

Using MATLAB effectively on Graham and Cedar

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Topics

- MATLAB on CC systems (Graham, Cedar)
- Interactive MATLAB jobs
- Standard MATLAB jobs in Slurm
- MATLAB Parallel Computing Toolbox (PCT)
- MATLAB Compile Runtime (MCR)

MATLAB licenses

- **Cedar**: license available for all CC account users
- **Graham**: using your institution license

inst_dal	inst_sfu	inst_ubc
inst_uwaterloo	inst_mcgill	inst_ualberta
inst_uryerson	inst_uwo	
inst_queens	inst_uvic	

- you are registered with your local MATLAB license
 - your CC username matches your institution ID
 - for those not on the above list, contact your local MATLAB license maintainer and CC staff
- for some, add your local MATLAB license passcode file matlab.lic:
/home/yourID/.licenses/matlab.lic

MATLAB versions

- module spider matlab

Versions:

matlab/2014a

matlab/2016b

matlab/2017a

matlab/2018a

- module load matlab/2018a

Interactive MATLAB jobs

- `salloc`: reserve compute resource

```
salloc --time=1:0:0 --ntasks=1 --account=def-jemmyhu --mem-per-cpu=5G
```

PCT (4 workers)

```
salloc --time=1:0:0 --cpus-per-task=4 --account=def-jemmyhu --mem=10G
```

- GUI

- Enable X11 on local host

```
salloc --x11 --time=1:0:0 --ntasks=1 --account=def-jemmyhu --mem-per-cpu=5G
```

- VNC

<https://docs.computecanada.ca/wiki/VNC>

salloc non-GUI interactive

```
graham.computecanada.ca - default - SSH Secure Shell
File Edit View Window Help
[Icons]
Quick Connect Profiles

[jemmyhu@gra-login2 ~]$ salloc --time=1:0:0 --ntasks=1 --account=def-jemmyhu --mem=5g
salloc: Pending job allocation 8976880
salloc: job 8976880 queued and waiting for resources
salloc: job 8976880 has been allocated resources
salloc: Granted job allocation 8976880
[jemmyhu@gra796 ~]$ module load matlab/2018a
[jemmyhu@gra796 ~]$ cd MATLAB/serial/
[jemmyhu@gra796 serial]$ ls
for_pi_2.m for_pi.log for_pi.m for_pi.sh
[jemmyhu@gra796 serial]$ matlab -nodisplay
Opening log file: /home/jemmyhu/java.log.13173

< M A T L A B (R) >
Copyright 1984-2018 The MathWorks, Inc.
R2018a (9.4.0.813654) 64-bit (glnxa64)
February 23, 2018

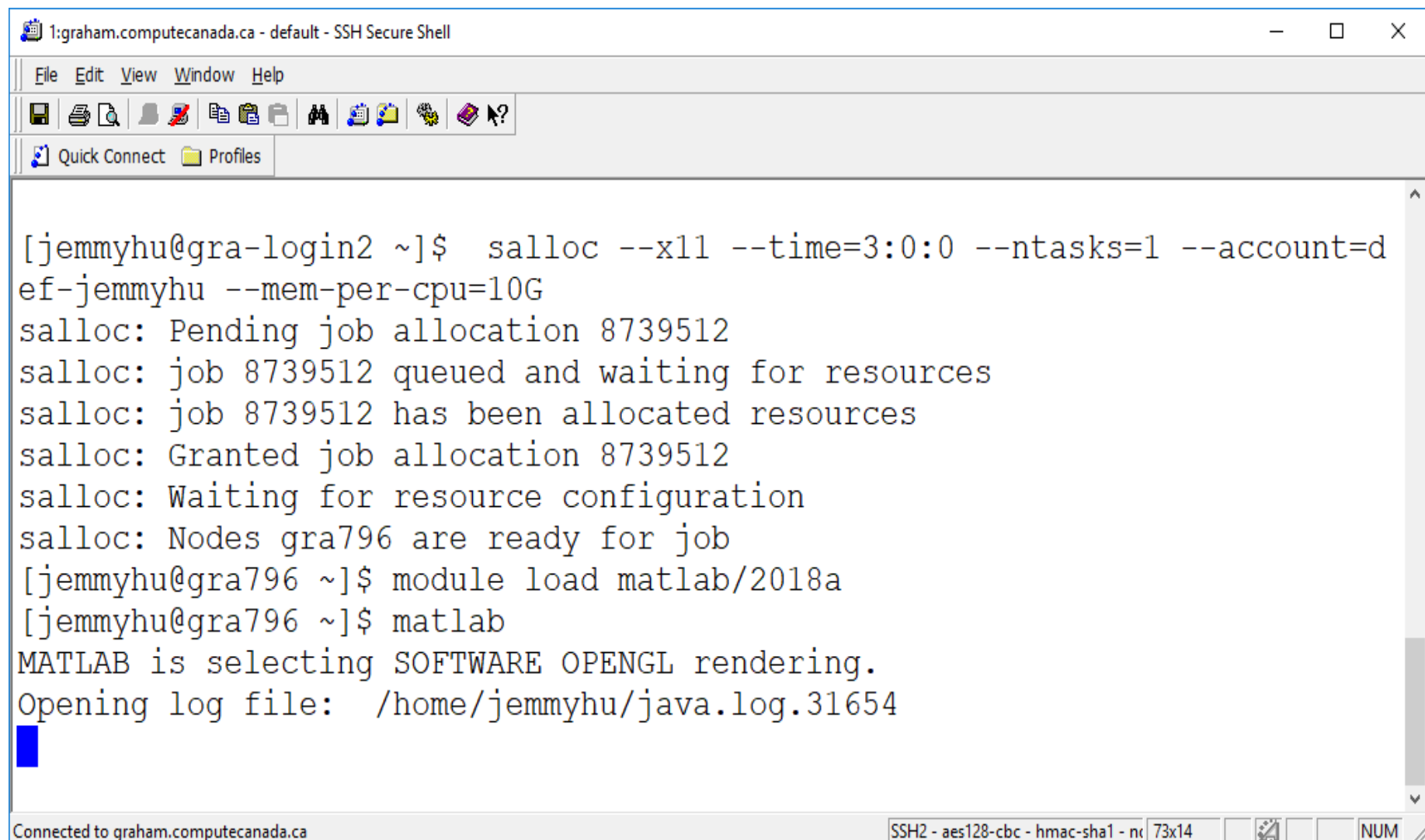
To get started, type one of these: helpwin, helpdesk, or demo.
For product information, visit www.mathworks.com.

>> for_pi_2
Elapsed time is 0.035018 seconds.
pi : 3.141592653589793116
Approximation: 3.141590653588764770
Error : 2e-06
>> █
```

Connected to graham.computecanada.ca

SSH2 - aes128-cbc - hmac-sha1 - n... 86x27 NUM

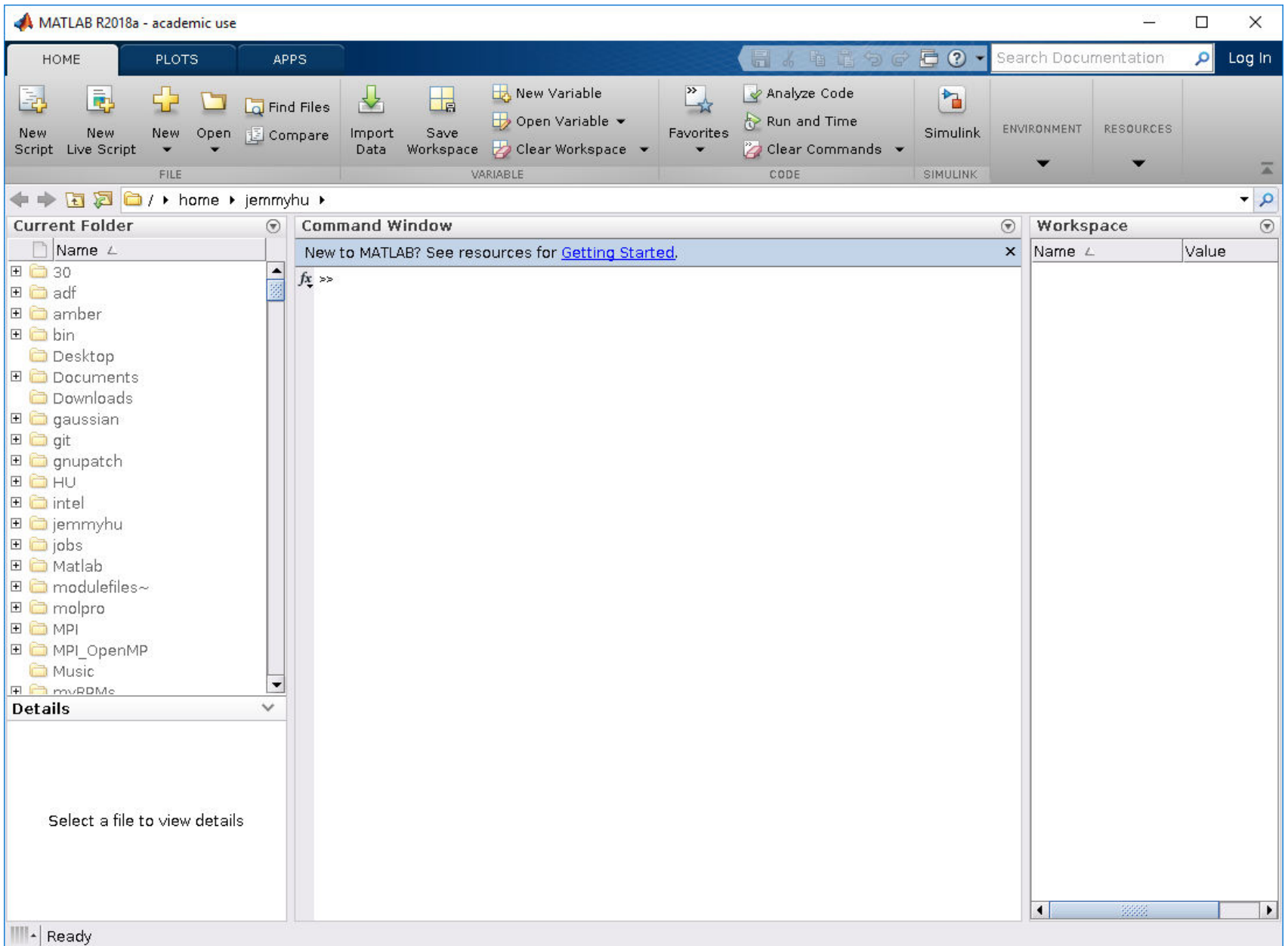
salloc GUI interactive



The screenshot shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The terminal displays the following commands and output:

```
[jemmyhu@gra-login2 ~]$ salloc --x11 --time=3:0:0 --ntasks=1 --account=d  
ef-jemmyhu --mem-per-cpu=10G  
salloc: Pending job allocation 8739512  
salloc: job 8739512 queued and waiting for resources  
salloc: job 8739512 has been allocated resources  
salloc: Granted job allocation 8739512  
salloc: Waiting for resource configuration  
salloc: Nodes gra796 are ready for job  
[jemmyhu@gra796 ~]$ module load matlab/2018a  
[jemmyhu@gra796 ~]$ matlab  
MATLAB is selecting SOFTWARE_OPENGL rendering.  
Opening log file: /home/jemmyhu/java.log.31654  
■
```

The terminal window includes a menu bar (File, Edit, View, Window, Help), a toolbar with various icons, and a status bar at the bottom showing "Connected to graham.computecanada.ca", "SSH2 - aes128-cbc - hmac-sha1 - n", "73x14", and "NUM".



MATLAB R2018a - academic use

HOME PLOTS APPS EDITOR PUBLISH VIEW

Find Files Compare Go To Find Insert Comment Indent Breakpoints Run Run and Advance Run Section Advance Run and Time

FILE NAVIGATE EDIT BREAKPOINTS RUN

/ > home > jemmyhu > Matlab > Demo

Current Folder

- for_pi.log
- for_pi.m
- for_pi.sh
- interactiveToBatch.m
- loopparallel.m
- mc_pi.log
- mc_pi.m
- mc_pi.sh
- mc_pi_par.log
- mc_pi_par.m
- mc_pi_par.sh
- mc_pi_par3.log
- mc_pi_par3.m
- mc_pi_par3.sh
- mybatch.m
- mybatch_par.m
- parfor_pi.log
- parfor_pi.m
- parfor_pi.sh
- parfor_pi4.log
- parfor_pi4.m

for_pi.m (Script)

Approximate pi by the numerical integral of $y = 4/(1 + x^2)$ from 0 to 1.

Editor - /home/jemmyhu/Matlab/Demo/for_pi.m

```
1 % Approximate pi by the numerical integral of y = 4/(1 + x^2) from 0 to 1.
2
3 r=10000000000;
4 sum=0;
5 step=1.0/n;
6
7 tic
8 for i=1:n
9     x=(i+0.5)*step;
10    sum= sum + (4.0/(1.0+x^2));
11 end
12 toc
13
14 piApp = sum*step;
15
16 fprintf('pi : %.18f\n', pi);
17 fprintf('Approximation: %.18f\n', piApp);
18 fprintf('Error : %g\n', abs(pi - piApp));
19
```

Workspace

Name	Value
------	-------

Command Window

New to MATLAB? See resources for [Getting Started](#).

>>

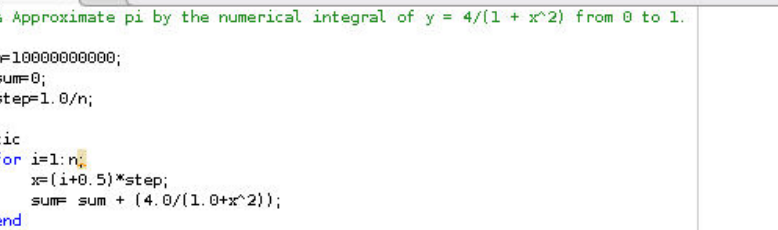
Ready

Ln 1 Col 1

Current Folder	
	Name
	for_pi.log
	for_pi.m
	for_pi.sh
	interactiveToBatch.m
	loopparallel.m
	mc_pi.log
	mc_pi.m
	mc_pi.sh
	mc_pi_par.log
	mc_pi_par.m
	mc_pi_par.sh
	mc_pi_par3.log
	mc_pi_par3.m
	mc_pi_par3.sh
	mybatch.m
	mybatch_par.m
	parfor_pi.log
	parfor_pi.m
	parfor_pi.sh
	parfor_pi4.log
	parfor_pi4.m
	parfor_pi4.sh

for_pi.m (Script)

Approximate pi by the numerical integral of $y = 4/(1 + x^2)$ from 0 to 1.



The image shows a MATLAB Editor window titled "Editor - /home/jemmyhu/Matlab/Demo/for_pi.m". The script file "for_pi.m" is open, and its contents are displayed in the editor area. The script calculates the numerical integral of $y = 4/(1+x^2)$ from 0 to 1 to approximate pi. It uses a loop to sum the function values at discrete points, then multiplies by the step size to get the final approximation. The results are printed using fprintf, showing the value of pi, the approximation, and the absolute error.

```
1 % Approximate pi by the numerical integral of y = 4/(1 + x^2) from 0 to 1.
2
3 n=10000000000;
4 sum=0;
5 step=1.0/n;
6
7 tic
8 for i=1:n
9     x=(i+0.5)*step;
10    sum= sum + (4.0/(1.0+x^2));
11 end
12 toc
13
14 piApp = sum*step;
15
16 fprintf('pi           : %.18f\n', pi);
17 fprintf('Approximation: %.18f\n', piApp);
18 fprintf('Error          : %g\n', abs(pi - piApp));
19
```

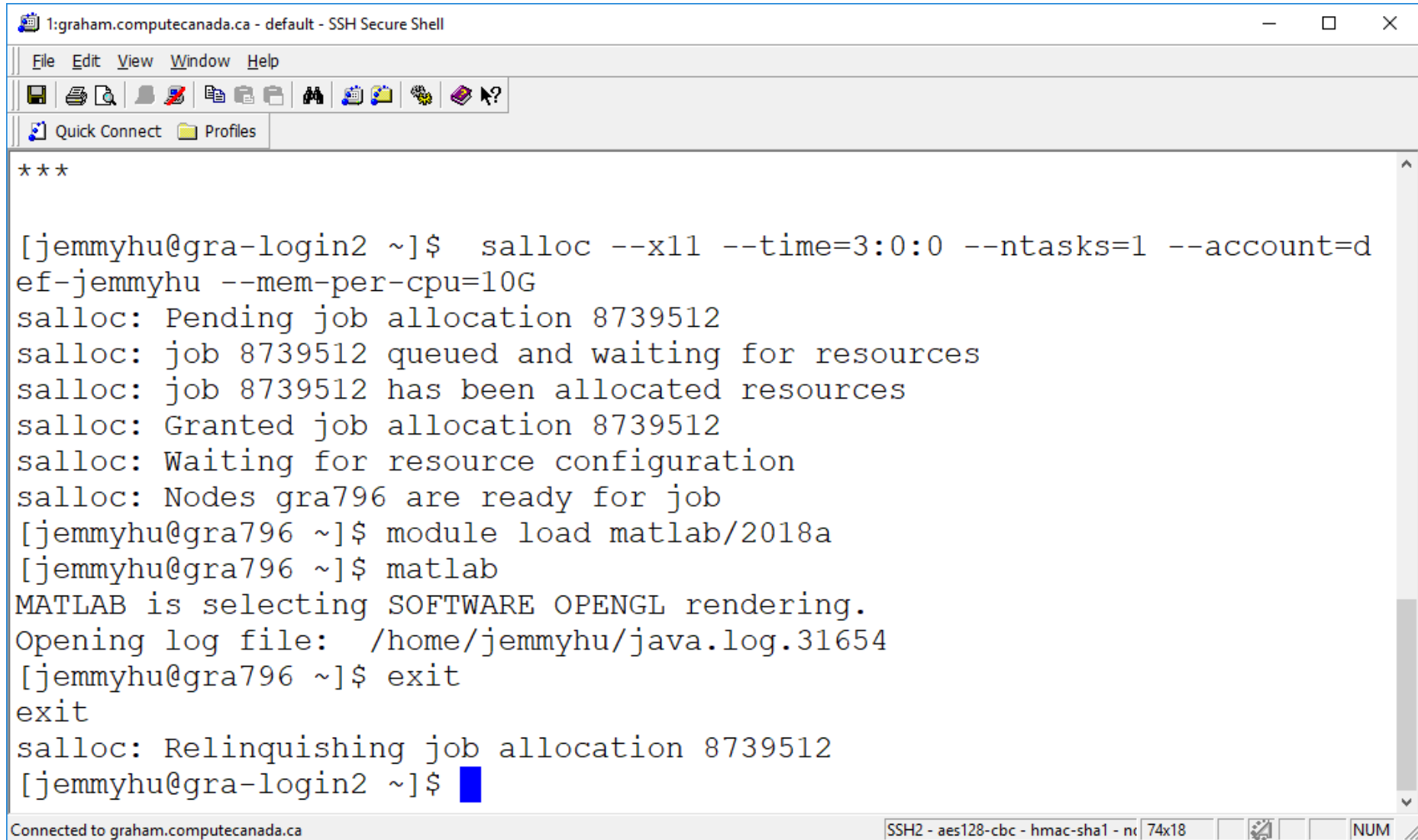
Name	Value
i	1.0000e+10
n	1.0000e+10
piApp	3.1416
step	1.0000e-10
sum	3.1416e+10
x	1.0000

Command Window

New to MATLAB? See resources for [Getting Started](#).

```
>> for_pi
Elapsed time is 118.100860 seconds.
pi      : 3.141592653589793116
Approximation: 3.141592653389450707
Error    : 2.00342e-10
>>
>>
>>
>>
>>
>>
>>
```

exit: terminate interactive Slurm session



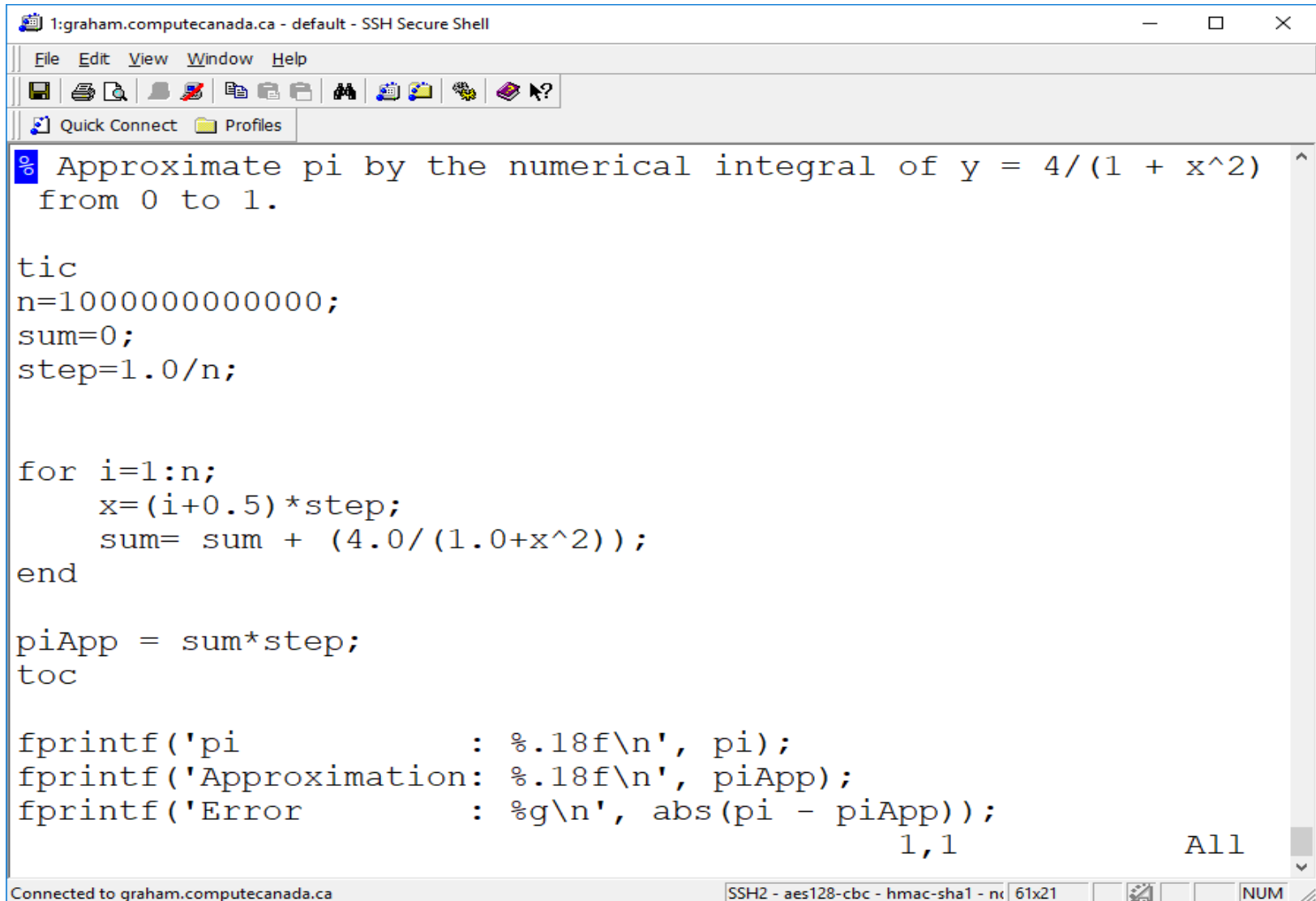
The screenshot shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window has a menu bar with "File", "Edit", "View", "Window", and "Help", and a toolbar with various icons. The terminal content shows a user named jemmyhu at the gra-login2 node submitting a Slurm job with the command `salloc --x11 --time=3:0:0 --ntasks=1 --account=def-jemmyhu --mem-per-cpu=10G`. The job is allocated and the user moves to the gra796 node. On the gra796 node, the user loads the MATLAB module and starts MATLAB. Finally, the user enters `exit` to terminate the session. The terminal shows the process of relinquishing the job allocation and returning to the login node. The status bar at the bottom indicates the connection is to graham.computecanada.ca, the encryption is SSH2 - aes128-cbc - hmac-sha1 - n, the window size is 74x18, and there are NUM tabs.

```
***  
[jemmyhu@gra-login2 ~]$ salloc --x11 --time=3:0:0 --ntasks=1 --account=def-jemmyhu --mem-per-cpu=10G  
salloc: Pending job allocation 8739512  
salloc: job 8739512 queued and waiting for resources  
salloc: job 8739512 has been allocated resources  
salloc: Granted job allocation 8739512  
salloc: Waiting for resource configuration  
salloc: Nodes gra796 are ready for job  
[jemmyhu@gra796 ~]$ module load matlab/2018a  
[jemmyhu@gra796 ~]$ matlab  
MATLAB is selecting SOFTWARE OPENGGL rendering.  
Opening log file: /home/jemmyhu/java.log.31654  
[jemmyhu@gra796 ~]$ exit  
exit  
salloc: Relinquishing job allocation 8739512  
[jemmyhu@gra-login2 ~]$
```

Connected to graham.computecanada.ca SSH2 - aes128-cbc - hmac-sha1 - n 74x18 NUM

MATLAB serial jobs in Slurm

for_pi.m:



The image shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window contains MATLAB code for approximating pi using numerical integration. The code is as follows:

```
% Approximate pi by the numerical integral of y = 4/(1 + x^2)
% from 0 to 1.

tic
n=1000000000000000;
sum=0;
step=1.0/n;

for i=1:n;
    x=(i+0.5)*step;
    sum= sum + (4.0/(1.0+x^2));
end

piApp = sum*step;
toc

fprintf('pi                : %.18f\n', pi);
fprintf('Approximation: %.18f\n', piApp);
fprintf('Error              : %g\n', abs(pi - piApp));
```

The terminal window has a menu bar with "File", "Edit", "View", "Window", and "Help". Below the menu bar is a toolbar with various icons. At the bottom of the window, there is a status bar that reads "Connected to graham.computecanada.ca" and "SSH2 - aes128-cbc - hmac-sha1 - n".

Example batch script ([for_pi.sh](#)) to run [for_pi.m](#)

```
#!/bin/bash
#SBATCH --account=def-jemmyhu # accounting group
#SBATCH --cpus-per-task=1      # number of cores
#SBATCH --mem-per-cpu=5G       # memory; default unit is megabytes
#SBATCH --time=0-01:00         # time (DD-HH:MM)
#SBATCH --output=for_pi.log     # output logfile

module load matlab/2018a
srun matlab -nodisplay -singleCompThread -r "for_pi"
```

or use the following in the .sh file

```
#SBATCH --input=for_pi.m
srun matlab -nodesktop -singleCompThread
```

- Submit the job
[sbatch for_pi.sh](#)

Output: for_pi.log



The image shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window has a menu bar with "File", "Edit", "View", "Window", and "Help". Below the menu bar is a toolbar with various icons. The main area of the terminal displays the following text:

```
< M A T L A B (R) >  
Copyright 1984-2018 The MathWorks, Inc.  
R2018a (9.4.0.813654) 64-bit (glnxa64)  
February 23, 2018  
  
For online documentation, see http://www.mathworks.com/support  
For product information, visit www.mathworks.com.  
  
Elapsed time is 1952.390467 seconds.  
pi          : 3.141592653589793116  
Approximation: 3.141592651310205486  
Error       : 2.27959e-09  
>>  
  
1,0-1      All
```

The status bar at the bottom of the window shows "Connected to graham.computecanada.ca", "SSH2 - aes128-cbc - hmac-sha1 - n", "66x16", and "NUM".

MATLAB Parallel Solutions

- Parallel Computing Toolbox (PCT)

Shared memory solution (intranode: cpus on one node)

- **parfor**, //parallel loop

- **spmd**, “labs” are used to solve tasks //parallel region
(PCT uses OpenMP for intranode threads)

- MATLAB Distributed Computing Server (MDCS)

- not available (no license for it)

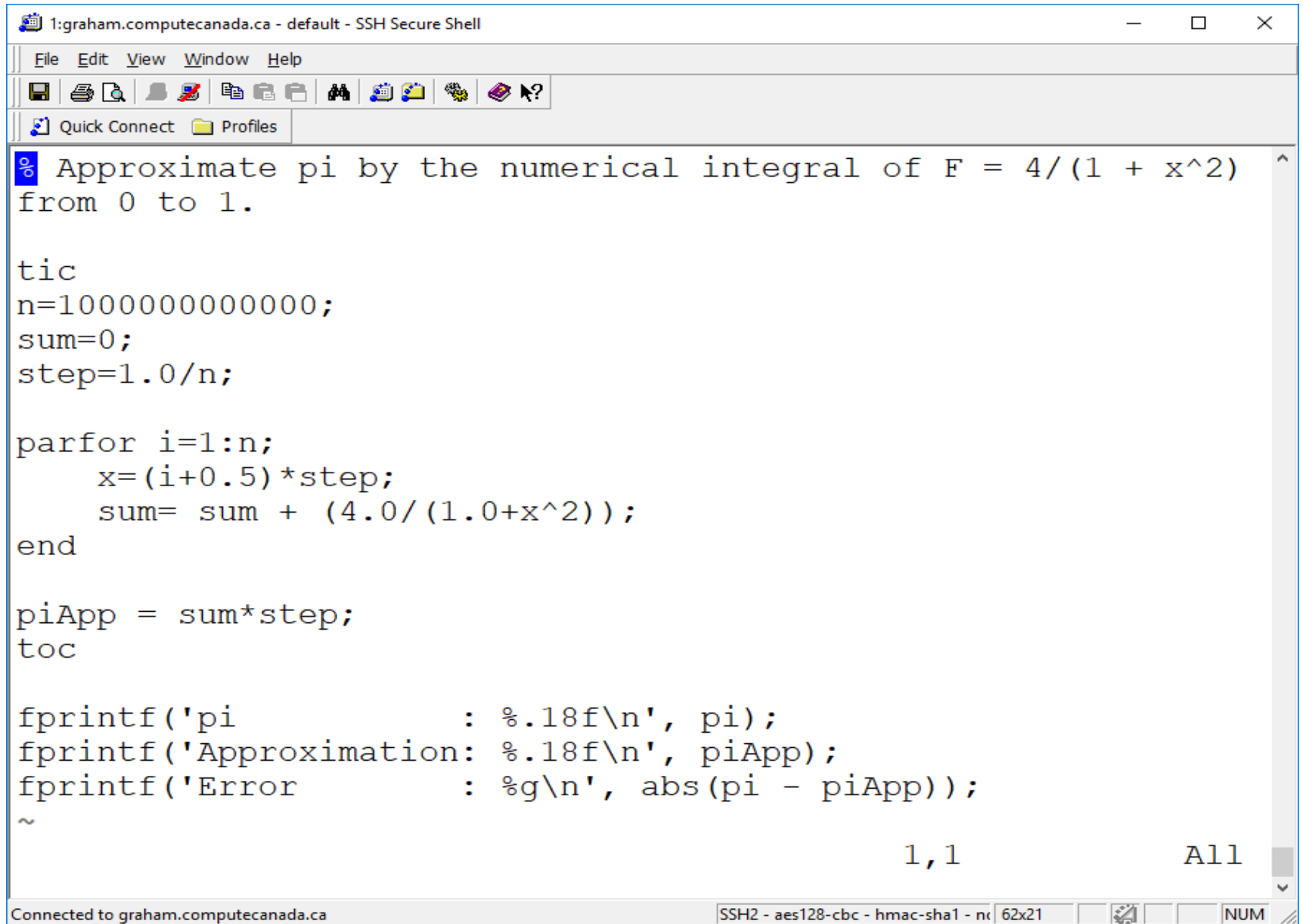
PCT: how many workers to use?

When MATLAB reaches the first parfor (spmd), it will try to start a parallel pool (lab) and then run the parfor (spmd) in parallel.

The number of workers on a machine/node:

- the available cores on a machine with < 12 cores
- Default is 12 workers on a machine/node with > 12 cores
- parpool to overwrite the workers

parfor example: parfor_pi.m



The screenshot shows an SSH terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window contains MATLAB code for approximating pi using the parfor function. The code calculates the numerical integral of $F = 4/(1 + x^2)$ from 0 to 1. The code includes comments, variable declarations, a parfor loop, and output formatting. The terminal shows the execution of the code, with the final output being "1,1" and "All".

```
% Approximate pi by the numerical integral of F = 4/(1 + x^2)
% from 0 to 1.

tic
n=1000000000000000;
sum=0;
step=1.0/n;

parfor i=1:n;
    x=(i+0.5)*step;
    sum= sum + (4.0/(1.0+x^2));
end

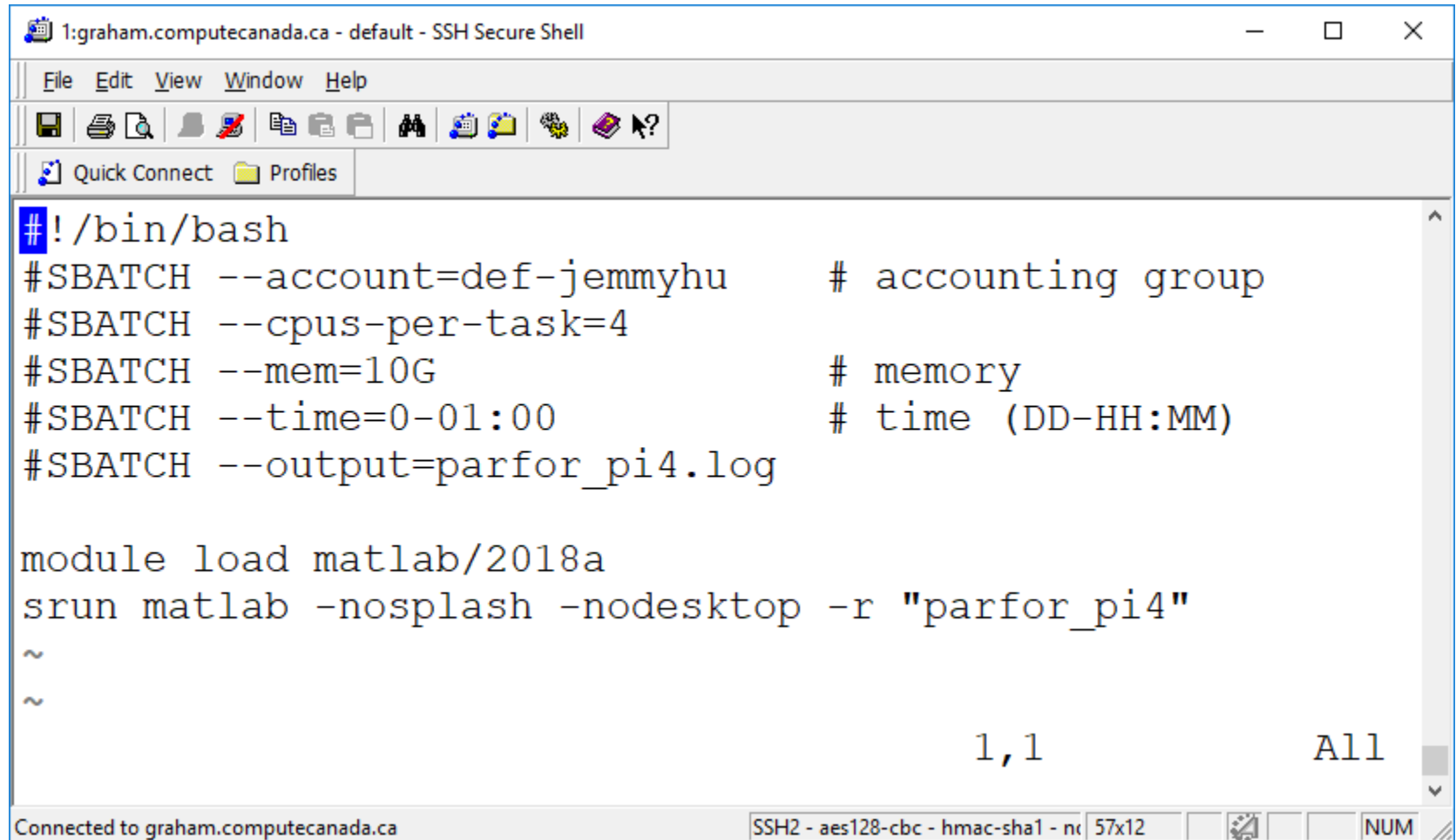
piApp = sum*step;
toc

fprintf('pi                : %.18f\n', pi);
fprintf('Approximation: %.18f\n', piApp);
fprintf('Error              : %g\n', abs(pi - piApp));
~

1,1                                All
```

Connected to graham.computecanada.ca | SSH2 - aes128-cbc - hmac-sha1 - n | 62x21 | NUM

Batch script: parfor_pi4.sh



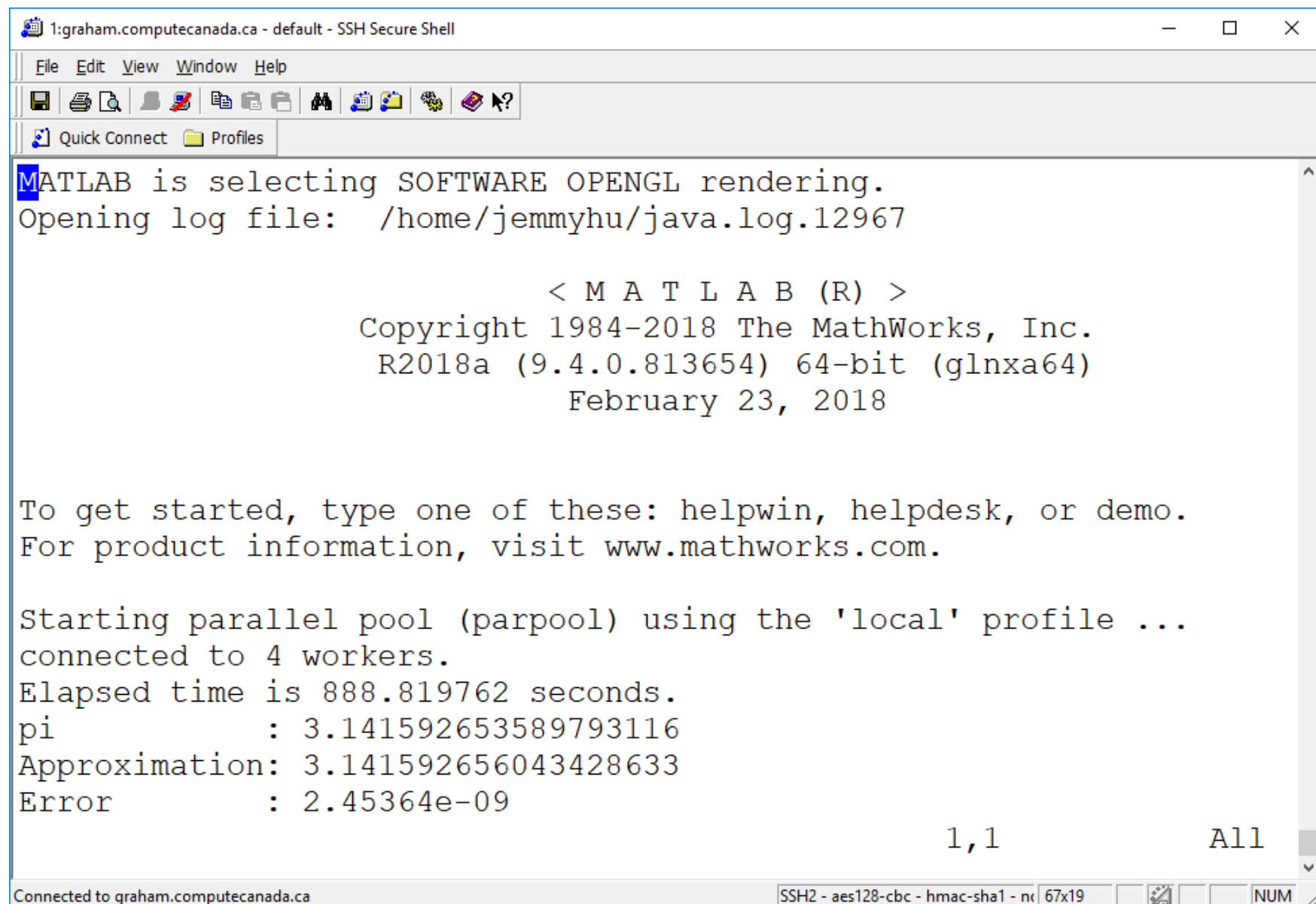
The image shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window has a menu bar with "File", "Edit", "View", "Window", and "Help". Below the menu bar is a toolbar with various icons. The main area of the terminal displays the following text:

```
#!/bin/bash
#SBATCH --account=def-jemmyhu      # accounting group
#SBATCH --cpus-per-task=4
#SBATCH --mem=10G                  # memory
#SBATCH --time=0-01:00             # time (DD-HH:MM)
#SBATCH --output=parfor_pi4.log

module load matlab/2018a
srun matlab -nosplash -nodesktop -r "parfor_pi4"
~
~
```

At the bottom right of the terminal area, the text "1,1" and "All" are visible. The status bar at the bottom of the window shows "Connected to graham.computecanada.ca", "SSH2 - aes128-cbc - hmac-sha1 - no", "57x12", and "NUM".

Output: parfor_pi4.log

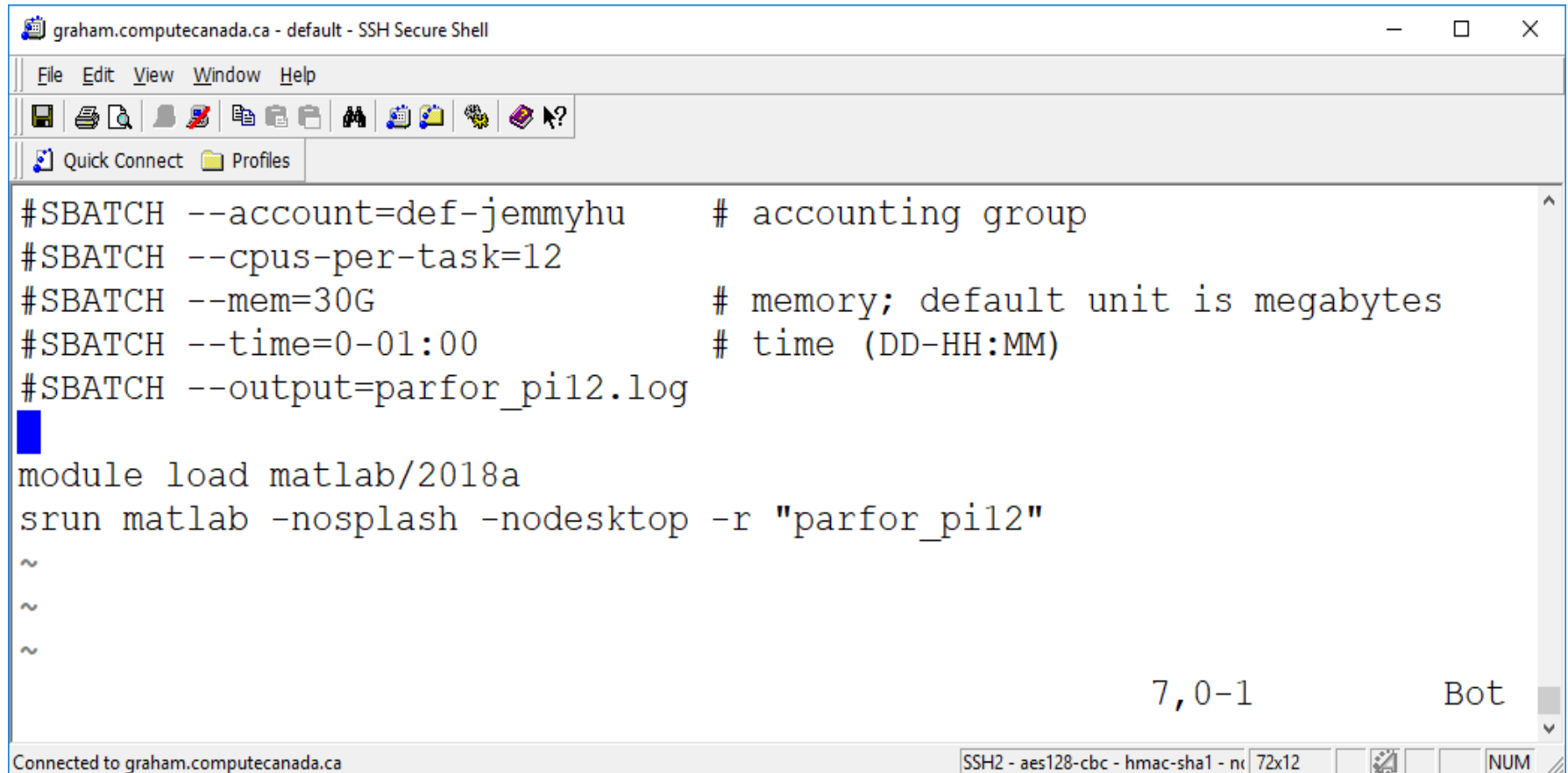


The screenshot shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window has a menu bar with "File", "Edit", "View", "Window", and "Help". Below the menu bar is a toolbar with various icons. The main text area displays the following output:

```
MATLAB is selecting SOFTWARE OPENGTL rendering.  
Opening log file: /home/jemmyhu/java.log.12967  
  
      < M A T L A B (R) >  
      Copyright 1984-2018 The MathWorks, Inc.  
      R2018a (9.4.0.813654) 64-bit (glnxa64)  
      February 23, 2018  
  
To get started, type one of these: helpwin, helpdesk, or demo.  
For product information, visit www.mathworks.com.  
  
Starting parallel pool (parpool) using the 'local' profile ...  
connected to 4 workers.  
Elapsed time is 888.819762 seconds.  
pi           : 3.141592653589793116  
Approximation: 3.141592656043428633  
Error        : 2.45364e-09  
  
1,1
```

The status bar at the bottom of the window shows "Connected to graham.computecanada.ca" on the left, and "SSH2 - aes128-cbc - hmac-sha1 - n" and "67x19" in the center. On the right side of the status bar, there are icons for a terminal, a file, and a numeric keypad labeled "NUM".

Batch script: parfor_pi12.sh



The image shows a terminal window titled "graham.computecanada.ca - default - SSH Secure Shell". The window has a menu bar with "File", "Edit", "View", "Window", and "Help". Below the menu bar is a toolbar with various icons. The main area of the terminal displays a batch script for MATLAB. The script includes several SBATCH directives for accounting, resource allocation, and output. It then loads the MATLAB 2018a module and runs a script named "parfor_pi12". The terminal shows the prompt "~" on three lines, indicating the script is running. The status bar at the bottom indicates the connection is to "graham.computecanada.ca" and the session is using "SSH2 - aes128-cbc - hmac-sha1 - n".

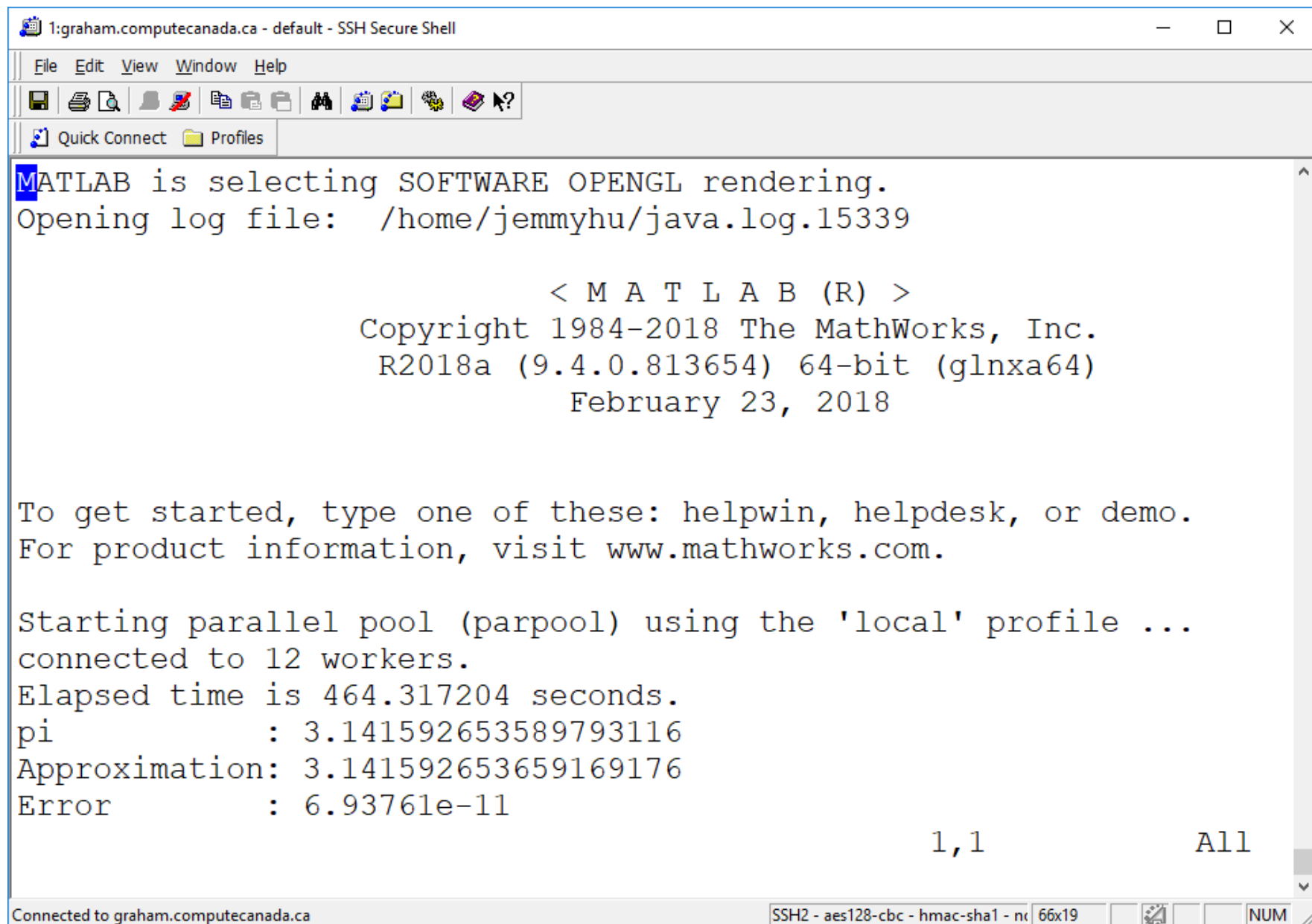
```
#SBATCH --account=def-jemmyhu      # accounting group
#SBATCH --cpus-per-task=12
#SBATCH --mem=30G                  # memory; default unit is megabytes
#SBATCH --time=0-01:00            # time (DD-HH:MM)
#SBATCH --output=parfor_pi12.log

module load matlab/2018a
srun matlab -nosplash -nodesktop -r "parfor_pi12"
~
~
~
```

7,0-1 Bot

Connected to graham.computecanada.ca SSH2 - aes128-cbc - hmac-sha1 - n 72x12 NUM

Output: parfor_pi12.log



1:graham.computecanada.ca - default - SSH Secure Shell

File Edit View Window Help

Quick Connect Profiles

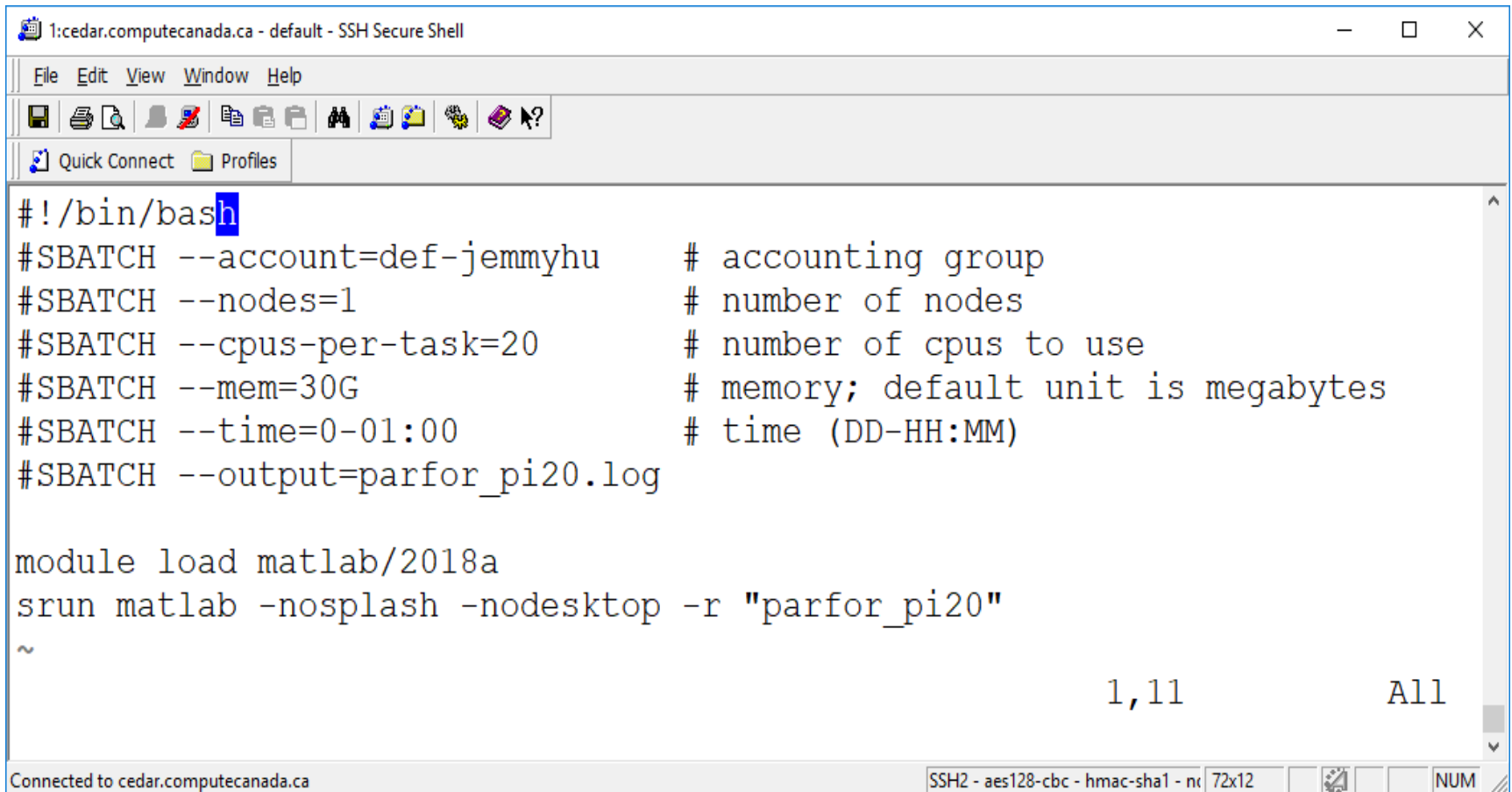
```
MATLAB is selecting SOFTWARE OPENGGL rendering.  
Opening log file: /home/jemmyhu/java.log.15339  
  
      < M A T L A B (R) >  
      Copyright 1984-2018 The MathWorks, Inc.  
      R2018a (9.4.0.813654) 64-bit (glnxa64)  
      February 23, 2018  
  
To get started, type one of these: helpwin, helpdesk, or demo.  
For product information, visit www.mathworks.com.  
  
Starting parallel pool (parpool) using the 'local' profile ...  
connected to 12 workers.  
Elapsed time is 464.317204 seconds.  
pi           : 3.141592653589793116  
Approximation: 3.141592653659169176  
Error        : 6.93761e-11  
  
1,1 All
```

Connected to graham.computecanada.ca

SSH2 - aes128-cbc - hmac-sha1 - nc 66x19

NUM

Batch script: parfor_pi20.sh



The image shows a terminal window titled "1:cedar.computecanada.ca - default - SSH Secure Shell". The window has a menu bar (File, Edit, View, Window, Help) and a toolbar with various icons. The terminal content is as follows:

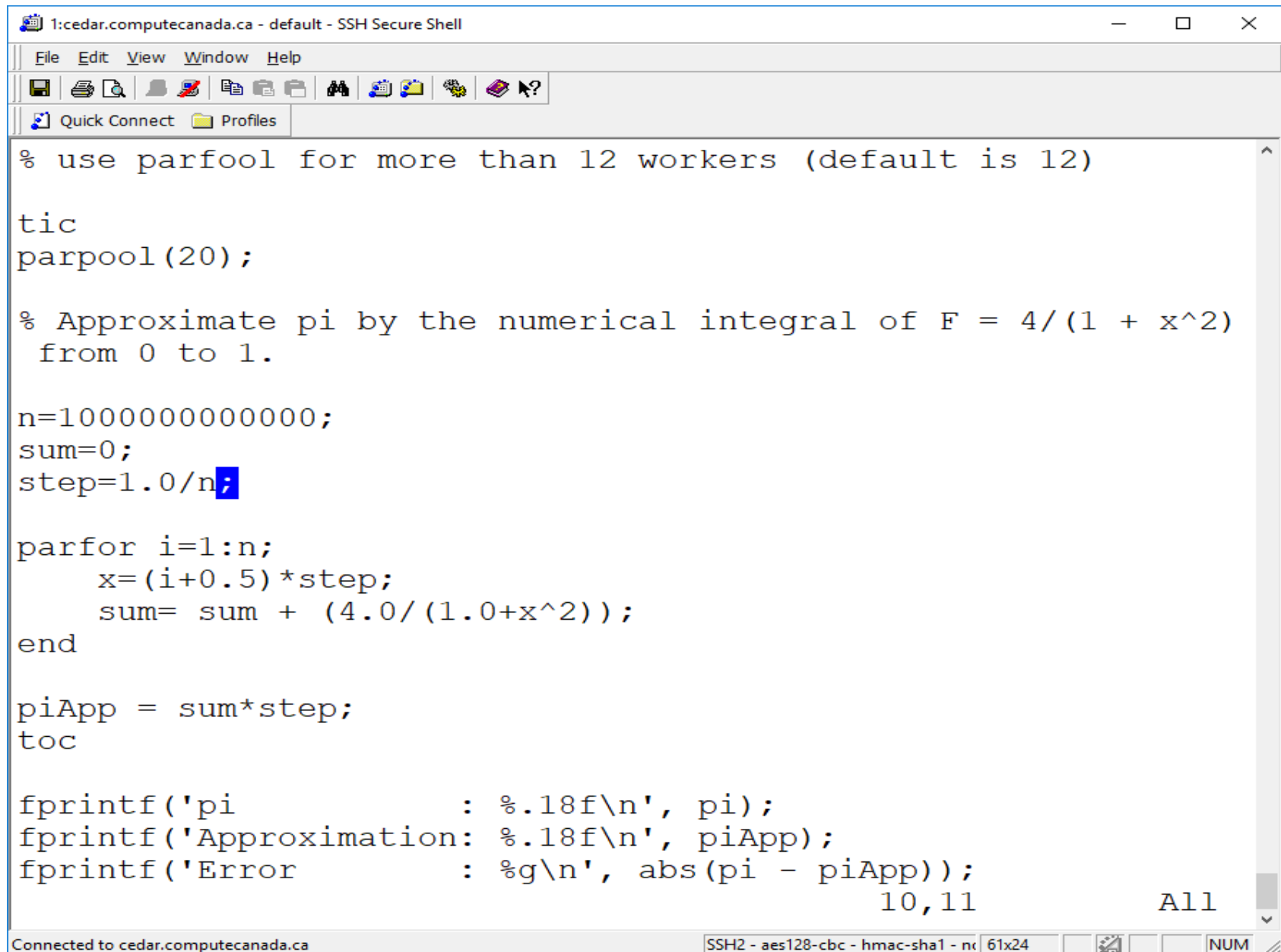
```
#!/bin/bash
#SBATCH --account=def-jemmyhu      # accounting group
#SBATCH --nodes=1                  # number of nodes
#SBATCH --cpus-per-task=20         # number of cpus to use
#SBATCH --mem=30G                  # memory; default unit is megabytes
#SBATCH --time=0-01:00             # time (DD-HH:MM)
#SBATCH --output=parfor_pi20.log

module load matlab/2018a
srun matlab -nosplash -nodesktop -r "parfor_pi20"
~
```

At the bottom right of the terminal, the text "1,11" and "All" are visible. The status bar at the bottom of the window shows "Connected to cedar.computecanada.ca", "SSH2 - aes128-cbc - hmac-sha1 - n", "72x12", and "NUM".

The same code will open 12 workers by default.

parpool(numWorkers): parfor_pi20.m



The screenshot shows a terminal window titled "1:cedar.computecanada.ca - default - SSH Secure Shell". The window contains MATLAB code for a parallel approximation of pi using the parpool function. The code includes comments, timing functions (tic/toc), variable declarations, a parfor loop, and fprintf statements for output. The output shows the value of pi, its approximation, and the absolute error.

```
% use parpool for more than 12 workers (default is 12)

tic
parpool(20);

% Approximate pi by the numerical integral of F = 4/(1 + x^2)
% from 0 to 1.

n=1000000000000000;
sum=0;
step=1.0/n;

parfor i=1:n;
    x=(i+0.5)*step;
    sum= sum + (4.0/(1.0+x^2));
end

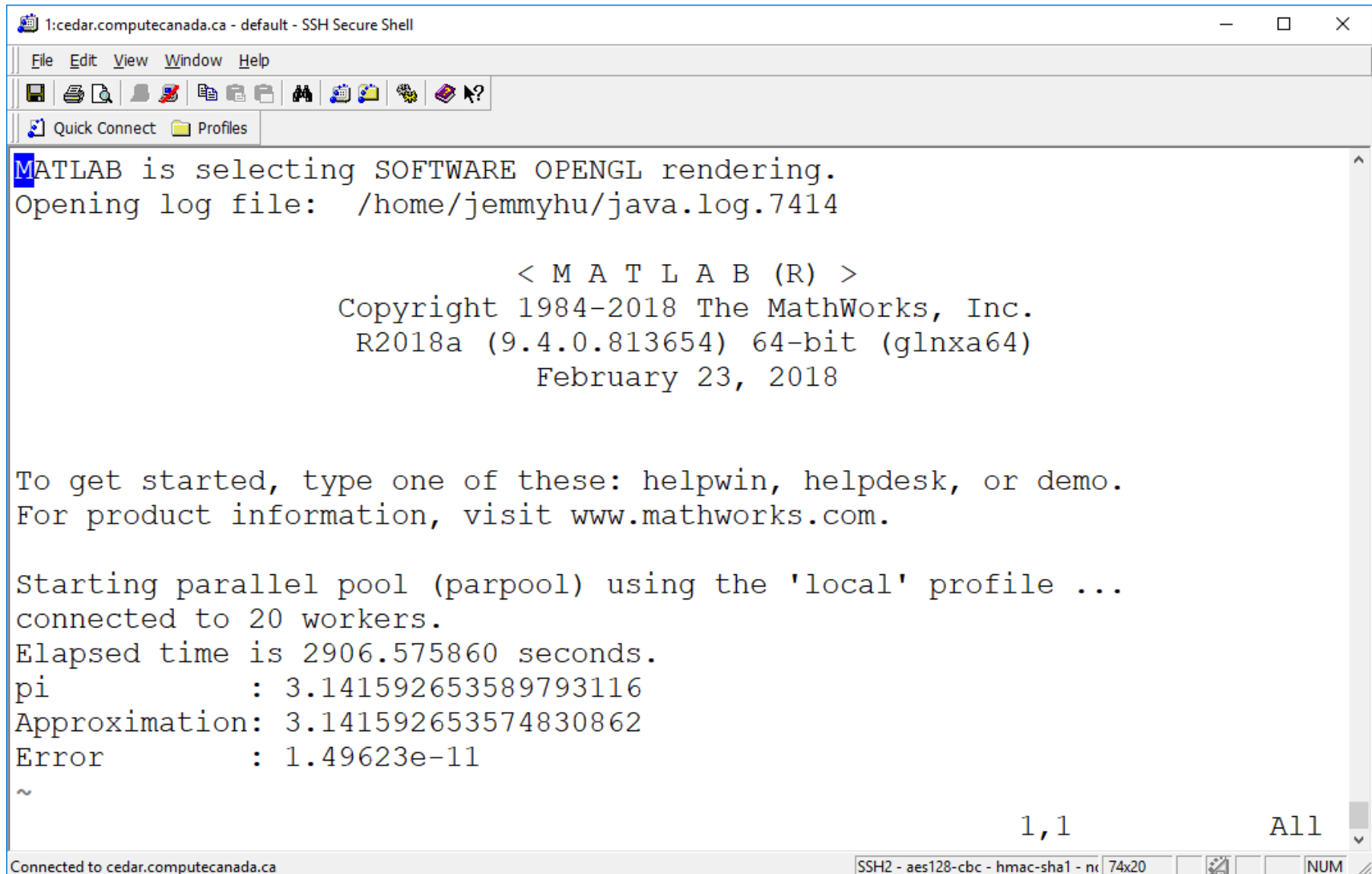
piApp = sum*step;
toc

fprintf('pi                : %.18f\n', pi);
fprintf('Approximation: %.18f\n', piApp);
fprintf('Error              : %g\n', abs(pi - piApp));
```

10,11 All

Connected to cedar.computecanada.ca SSH2 - aes128-cbc - hmac-sha1 - no 61x24 NUM

Output: parfor_pi20.log



The image shows a terminal window titled "1:cedar.computecanada.ca - default - SSH Secure Shell". The window has a menu bar (File, Edit, View, Window, Help) and a toolbar with various icons. Below the toolbar, there are tabs for "Quick Connect" and "Profiles". The main area of the terminal displays the following text:

```
MATLAB is selecting SOFTWARE OpenGL rendering.  
Opening log file: /home/jemmyhu/java.log.7414  
  
      < M A T L A B (R) >  
      Copyright 1984-2018 The MathWorks, Inc.  
      R2018a (9.4.0.813654) 64-bit (glnxa64)  
      February 23, 2018  
  
To get started, type one of these: helpwin, helpdesk, or demo.  
For product information, visit www.mathworks.com.  
  
Starting parallel pool (parpool) using the 'local' profile ...  
connected to 20 workers.  
Elapsed time is 2906.575860 seconds.  
pi           : 3.141592653589793116  
Approximation: 3.141592653574830862  
Error        : 1.49623e-11  
~  
  
1,1 All
```

At the bottom of the window, a status bar shows "Connected to cedar.computecanada.ca", "SSH2 - aes128-cbc - hmac-sha1 - nc", "74x20", and "NUM".

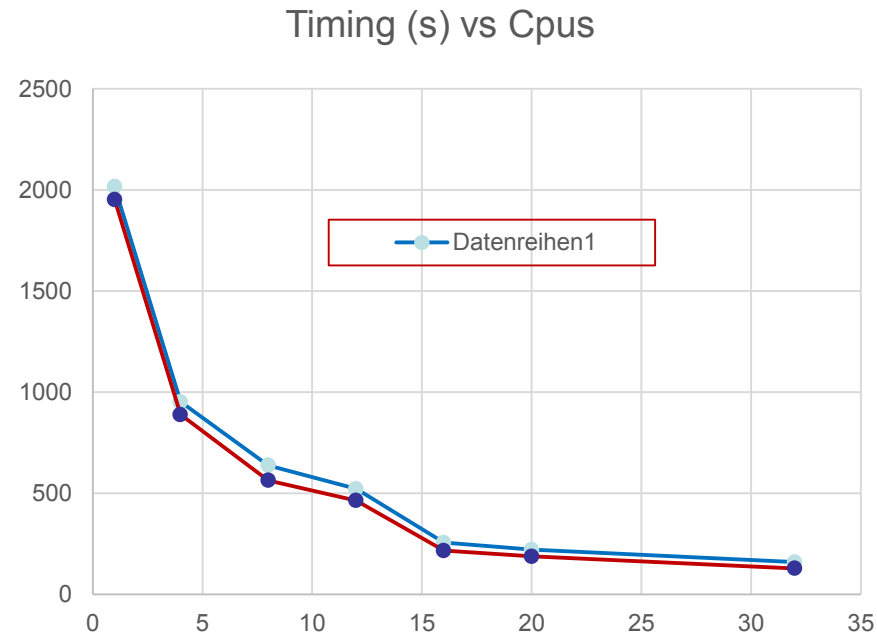
Cluster's Node Type

Cluster	Nodes	Cores	Avail memory
Graham	884	32	125G or 128000M
Cedar	576	32	125G or 128000M
	640	48	187G

How many cpus/workers to use for a job?

Timing for parfor_pi.m on Graham

worker s/cpus	tic/toc timing (s)	Elapsed/ sacct (s)	Ratio (speedup)
1	1952.39	2017	1
4	888.81	952	2.1
8	563.41	638	3.2
12	464.32	522	3.9
16	216.69	256	7.9
20	187.96	221	9.2
32	128.42	159	12.7



sacct: job history / resource usage stats

1:graham.computecanada.ca - default - SSH Secure Shell

File

Edit

View

Window

Help

<

Connected to graham.computecanada.ca

SSH2 - aes128-cbc - hmac-sha1 - ni 163x29

NUM

Effective usage?

- Performance / Scale

- understand your code
- use MATLAB Code Analyzer
- how does your code scale?

Effective use of the compute resource (cpus, memory) !

- Site license limits on Graham ?

- UWaterloo license users may have seen limited workers on Graham?

```
#SBATCH --cpus-per-task=20
```

```
parpool(19);
```

- Do not know much about other site licenses

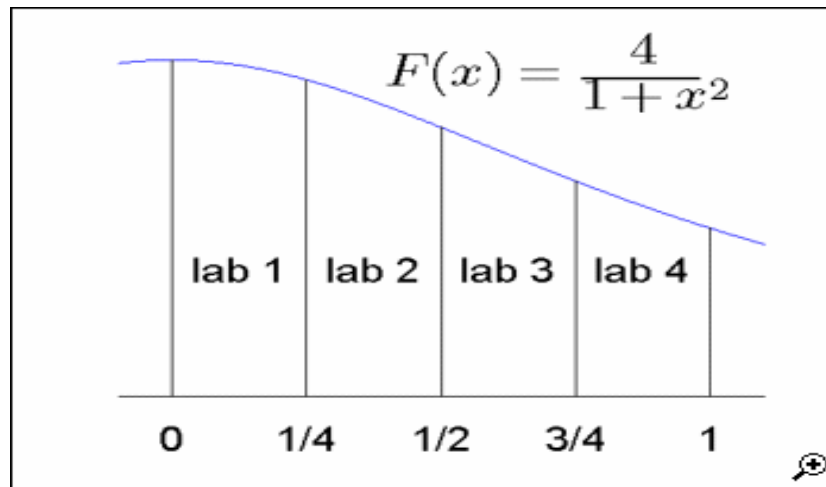
SPMD: calculate pi using MATLAB

use the fact that

$$\int_0^1 \frac{4}{1+x^2} dx = 4(\text{atan}(1) - \text{atan}(0)) = \pi$$

to approximate pi by approximating the integral on the left.

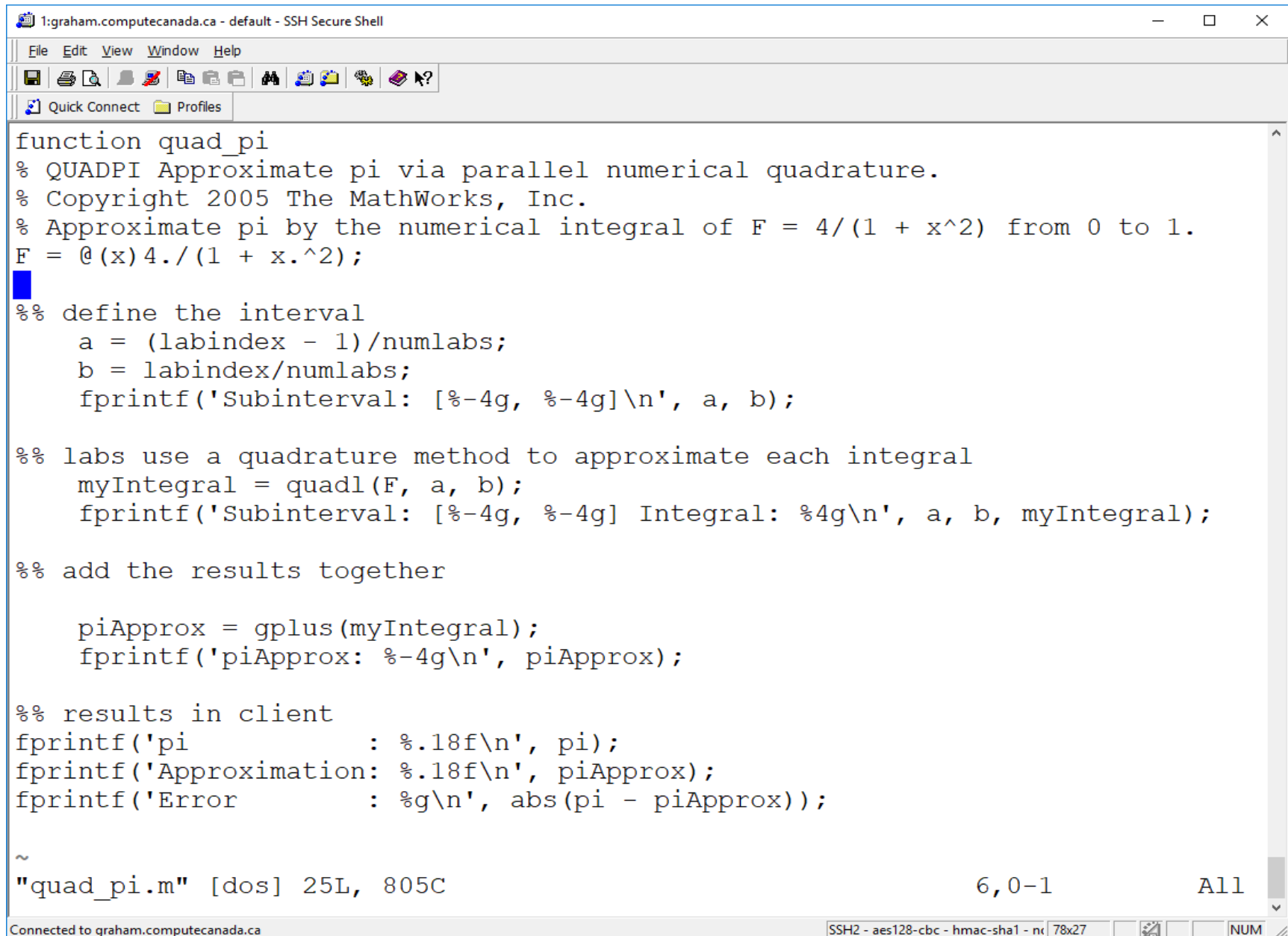
divide the work between the labs by having each lab calculate the integral the function over a subinterval of $[0, 1]$ as shown in the picture



Steps

- All labs/workers will compute the same function: $F=4/(1+x^2)$
- Each worker/lab will calculate over a subinterval $[a,b]$ of $[0, 1]$,
for 2 labs, the subinterval will be:
[0, 0.50]
[0.50, 1.0]
 $a = (\text{labindex}-1)/\text{numlabs}$
 $b = \text{labindex}/\text{numlabs}$
- Use a MATLAB quadrature method to compute the integral
 $\text{myIntegral} = \text{quadl}(F, a, b)$
- Add together to form the entire integral over $[0,1]$
 $\text{piApprox} = \text{gplus}(\text{myIntegral})$

quad_pi.m

A screenshot of an SSH Secure Shell window. The title bar reads "1:graham.computecanada.ca - default - SSH Secure Shell". The window contains a MATLAB script named "quad_pi.m". The script defines a function "quad_pi" that approximates pi using parallel numerical quadrature. It includes comments explaining the method and copyright information. The script uses the "quadl" function for numerical integration and "gplus" for parallel summation. At the bottom of the window, a status bar shows "Connected to graham.computecanada.ca", "SSH2 - aes128-cbc - hmac-sha1 - n", "78x27", and "NUM".

```
function quad_pi
% QUADPI Approximate pi via parallel numerical quadrature.
% Copyright 2005 The MathWorks, Inc.
% Approximate pi by the numerical integral of F = 4/(1 + x^2) from 0 to 1.
F = @(x) 4./(1 + x.^2);

%% define the interval
a = (labindex - 1)/numlabs;
b = labindex/numlabs;
fprintf('Subinterval: [%-4g, %-4g]\n', a, b);

%% labs use a quadrature method to approximate each integral
myIntegral = quadl(F, a, b);
fprintf('Subinterval: [%-4g, %-4g] Integral: %4g\n', a, b, myIntegral);

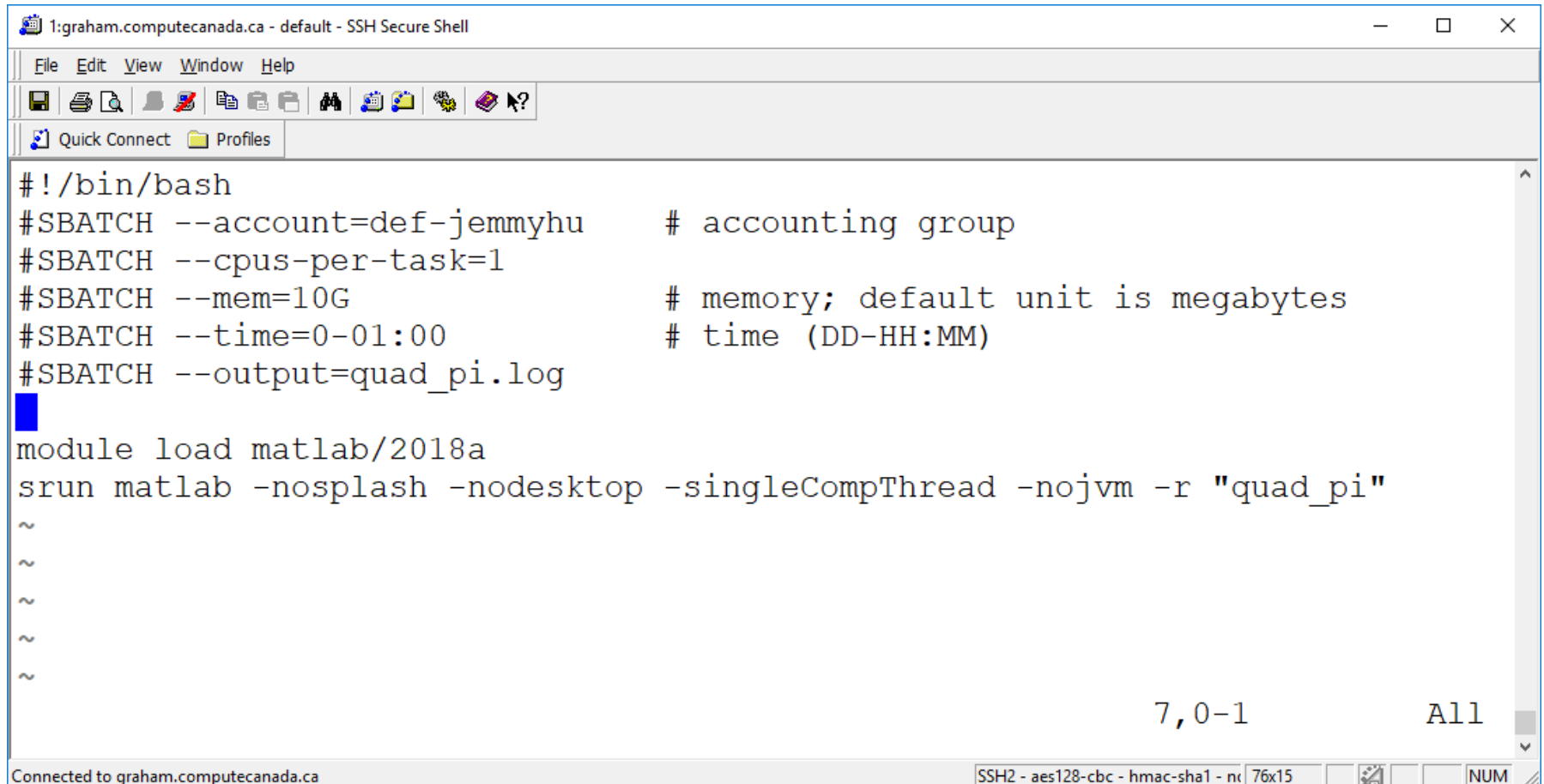
%% add the results together

piApprox = gplus(myIntegral);
fprintf('piApprox: %-4g\n', piApprox);

%% results in client
fprintf('pi           : %.18f\n', pi);
fprintf('Approximation: %.18f\n', piApprox);
fprintf('Error          : %g\n', abs(pi - piApprox));

~
"quad_pi.m" [dos] 25L, 805C
```

script ([quad_pi.sh](#)) to run [quad_pi.m](#) (serial)

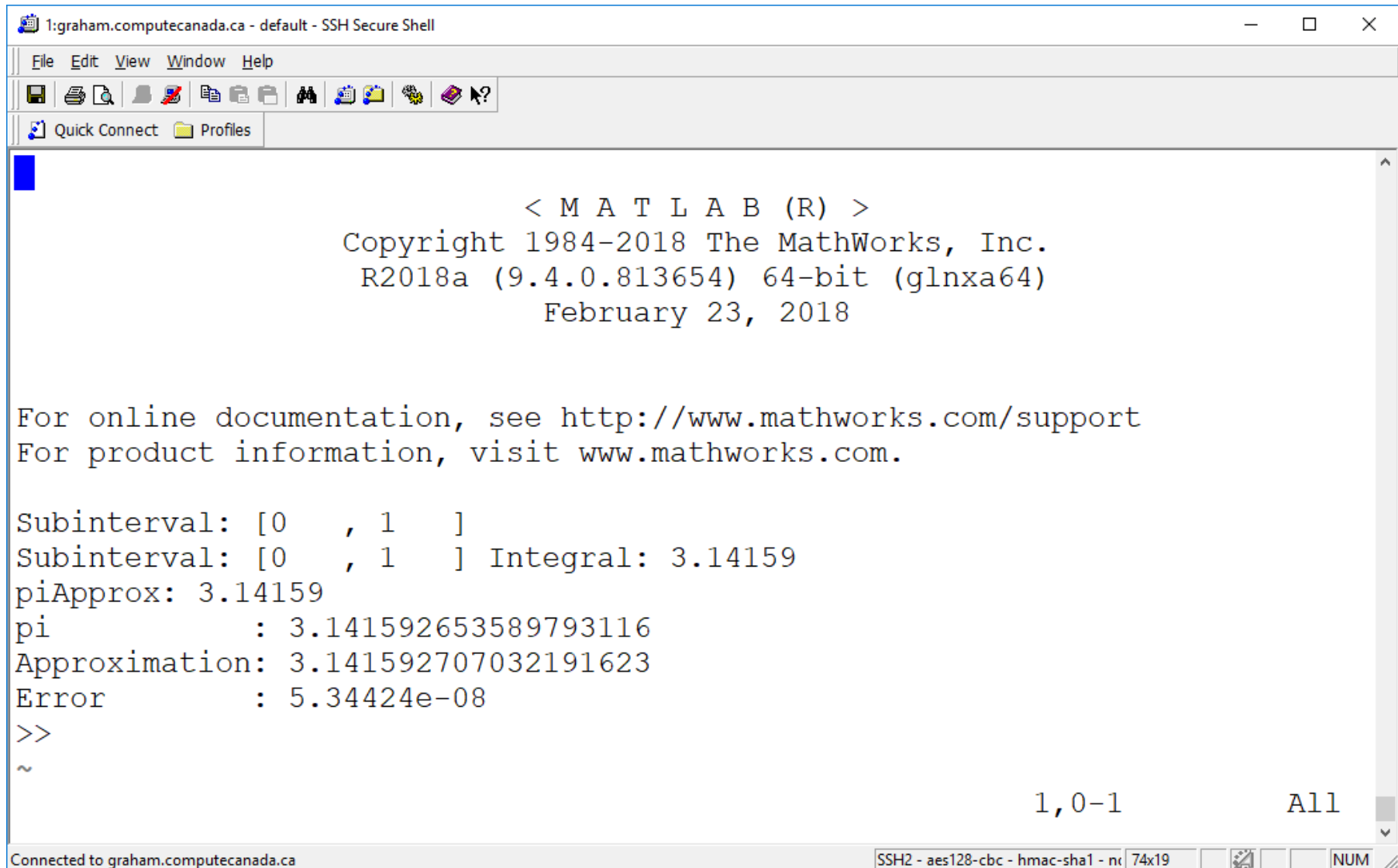


The image shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window has a menu bar with "File", "Edit", "View", "Window", and "Help". Below the menu bar is a toolbar with various icons. The main area of the terminal displays the following text:

```
#!/bin/bash
#SBATCH --account=def-jemmyhu      # accounting group
#SBATCH --cpus-per-task=1
#SBATCH --mem=10G                  # memory; default unit is megabytes
#SBATCH --time=0-01:00             # time (DD-HH:MM)
#SBATCH --output=quad_pi.log
[redacted]
module load matlab/2018a
srun matlab -nosplash -nodesktop -singleCompThread -nojvm -r "quad_pi"
~
~
~
~
~
```

At the bottom right of the terminal area, the text "7,0-1" and "All" are visible. The status bar at the bottom of the window shows "Connected to graham.computecanada.ca", "SSH2 - aes128-cbc - hmac-sha1 - n", "76x15", and "NUM".

Output: quad_pi.log



The screenshot shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window has a menu bar with "File", "Edit", "View", "Window", and "Help". Below the menu bar is a toolbar with various icons. The main area of the window displays the output of a MATLAB script. The output includes the MATLAB logo, copyright information for The MathWorks, Inc. (1984-2018), the version R2018a (9.4.0.813654) 64-bit (glnxa64), and the date February 23, 2018. It also provides links for online documentation and product information. The core of the output is the result of a quad integration of pi, showing the subinterval [0, 1], the integral value 3.14159, and the approximation 3.14159. The error is given as 5.34424e-08. The window ends with a tilde symbol and a status bar at the bottom showing the connection details and the current window title.

```
< M A T L A B (R) >
Copyright 1984-2018 The MathWorks, Inc.
R2018a (9.4.0.813654) 64-bit (glnxa64)
February 23, 2018

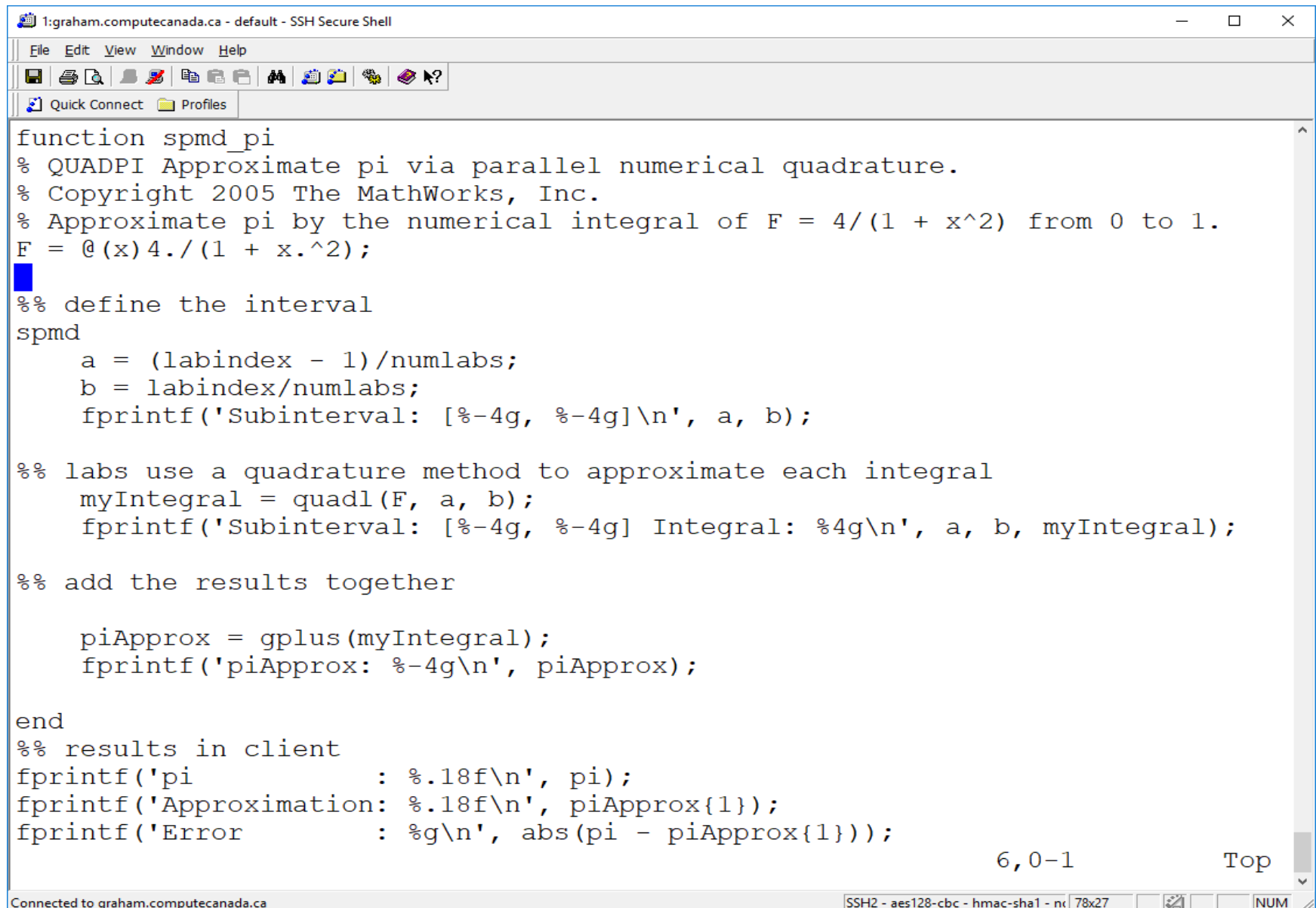
For online documentation, see http://www.mathworks.com/support
For product information, visit www.mathworks.com.

Subinterval: [0 , 1 ]
Subinterval: [0 , 1 ] Integral: 3.14159
piApprox: 3.14159
pi          : 3.141592653589793116
Approximation: 3.141592707032191623
Error       : 5.34424e-08
>>
~

1,0-1 All
```

Connected to graham.computecanada.ca SSH2 - aes128-cbc - hmac-sha1 - n 74x19 NUM

spmd_pi.m



The image shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window contains the MATLAB script "spmd_pi.m" which uses the spmd function for parallel numerical quadrature to approximate pi. The script defines a function that calculates the integral of $F = 4/(1 + x^2)$ from 0 to 1 using multiple labs. The output shows the subinterval [0.5, 1.0] and the integral value 2.000000000000000.

```
function spmd_pi
% QUADPI Approximate pi via parallel numerical quadrature.
% Copyright 2005 The MathWorks, Inc.
% Approximate pi by the numerical integral of F = 4/(1 + x^2) from 0 to 1.
F = @(x) 4./(1 + x.^2);
%% define the interval
spmd
    a = (labindex - 1)/numlabs;
    b = labindex/numlabs;
    fprintf('Subinterval: [%-4g, %-4g]\n', a, b);

%% labs use a quadrature method to approximate each integral
    myIntegral = quadl(F, a, b);
    fprintf('Subinterval: [%-4g, %-4g] Integral: %4g\n', a, b, myIntegral);

%% add the results together

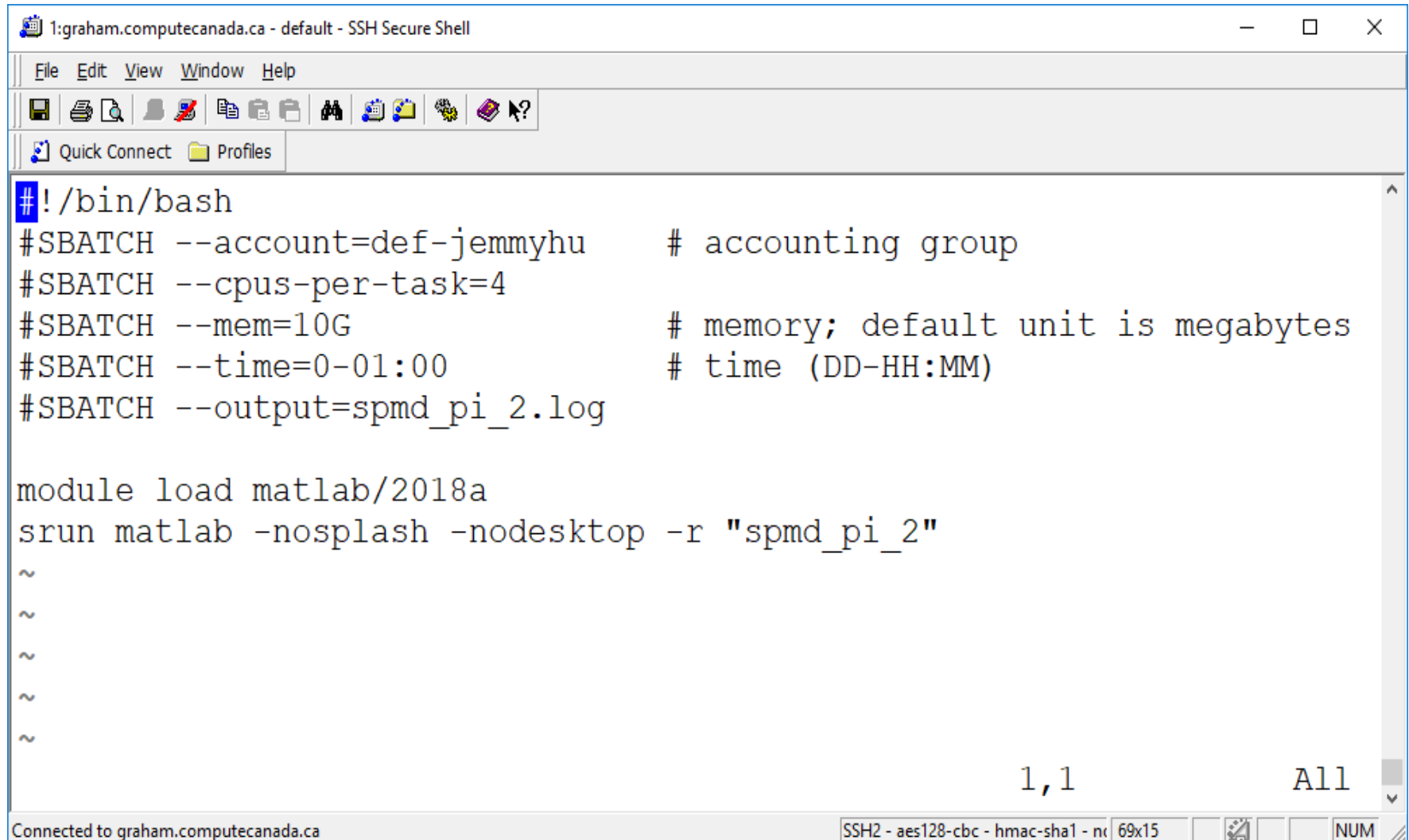
    piApprox = gplus(myIntegral);
    fprintf('piApprox: %-4g\n', piApprox);

end
%% results in client
fprintf('pi                : %.18f\n', pi);
fprintf('Approximation: %.18f\n', piApprox{1});
fprintf('Error            : %g\n', abs(pi - piApprox{1}));
```

6, 0-1 Top

Connected to graham.computecanada.ca SSH2 - aes128-cbc - hmac-sha1 - nc 78x27 NUM

batch script, spmd_pi.sh (4 cpus/workers/labs)



The screenshot shows a terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The window has a menu bar with "File", "Edit", "View", "Window", and "Help". Below the menu bar is a toolbar with various icons for file operations and a "Quick Connect" button. The main area of the window displays a batch script for MATLAB. The script starts with a shebang line "#!/bin/bash" and followed by several SBATCH directives: "#SBATCH --account=def-jemmyhu" (commented as "# accounting group"), "#SBATCH --cpus-per-task=4", "#SBATCH --mem=10G" (commented as "# memory; default unit is megabytes"), "#SBATCH --time=0-01:00" (commented as "# time (DD-HH:MM)"), and "#SBATCH --output=spmd_pi_2.log". Below these directives, the script contains the commands "module load matlab/2018a" and "srun matlab -nosplash -nodesktop -r \"spmd_pi_2\"". The output of the script shows five tilde characters "~" on separate lines. At the bottom right of the terminal, the text "1,1" and "All" are visible. The status bar at the bottom of the window indicates "Connected to graham.computecanada.ca" on the left, and "SSH2 - aes128-cbc - hmac-sha1 - n" and "69x15" on the right, along with a "NUM" button.

```
#!/bin/bash
#SBATCH --account=def-jemmyhu      # accounting group
#SBATCH --cpus-per-task=4
#SBATCH --mem=10G                  # memory; default unit is megabytes
#SBATCH --time=0-01:00             # time (DD-HH:MM)
#SBATCH --output=spmd_pi_2.log

module load matlab/2018a
srun matlab -nosplash -nodesktop -r "spmd_pi_2"
~
~
~
~
~

1,1                                All
```

Connected to graham.computecanada.ca

SSH2 - aes128-cbc - hmac-sha1 - n 69x15 NUM

Output: spmd_pi.log (4 cpus/workers/labs)

```
1:graham.computecanada.ca - default - SSH Secure Shell
File Edit View Window Help
Quick Connect Profiles

Starting parallel pool (parpool) using the 'local' profile ...
connected to 4 workers.
Lab 1:
  Subinterval: [0 , 0.25]
Lab 2:
  Subinterval: [0.25, 0.5 ]
Lab 3:
  Subinterval: [0.5 , 0.75]
Lab 4:
  Subinterval: [0.75, 1 ]
Lab 2:
  Subinterval: [0.25, 0.5 ] Integral: 0.874676
  piApprox: 3.14159
Lab 3:
  Subinterval: [0.5 , 0.75] Integral: 0.719414
  piApprox: 3.14159
Lab 4:
  Subinterval: [0.75, 1 ] Integral: 0.567588
  piApprox: 3.14159
Lab 1:
  Subinterval: [0 , 0.25] Integral: 0.979915
  piApprox: 3.14159
pi : 3.141592653589793116
Approximation: 3.141592653589790451
Error : 2.66454e-15

32,1 Bot
```

Connected to graham.computecanada.ca SSH2 - aes128-cbc - hmac-sha1 - n 76x26 NUM

MATLAB Compile Runtime, MCR

- module spider mcr

Versions:

mcr/R2013a
mcr/R2013b
mcr/R2014a
mcr/R2014b
mcr/R2015a
mcr/R2015b
mcr/R2016a
mcr/R2016b
mcr/R2017a
mcr/R2017b
mcr/R2018a

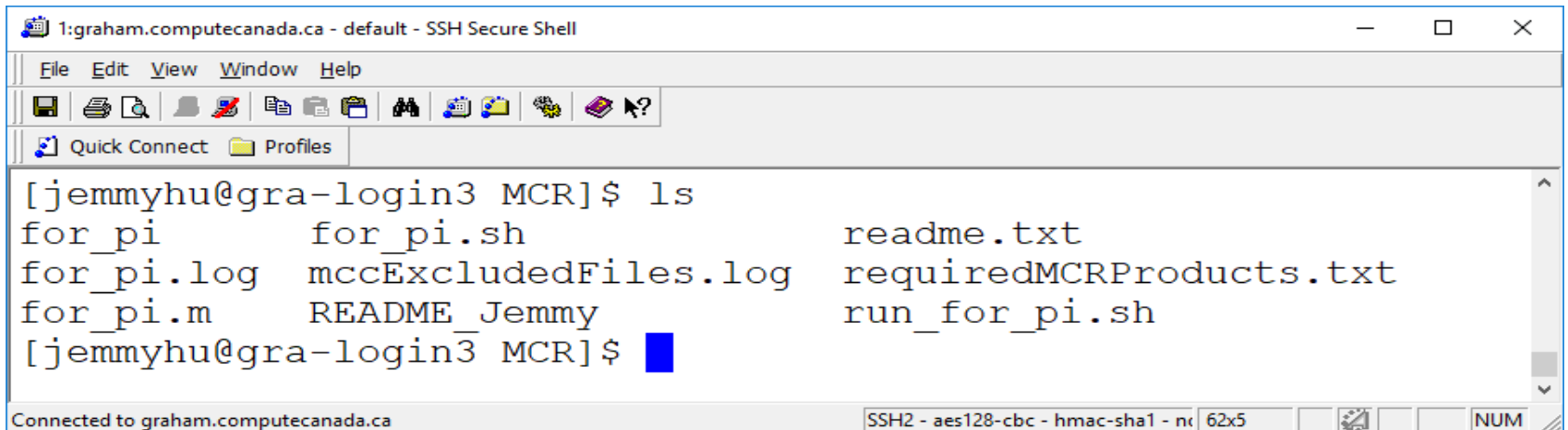
- module load version (mcr/R2018a)

Steps in MCR

- compile serial code using mcc:

module load matlab/2018a

mcc -m -R ' -nodisplay -singleCompThread' for_pi



The screenshot shows an SSH terminal window titled "1:graham.computecanada.ca - default - SSH Secure Shell". The terminal displays the output of the command `ls` in the `MCR` directory. The files listed are:

<code>for_pi</code>	<code>for_pi.sh</code>	<code>readme.txt</code>
<code>for_pi.log</code>	<code>mccExcludedFiles.log</code>	<code>requiredMCRProducts.txt</code>
<code>for_pi.m</code>	<code>README_Jemmy</code>	<code>run_for_pi.sh</code>

The terminal prompt is `[jemmyhu@gra-login3 MCR]$`. The status bar at the bottom indicates the connection is to `graham.computecanada.ca` using `SSH2 - aes128-cbc - hmac-sha1 - n` with a resolution of `62x5` and a keyboard layout of `NUM`.

- setup path:

module load mcr/R2018a

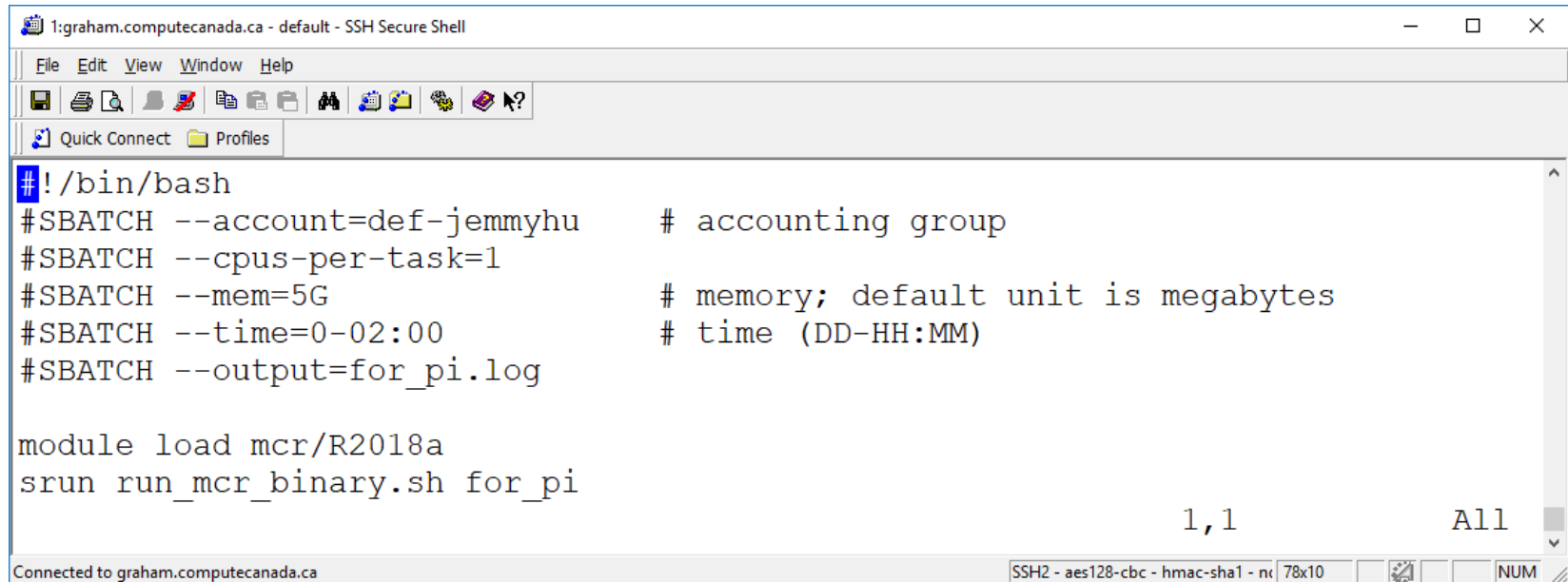
setrpaths.sh --path for_pi

- interactive run command:

run_mcr_binary.sh for_pi

for_pi.sh

/home/jemmyhu/MATLAB/MCR/



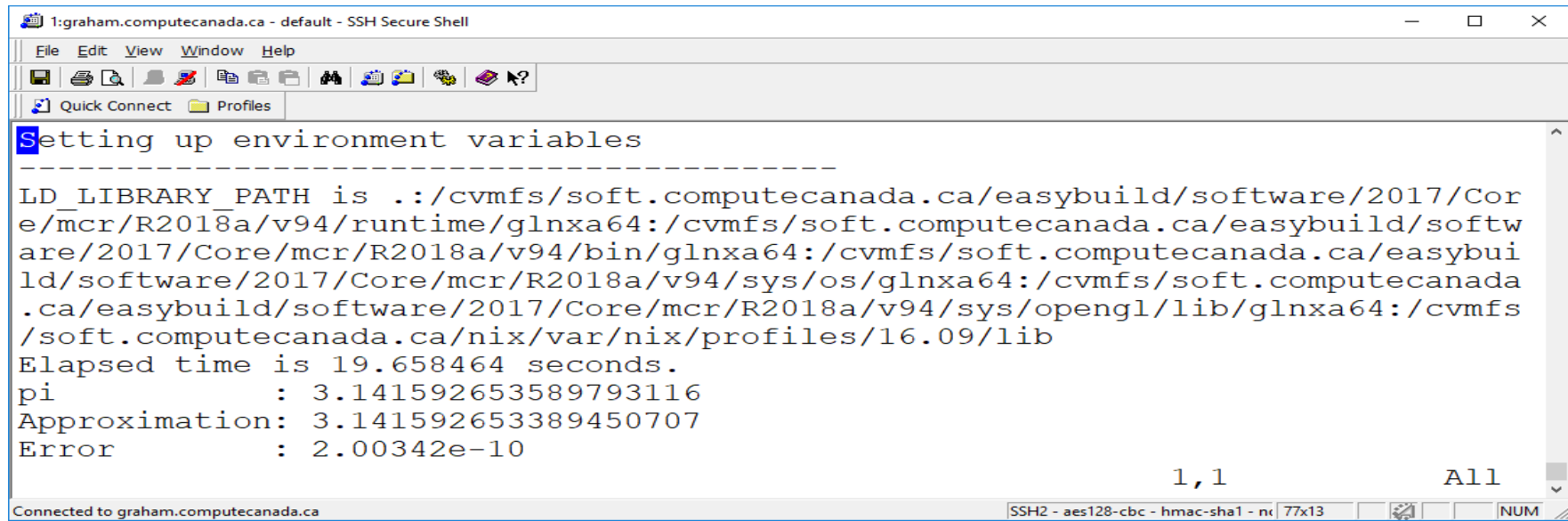
```
1:graham.computecanada.ca - default - SSH Secure Shell
File Edit View Window Help
Quick Connect Profiles

#!/bin/bash
#SBATCH --account=def-jemmyhu      # accounting group
#SBATCH --cpus-per-task=1
#SBATCH --mem=5G                   # memory; default unit is megabytes
#SBATCH --time=0-02:00             # time (DD-HH:MM)
#SBATCH --output=for_pi.log

module load mcr/R2018a
srun run_mcr_binary.sh for_pi

1,1 All
Connected to graham.computecanada.ca  SSH2 - aes128-cbc - hmac-sha1 - nc 78x10 NUM
```

for_pi.log



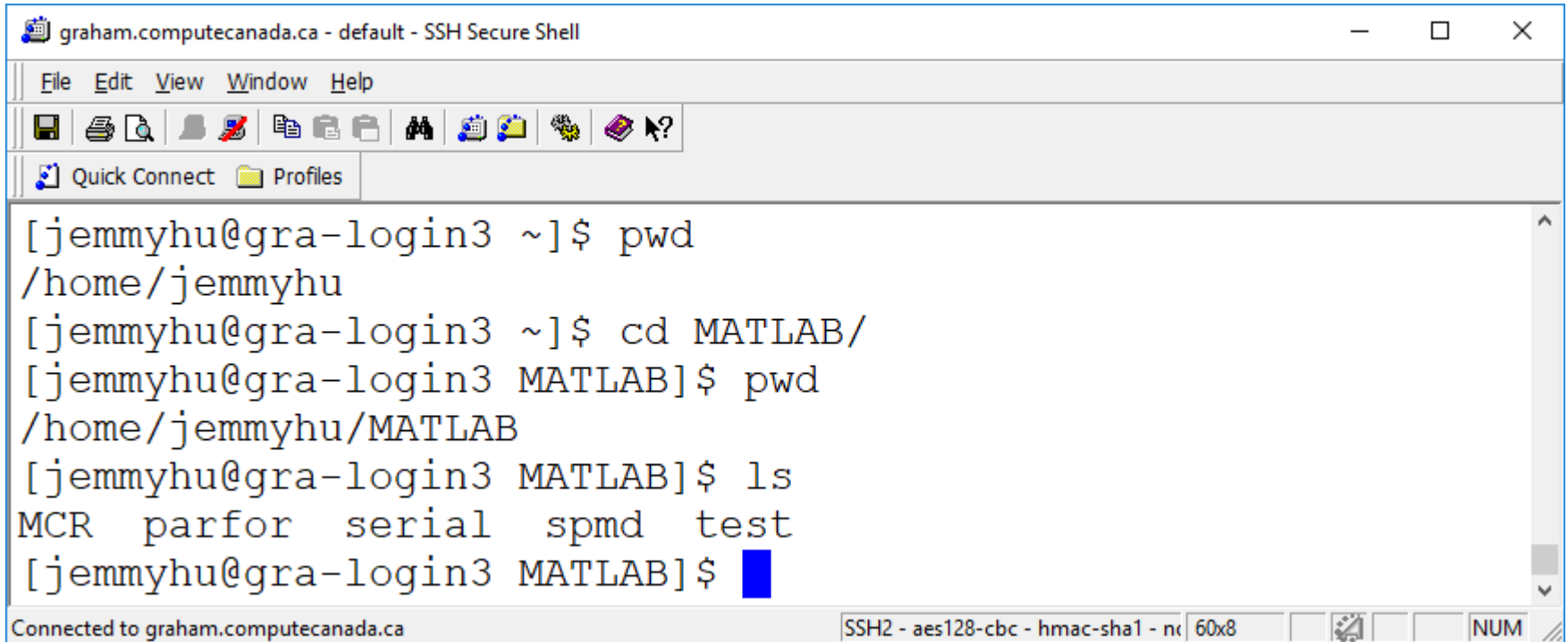
```
1:graham.computecanada.ca - default - SSH Secure Shell
File Edit View Window Help
Quick Connect Profiles

Setting up environment variables
-----
LD_LIBRARY_PATH is ./cvmfs/soft.computecanada.ca/easybuild/software/2017/Core/mcr/R2018a/v94/runtime/glnxa64:/cvmfs/soft.computecanada.ca/easybuild/software/2017/Core/mcr/R2018a/v94/bin/glnxa64:/cvmfs/soft.computecanada.ca/easybuild/software/2017/Core/mcr/R2018a/v94/sys/os/glnxa64:/cvmfs/soft.computecanada.ca/easybuild/software/2017/Core/mcr/R2018a/v94/sys/opengl/lib/glnxa64:/cvmfs/soft.computecanada.ca/nix/var/nix/profiles/16.09/lib
Elapsed time is 19.658464 seconds.
pi          : 3.141592653589793116
Approximation: 3.141592653389450707
Error       : 2.00342e-10

1,1 All
Connected to graham.computecanada.ca  SSH2 - aes128-cbc - hmac-sha1 - nc 77x13 NUM
```

Materials/Examples

On Graham and Cedar: /home/jemmyhu/MATLAB

A screenshot of an SSH terminal window titled "graham.computeCanada.ca - default - SSH Secure Shell". The window has a menu bar with "File", "Edit", "View", "Window", and "Help". Below the menu bar is a toolbar with various icons for file operations and system functions. The terminal content shows a user named "jemmyhu" at a "gra-login3" machine. The user enters "pwd" and the output is "/home/jemmyhu". Then the user enters "cd MATLAB/" and the output is "/home/jemmyhu/MATLAB". Finally, the user enters "ls" and the output is "MCR parfor serial spmd test". The terminal status bar at the bottom shows "Connected to graham.computeCanada.ca", "SSH2 - aes128-cbc - hmac-sha1 - n", "60x8", and "NUM".

```
graham.computeCanada.ca - default - SSH Secure Shell
File Edit View Window Help
[jemmyhu@gra-login3 ~]$ pwd
/home/jemmyhu
[jemmyhu@gra-login3 ~]$ cd MATLAB/
[jemmyhu@gra-login3 MATLAB]$ pwd
/home/jemmyhu/MATLAB
[jemmyhu@gra-login3 MATLAB]$ ls
MCR parfor serial spmd test
[jemmyhu@gra-login3 MATLAB]$
```

Compute Canada wiki page:

<https://docs.computeCanada.ca/wiki/MATLAB>