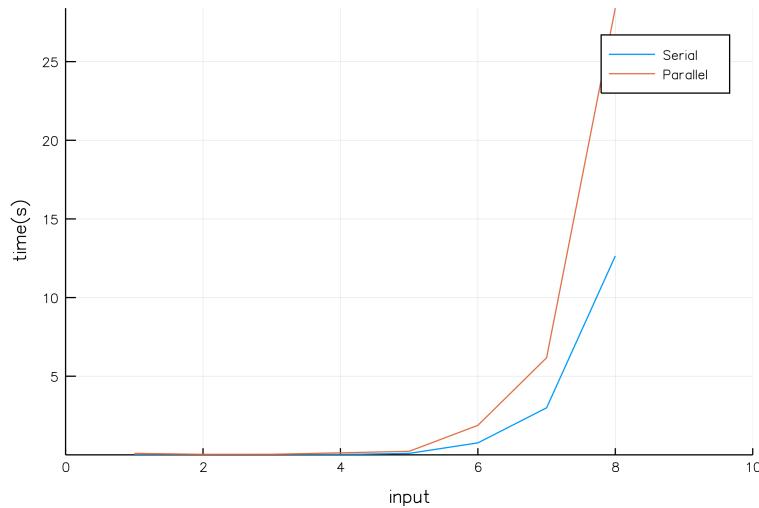


Figure 23: Compared execution time of function struct2lar

## Execution time on Tesla

```
input=[1,10,20,50,10^2,2*10^2,5*10^2,10^3,2*10^3]  
y,yp=timeFstruct(struct2lar,pstruct2lar,square,input)
```

```

p=plot(input,y,xaxis="input",yaxis="time",xlims=(0,length(input)+1),
       ylims=(0,maximum(y)+0.5), label=["Serial"],lw=2)
pp=plot(input,yp,xaxis="input",yaxis="time",xlims=(0,length(input)+1),
        ylims=(0,maximum(y)+0.5),label=["Parallel"],lw=2)

```

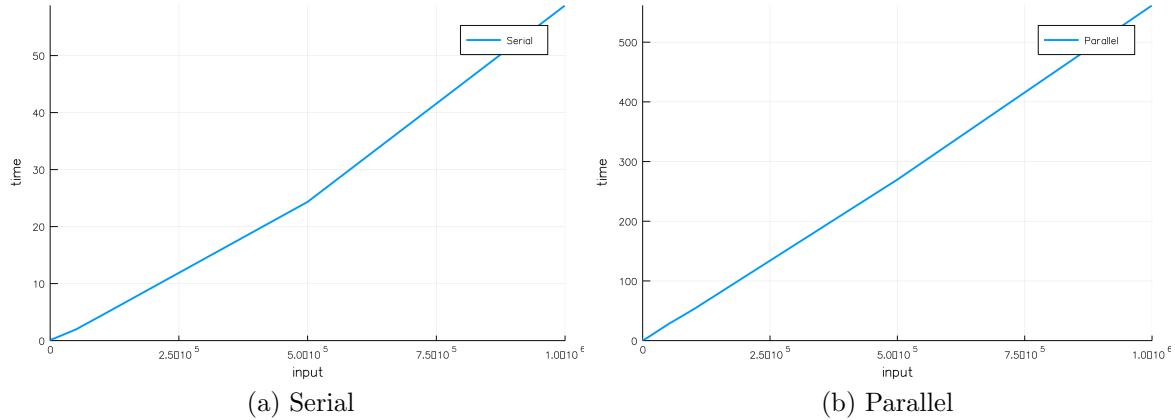


Figure 24: Execution Time of function struct2lar on Tesla

### Compare

```

yc=[y,yp]
pc=plot(input,yc,label=["Serial" "Parallel"])

```

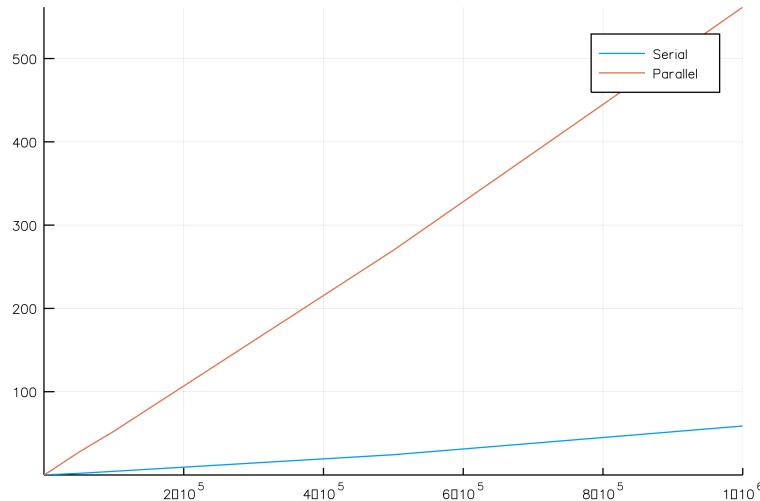


Figure 25: Compared execution time of function struct2lar on Tesla

## 2.10 larRemoveVertices

### 2.10.1 Conversion

Python

```
def larRemoveVertices(V,FV):
    vertDict = dict()
    index,defaultValue,CW,W = -1,-1,[],[]
    for k,incell in enumerate(FV):
        outcell = []
        for v in incell:
            key = vcode(4)(V[v])
            if vertDict.get(key,defaultValue) == defaultValue:
                index += 1
                vertDict[key] = index
                outcell += [index]
                W += [eval(key)]
            else:
                outcell += [vertDict[key]]
        FW += [outcell]
    return W,FW
```

Julia

```
function larRemoveVertices(V,FV)
    vertDict= Dict()
    index,defaultValue,CW,W,FW = -1,-1,[],[],[]
    for (k,incell) in enumerate(FV)
        outcell=[]
        for v in incell
            key=vcode(4)(V[v+1])
            if get(vertDict,key,defaultValue)==defaultValue
                index =index+1
                vertDict[key]=index
                append!(outcell,index)
                append!(W,[eval(parse(key))])
            else
                append!(outcell,vertDict[key])
            end
        end
        append!(FW,[outcell])
    end
    return W,FW
end
```

### 2.10.2 Parallelization

```
@everywhere function plarRemoveVertices(V,FV)
    vertDict= Dict()
    index,defaultValue,CW,W,FW = -1,-1,[],[],[]
    @async begin
        for (k,incell) in enumerate(FV)
            outcell=[]
            @sync begin
```

```

for v in incell
    key=vcode(4)(V[v+1])
    if get(vertDict,key,defaultValue)==defaultValue
        index =index+1
        vertDict[key]=index
        append!(outcell,index)
        append!(W,[eval(parse(key))])
    else
        append!(outcell,vertDict[key])
    end
end
append!(FW,[outcell])
end
return W,FW
end

```

### 2.10.3 Unit-Test

#### Serial Tests

```

V=[[0,0,0],[0,0,1],[0,1,0],[0,1,1],[1,0,0],[1,0,1],[1, 1, 0],[1, 1, 1]]
FV=[[0,1,2,3],[4,5,6,7],[0,1,4,5],[2,3,6,7],[0,2,4,6],[1,3,5,7]]

```

```

@testset "larRemoveVertices Tests" begin
    @test typeof(larRemoveVertices(V,FV))==Tuple{Array{Any,1},Array{Any,1}}
    @test length(larRemoveVertices(V,FV)[1])<= length(V)
end

```

#### Parallel Tests

```

V=[[0,0,0],[0,0,1],[0,1,0],[0,1,1],[1,0,0],[1,0,1],[1, 1, 0],[1, 1, 1]]
FV=[[0,1,2,3],[4,5,6,7],[0,1,4,5],[2,3,6,7],[0,2,4,6],[1,3,5,7]]

```

```

@testset "plarRemoveVertices Tests" begin
    @test typeof(plarRemoveVertices(V,FV))==Tuple{Array{Any,1},Array{Any,1}}
    @test length(plarRemoveVertices(V,FV)[1])<= length(V)
end

```

## 2.11 Result

### Execution time on PC

```

times=[]
ptimes=[]
append!(times,Time(larRemoveVertices,[l[i][1],l[i][2]])) for i in range(1,length(l)-1)
append!(ptimes,Time(plarRemoveVertices,[l[i][1],l[i][2]])) for i in range(1,length(l)-1)

```

```

plot(times,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Serial"])
plot(ptimes,xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",label=["Parallel"])

```

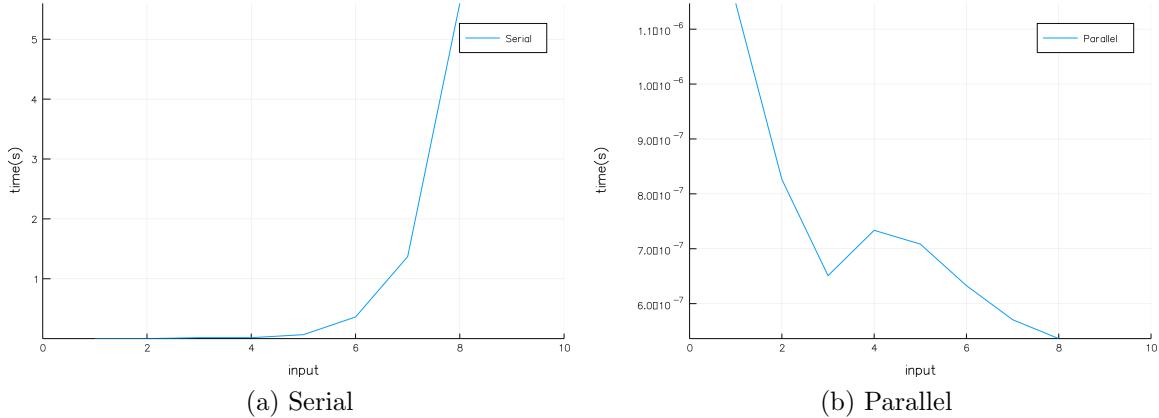


Figure 26: Execution time of function larRemoveVertices

### Compare

```

plot([times,ptimes],xlabel="input",xlims=(0,length(times)+2),ylabel="time(s)",
label=["Serial","Parallel"])

```

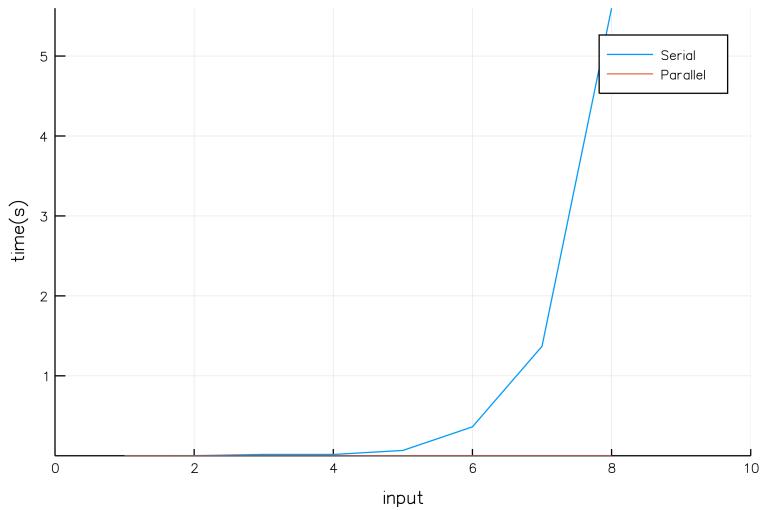


Figure 27: Compared execution time of function larRemoveVertices

### 3 Examples

In the following section some examples of how to use the module are presented.

#### Examples 1

```
square= ([[0,0],[0,1],[1,0],[1,1]],[[0,1,2,3]])
table= larApply(t(-.5,-.5))(square)
chair= larApply(s(.35,.35))(table)
chair1= larApply(t(.75,0))(chair)
chair2= larApply(r(pi/2))(chair1)
chair3= larApply(r(pi/2))(chair2)
chair4= larApply(r(pi/2))(chair3)
```

This execution return the following immage:

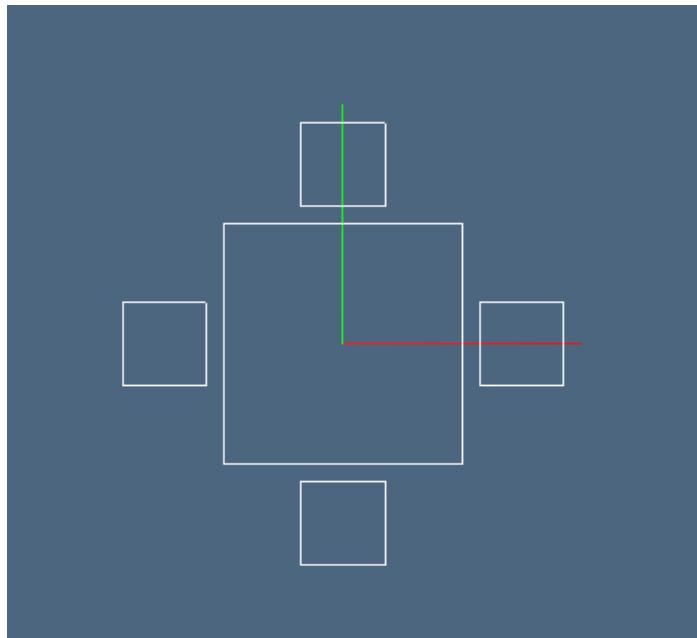


Figure 28: Table with four chair

#### Examples 2

```
desk=[[0, 0],[0, 1],[0, 2],[1, 0],[1, 1],[1, 2],[2, 0],[2, 1],[2, 2],[3, 0],[3, 1],[3, 2],
[4, 0],[4, 1],[4, 2],[5, 0],[5, 1],[5, 2],[6, 0],[6, 1],[6, 2],[7, 0],[7, 1],[7, 2],[8, 0],
[8, 1],[8, 2],[9, 0],[9, 1],[9, 2],[10, 0],[10, 1],[10, 2],[11, 0],[11, 1],[11, 2],[12, 0],
[12, 1],[12, 2],[13, 0],[13, 1],[13, 2],[14, 0],[14, 1],[14, 2],[15, 0],[15, 1],[15, 2],
[16, 0],[16, 1],[16, 2],[17, 0],[17, 1],[17, 2],[18, 0],[18, 1],[18, 2],[19, 0],[19, 1],
[19, 2],[20, 0],[20, 1],[20, 2]], [[0, 1, 3, 4],[1, 2, 4, 5],[3, 4, 6, 7],[4, 5, 7, 8],
[6, 7, 9, 10],[7, 8, 10, 11],[9, 10, 12, 13],[10, 11, 13, 14],[12, 13, 15, 16],
[13, 14, 16, 17],[15, 16, 18, 19],[16, 17, 19, 20],[18, 19, 21, 22],[19, 20, 22, 23],
```

```

[21, 22, 24, 25], [22, 23, 25, 26], [24, 25, 27, 28], [25, 26, 28, 29], [27, 28, 30, 31],
[28, 29, 31, 32], [30, 31, 33, 34], [31, 32, 34, 35], [33, 34, 36, 37], [34, 35, 37, 38],
[36, 37, 39, 40], [37, 38, 40, 41], [39, 40, 42, 43], [40, 41, 43, 44], [42, 43, 45, 46],
[43, 44, 46, 47], [45, 46, 48, 49], [46, 47, 49, 50], [48, 49, 51, 52], [49, 50, 52, 53],
[51, 52, 54, 55], [52, 53, 55, 56], [54, 55, 57, 58], [55, 56, 58, 59], [57, 58, 60, 61],
[58, 59, 61, 62]]]

seat=larApply(s(0.02,0.3))(desk)
seat=larApply(t(0.55,-0.85))(seat)
line=Struct([desk,repeat([seat,t(1.65,0)],outer=12)...])
line=Struct([line,t(23,0),line])
lines=Struct([repeat([line,t(0,-3)],outer=6)...])
teacherdesk=larApply(s(0.5,0.8))(desk)
teacherdesk=larApply(t(16.5,5))(teacherdesk)
chair=larApply(s(0.15,0.5))(teacherdesk)
chair=larApply(t(18,5))(chair)
classroom=Struct([teacherdesk,chair,lines])
class=evalStruct(classroom)

```

This execution return the following immage:

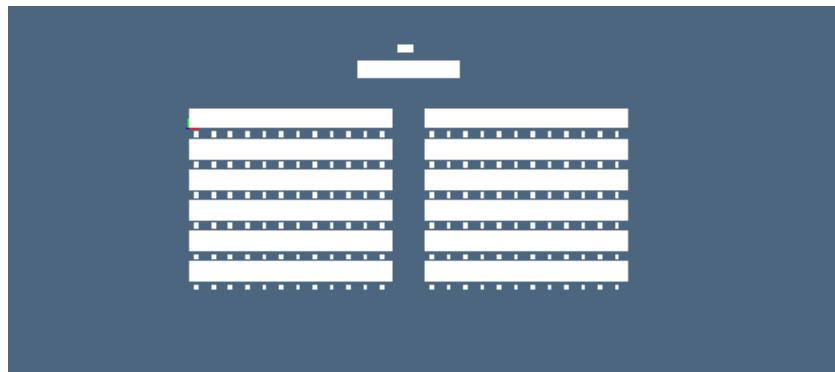


Figure 29: Classroom

## 4 Conclusion

As shown in the plots, generally, parallelization slows execution times, especially when the functions are generated by large Struct objects. In this case, execution times stay large even when the tests are performed in the sequential framework on Tesla. Conversely, functions generated by the increase of array objects show lower times of execution. This suggests that functions generated by user defined Struct objects are systematically slower than those generated using native language objects (as Tuples or Arrays).

## References

- [1] A.Paoluzzi Hierarchical structures with LAR,March 29,2016.
- [2] Julia Documentation.