Carl von Ossietzky Universität Oldenburg

Betriebseinheit für technisch-wissenschaftliche Infrastruktur

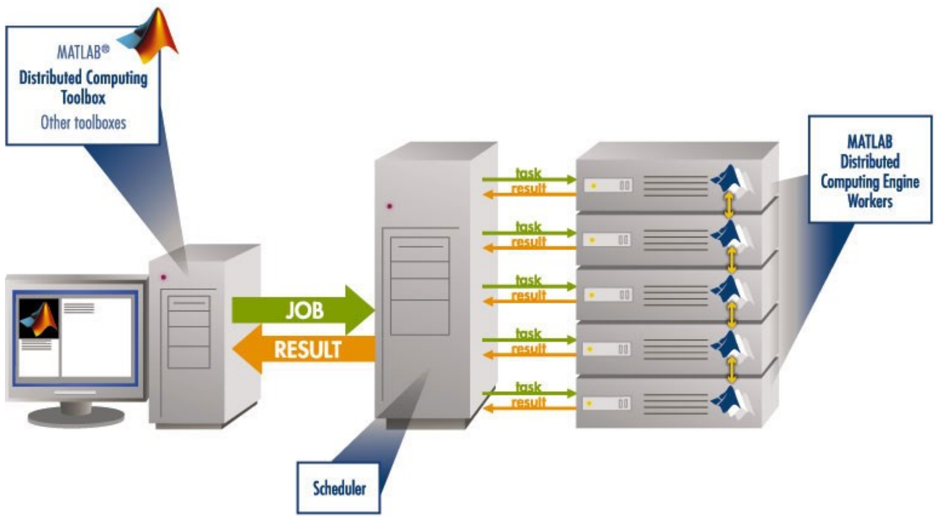
Introduction to High-Performance Computing

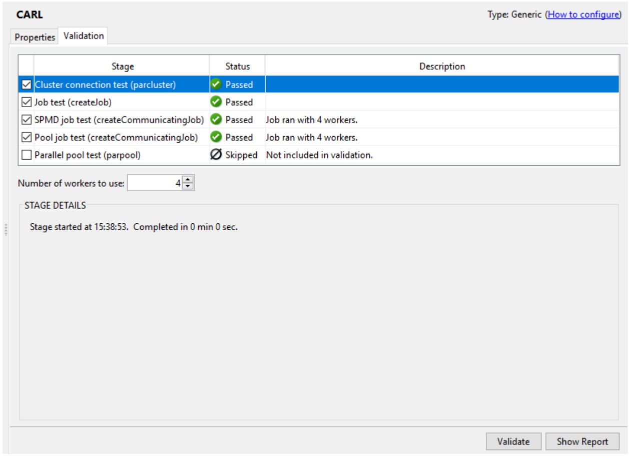
Session 09

Matlab Distributed Compute Server (MDCS)

Previous Session

- introduction to MDCS
  - MDCS can be used to off-load Matlab computations to the HPC cluster in a simple workflow
  - allows parallelization across multiple compute nodes
- configuration of MDCS
  - prepare your local computer for MDCS
- usage of MDCS
  - basic example for submitting a job and retrieving results

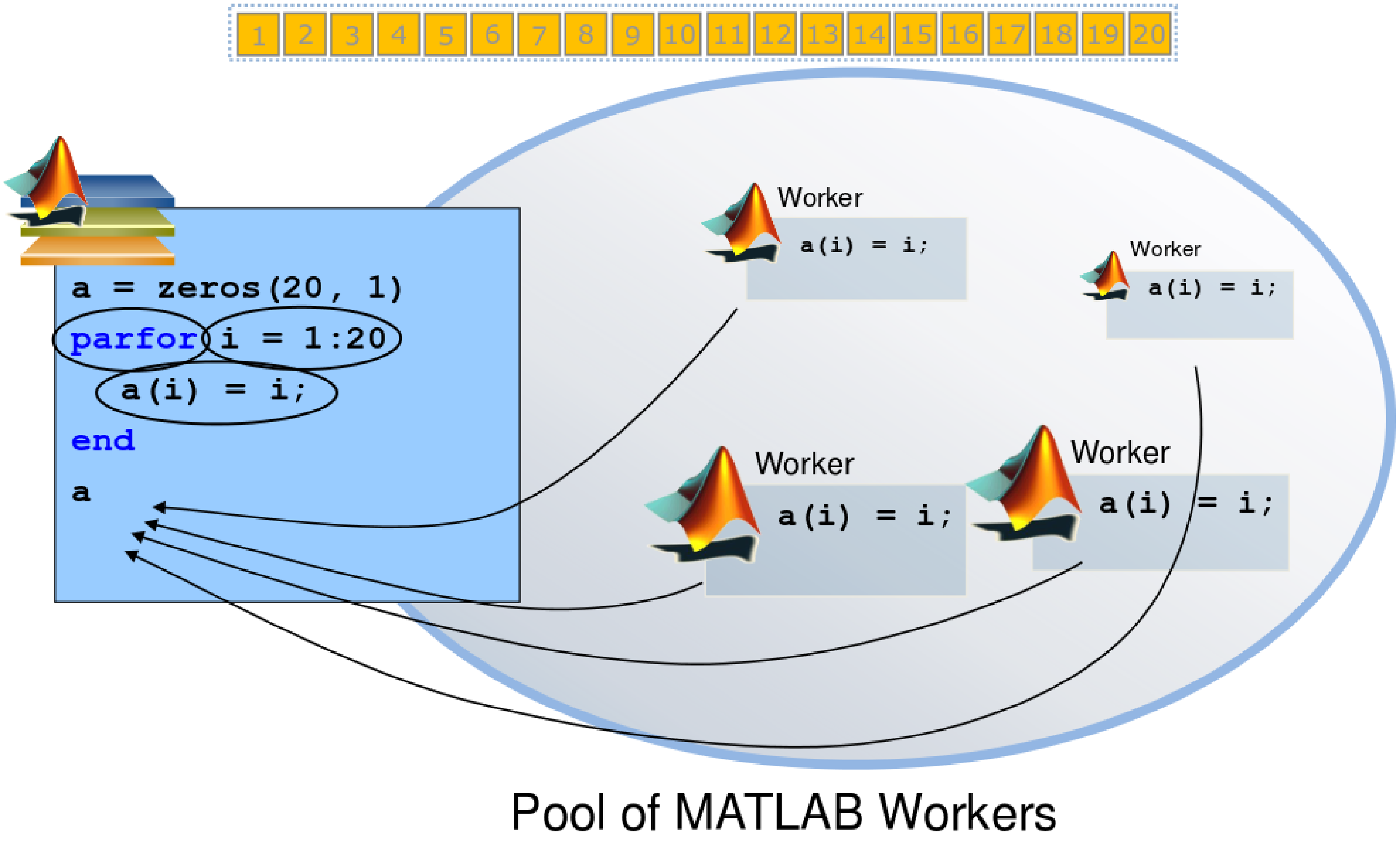





```
>> sched = parcluster('CARL');
>> job = batch(sched, 'paramSweep_batch', 'Pool', 7, ...
               'AttachedFiles', {'odesystem.m'});
>> job.State
>> jobData = load(job);
```

Parallelization with `parfor`

Mechanics of `parfor` Loops



Converting `for` to `parfor`

- requirements for **`parfor`** loops
  - task independent
  - order independent
  - loop index must be consecutive increasing integers

- constraints on the loop body
  - cannot introduce variables (e.g. **`eval`**, **`load`**, **`global`**)
  - cannot contain **`break`** or **`return`** statements
  - cannot contain another **`parfor`** loop
  - …

https://de.mathworks.com/help/parallel-computing/troubleshoot-variables-in-parfor-loops.html

Variable Classification

- all variables referenced at the top level of the `parfor` must be resolved and classified

Classification	Description
loop	serves as a loop index for arrays
sliced	an array whose segments are operated on by different iterations
broadcast	a variable defined before the loop whose value is used inside the loop, but never assigned in the loop
reduction	accumulates a value across iterations of the loop, regardless of iteration order
temporary	variable created inside the loop but unlike sliced or reduction variables, not available outside the loop

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Variable Classification Example

- matrix-vector multiplication

```
N=2048;                    % N is broadcast
b=rand(N,1);               % b is broadcast
A=rand(N,N);               % A is slices input

parfor i=1:N               % i is loop index
  c(i)=A(i,:)*b(:);        % c is sliced output
end
c                          % using c outside the loop
```

`parfor` Examples

- this example cannot be parallized in `parfor`

```
j=zeros(100);          %pre-allocate vector
j(1)=5;
for i=2:100;
    j(i)=j(i-1)+5;
end;
```

  – order of iterations is important

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`parfor` Examples

- functions with multiple output may confuse Matlab

```
for i=1:10
   [x{i}(:,1), x{i}(:,2)]=functionName(z,w);
end;
```

  - use this instead

```
for i=1:10
    [x1, x2]=functionName(z,w);
    x{i}=[x1 x2];
end;
```

parfor Examples

- be careful not to broadcast unnecessary data (false sharing)

```
data.raw = ...
data.processed = ...

% Inefficient variant:
parfor idx = 1 : N
    % do something with data.processed
end

% This is better:
processedData = data.processed;
parfor idx = 1 : N
    % do something with processedData
end
```

https://undocumentedmatlab.com/blog/a-few-parfor-tips

`parfor` Considerations

- **`parfor`** often only involves minimal code changes
- if a for loop cannot be converted to **`parfor`**, consider wrapping a subset of loop body in a function
  - e.g. load works not in **`parfor`**, however it does work in function that is called inside a **`parfor`** loop
- more information http://blogs.mathworks.com/loren/2009/10/02/using-parfor-loops-getting-up-and-running/
- there is a Code-Analyzer to diagnose **`parfor`** issues

Parallelization with `spmd`

(single program multiple data)

Parallelization with `spmd`

```
                     Client        Worker 1     Worker 2
                     a  b  e  |  c  d  f  |  c  d  f
                     ----------------------------------
a = 3;               3  -  -  |  -  -  -  |  -  -  -
b = 4;               3  4  -  |  -  -  -  |  -  -  -
spmd                          |           |
  c = labindex();    3  4  -  |  1  -  -  |  2  -  -
  d = c + a;         3  4  -  |  1  4  -  |  2  5  -
end                           |           |
e = a + d{1};        3  4  7  |  1  4  -  |  2  5  -
c{2} = 5;            3  4  7  |  1  4  -  |  5  6  -
spmd                          |           |
  f = c * b;         3  4  7  |  1  4  4  |  5  6 20
end
```

Parallelization with `spmd`

- when a **`spmd`** block ends the workspace is saved, the worker is paused
- data is preserved from one block to the next
- does not apply to **`spmd`** block in a function after the function is completed (as regular variables local to a function)

SPMD Example

```
% read image file
x = imread('uol.jpeg');

% add noise and store noisy image
y = imnoise(x, 'salt & pepper', 0.30);

% distribute image (last column is color chanel)
yd = distributed(y);

% remove noise with filter in parallel
spmd
    yl    = getLocalPart(yd);
    yl    = medfilt2(yl, [3,3]);
end

% put together filtered image and store it
xdim = size(x);
z(1:xdim(1),1:xdim(2),1) = yl{1};
z(1:xdim(1),1:xdim(2),2) = yl{2};
z(1:xdim(1),1:xdim(2),3) = yl{3};
```

- read image
- add noise to image
- distribute data
- parallel working on image data (filter)
- on master process put together filtered image



Distributed Data

- Matlab provides different functions to manage distributed data
  - with **`distributed(X)`** you can distribute data among workers
  - with **`distributed.METHOD`** you can create data distributed among workers
  - workers can create codistributed data structures which become distributed data outside of the **`spmd`** block
  - a datastore can be distributed to read manage large data files with multiple workers
  - see ‘**`help distributed`**’ for more information

Distributed Data

distributing data
from client

```
p = parpool('local', 4);      % create a local pool of workers
A = zeros(4);                 % create a 4x4 matrix with zeros
A                             % print A on client
B = distributed(A);           % distribute A to the workers
spmd                          % begin parallel spmd region
   B = B + labindex;          % modify distributed data in B
end                           % end parallel spmd region
B                             % print B on client
delete(p);
```

vs.

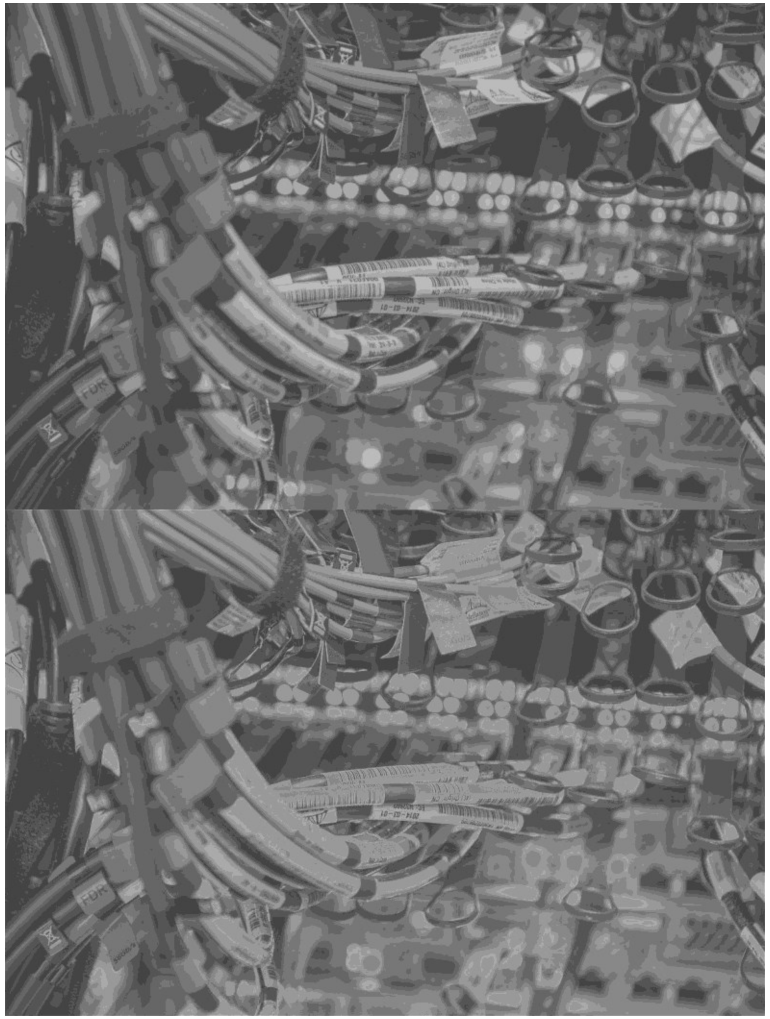
codistributed data
created on workers

```
p = parpool('local', 4);                    % create a pool of workers
spmd                                        % begin parallel spmd region
   codist = codistributor1d(2, [1,1,1,1]);  % define distribution
   B = zeros(4, codist);                    % created codistributed array
   B = B + labindex;                        % modify distributed data in B
end                                         % end parallel spmd region
B                                           % print B on client
delete(p);
```

Example: Image Contrast

- a Matlab script that uses a simple function to change the contrast of an gray-scale image

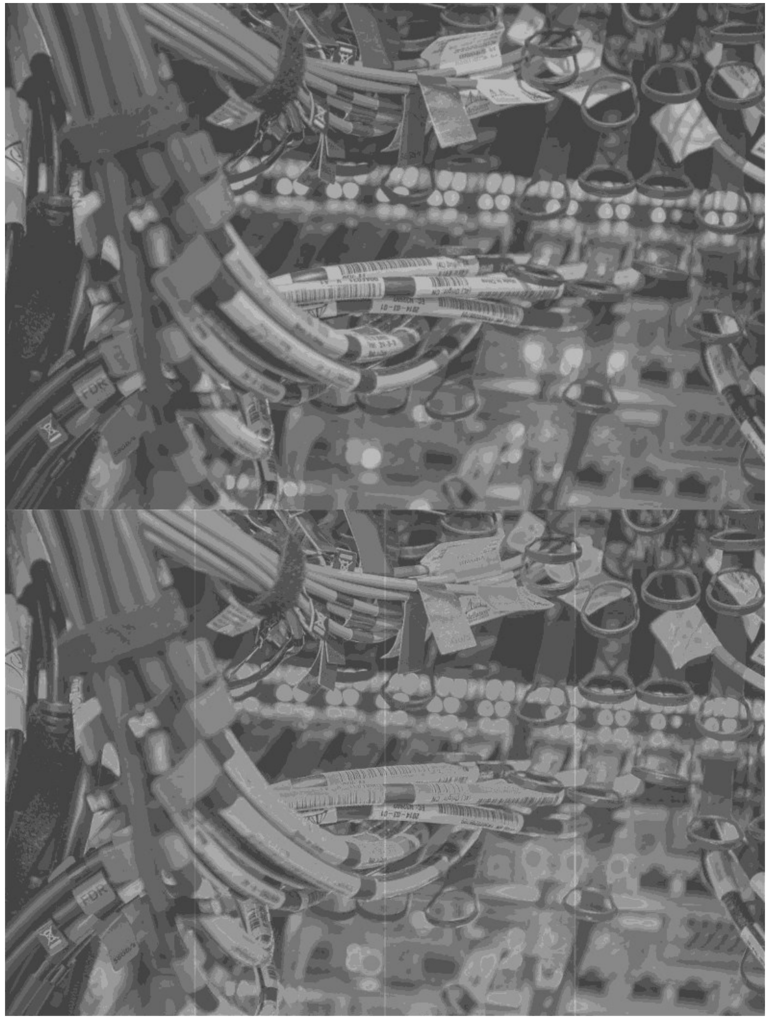
```
% read an image (gray-scale)
y = imread('low_contrast.jpg');

% setup function for contrast manipulation
c = 1.7;
adjustContrast = @(x) c*x(2,2)+(1.0-c)*(mean(x(:)-x(2,2)/9.0));

% apply filter
z = nlfilter(y, [3,3], adjustContrast);

% save image side-by side
imwrite(cat(1,y,z), 'contrast_serial.jpg');
```



Example: Image Contrast

- parallelize with SPMD

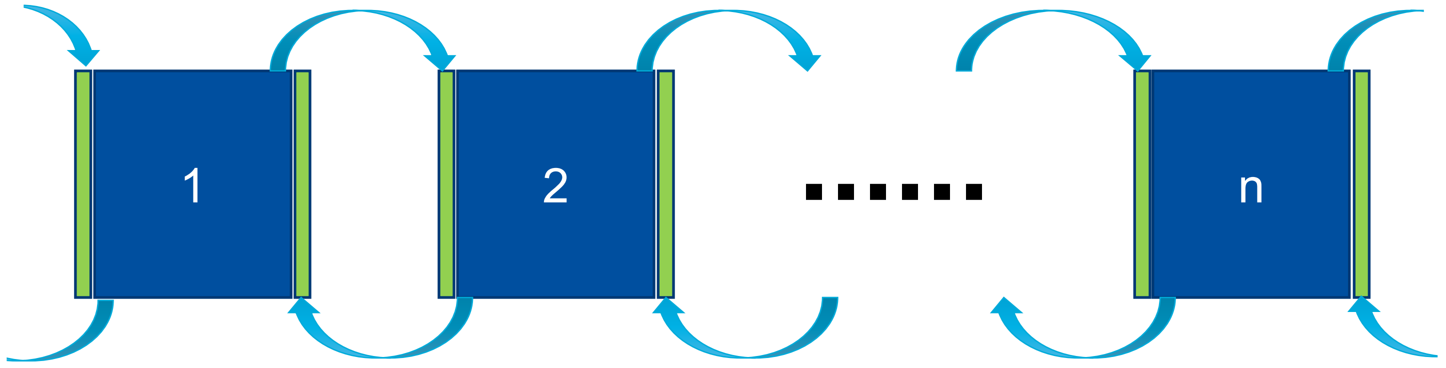
```
% read an image (gray-scale)
y = imread('low_contrast.jpg');

% setup function for contrast manipulation
c = 1.7;
adjustContrast = @(x) c*x(2,2)+(1.0-c)*(mean(x(:)-x(2,2)/9.0));

% distribute image by columns
yd = distributed(y);

% now work in parallel
spmd
    yl = getLocalPart(yd);

    % apply filter
    yl = nlfilter(yl, [3,3], adjustContrast);

end

% combine local images
z = [ yl{:}];

% save image side-by side
imwrite(cat(1,y,z), 'contrast_spmd.jpg');
```



- algorithm produces artifacts when parallelized on multiple workers
  - problem is that increasing contrast requires information from neighbouring pixel
  - distributing the data adds additional boundaries

Communication between Matlab Workers

- solution is communication between workers
  - each worker has to sent one boundary left and one right
  - each worker has to receive one boundary from left and one from right
  - extra columns are added before filter is applied, and need to be removed again afterwards

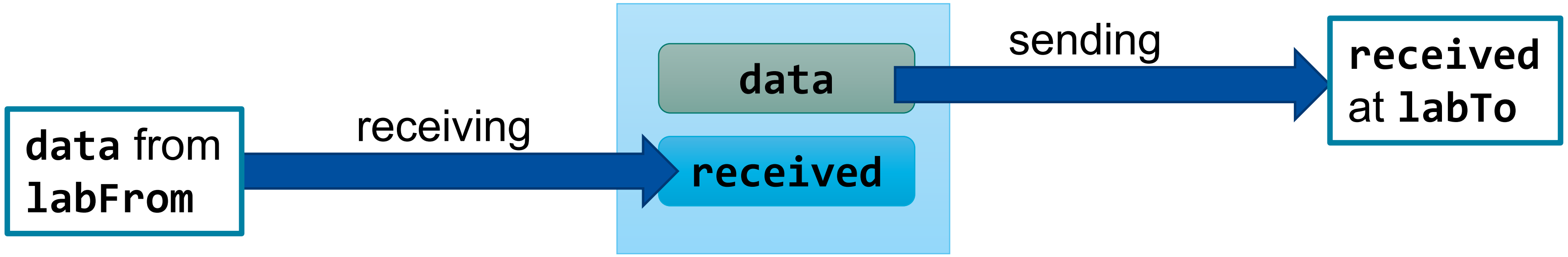


Communication between Matlab Workers

- the function **`labSendReceive`** simultaneously sends and receives data

```
received = labSendReceive(labTo, labFrom, data)
```

  - sends **`data`** to **`labTo`**
  - receives **`data`** from **`labFrom`** and stores it in **`received`**



Communication between Matlab Workers

```
column = labSendReceive ( previous, next, xl(:,1) );

if ( labindex() < numlabs() )
  xl = [ xl, column ];
end

column = labSendReceive ( next, previous, xl(:,end -1));

if ( 1 < labindex() )
  xl = [ column, xl ];
end
```

Exercise

Exercises

- try out the following examples from the lecture

1. MDCS configuration
2. basic example with parfor
3. SPMD example noise reduction
4. SPMD example contrast
5. SPMD example heat

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Heat Example in Matlab

```
% 2d-heat example in Matlab
% initial setup
NXPROB = 20;        % number of grid rows
NYPROB = 20;        % number of grid columns
STEPS  = 100;       % number of iterations
TIME   = 0;         % initial and current time

uvals  = zeros(2, NXPROB, NYPROB);  % allocate grid
uvals  = inidat(uvals);             % initialize grid

plotdat(uvals, 1, TIME);            % make plot

it = 1;
for TIME=1:STEPS                    % time iteration
    uvals = updateu(uvals, it);     % update thermal energy
    it    = 3 - it;
end

plotdat(uvals, 1, TIME);            % make plot
```

The End

contact me directly of you have questions about the course

contact hpcsupport@uol.de if you have requests or encounter problems regarding the HPC cluster

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