Parallel programming in Madagascar

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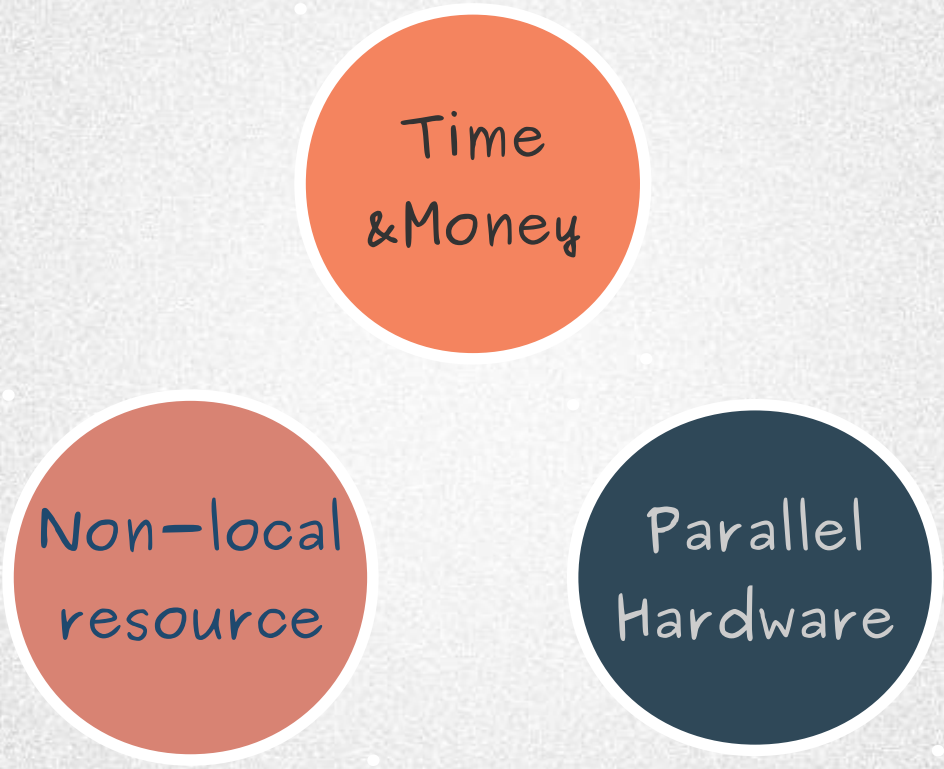
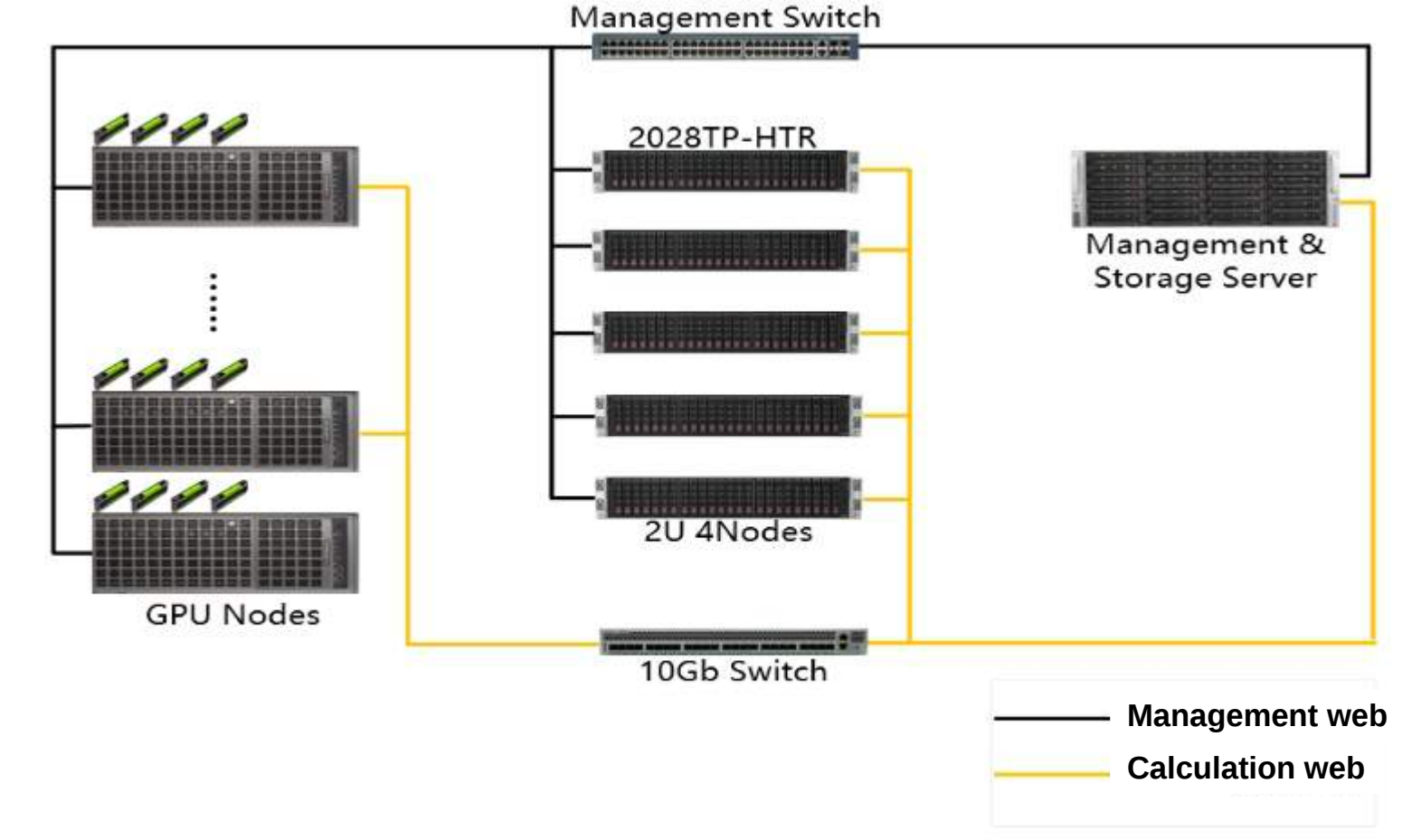
Why parallel ?



HPC structure



Outline

Parallel calculation in Madagascar with

- OpenMP
- MPI
- Pscons

Obtain demos

```
git clone https://github.com/Chenlonw/MadagascarSummer2017.git
```

OpenMp

Installation

OpenMP is a feature of the compiler and its parallel calculation is based on the shared-memory

In Madagascar, you can do parallel programming with the OpenMP either internally or externally

- #include <omp.h> plus -fopenmp
- sfomp

Internal usage

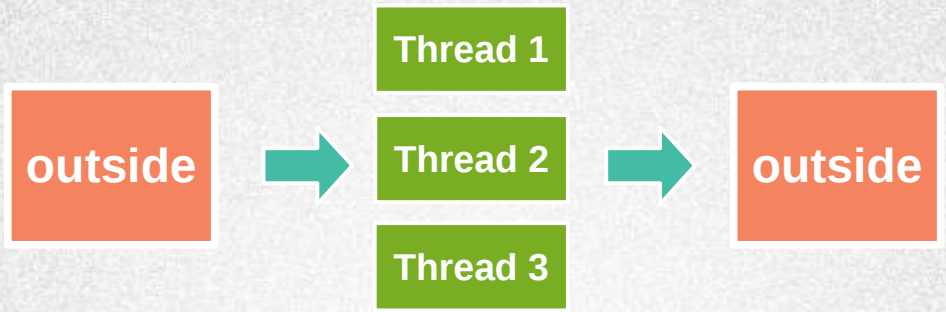
hello.c:

```
#include <omp.h>
#include <stdio.h>

int main()
{
	#pragma omp parallel
	{
		printf("Hello world from %d of %d\n", omp_get_thread_num(), omp_get_num_threads());
	}
	return 0;
}
```

compile

gcc hello.c -o hello -fopenmp / icc hello.c -o hello -openmp

Tutorials



OpenMP Parallel Part

The default scoping of variable is **shared** unless specified

- #pragma omp parallel {}
- #pragma omp parallel for
- Reduction

Exercise 1

```
#include <omp.h>
#include <stdio.h>

int main()
{
        #pragma omp parallel
        {

                #pragma omp master
                {
                        printf("Hello world from %d \n", omp_get_thread_num());
                }

                #pragma omp single  // Threads will meet barrier automatically
                {
                        printf("Hello world from %d \n", omp_get_thread_num());
                }

                #pragma omp barrier
                printf("Number of threads %d \n", omp_get_num_threads());
        }
}
```

Code inside a parallel region will be copied to several copies and executed by different threads

Only responsible for master thread

Only be executed by a single thread

All threads will stop here until the slowest one finished

Exercise 2

```
gcc sin.c -fopenmp -lm -o sin
```

With OpenMP **Time 0.00328**

Without OpenMP **Time 0.01896**

```c
#include <omp.h>
#include <stdio.h>
#include <math.h>

int main ()
{
        long i;
        long n=100000;

        double X[n],Y[n];

        for (i=0;i<n;i++)
                X[i]=(double)i;

        double wstart = omp_get_wtime();

        #pragma omp parallel for
        for (i=0;i<n;i++)
                Y[i]= sin(X[i])+cos(X[i]);

        printf("Time %f\n",omp_get_wtime()-wstart);
}
```

i is private variable here

Exercise 3

$$\pi = \int_0^1 \frac{4.0}{1+x^2}\,\mathrm{d}x$$

reduction

```
#include <omp.h>
#include <stdio.h>

int main()
{
        long i;
        double x, mypi,sum=0.0;
        double vpi = 3.141592654;
        double tol = 0.0000001;
        long nsteps = 10000000;
        double step,diff,wend;

        double wstart = omp_get_wtime();

        step = 1.0/ (double) nsteps;

        // #pragma omp parallel for private (x) reduction(+:sum)
        #pragma omp parallel for private (x)
        for(i=0;i<nsteps;i++)
        {
                x = (i + 0.5) * step;
                #pragma omp atomic
                sum += 4.0/(1.0 + x * x);
        }

        mypi = step * sum;
        wend = omp_get_wtime();

        diff = mypi-vpi;
        if (diff<0) diff *=-1.0;

        if (diff>tol)
                printf("Error in pi: %f\n",mypi);
        else
                printf("PI %1.10f\n", mypi);
        printf("Time: %f\n",wend-wstart );
}
```

set x as private

execute summation successively

With Reduction	Time 0.073934
Without Reduction	Time 2.564278

In Madagascar

```
grep "pragma omp" $RSFSRC/*/*/M*.c |\
awk -F ':' '{ print $1 }' |\
uniq
```

139 standalone programs (approximately 11% of Madagascar programs) were using OMP on the last check (2014-02-09)

external usage

If the input data is supposed to be parallel, sfomp command splits the data along the given axis and runs it through parallel threads

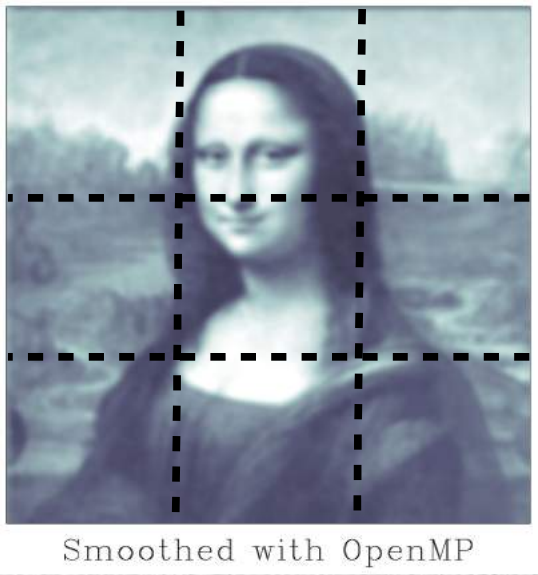
OpenMP wrapper for embarassingly parallel jobs.			
sfomp < inp.rsf > out.rsf split=ndim join=axis			
int	**join=axis**		axis to join
int	**split=ndim**		axis to split

```
sfomp sfsmooth rect1=5 rect2=5 < in.rsf > out.rsf
```

Smoothing Mona

Mona Lisa

Without OpenMP



With OpenMP

Smoothing Mona

Run smoothing function with parallel threads

```
Flow('patch','mona','patch w=200,200 p=3,3 | put n3=9 n4=1')

Flow('patch2','patch','smooth rect1=%d rect2=%d repeat=2' \
     % (rect,rect), split=[3,'omp'])

Flow('pmona2','patch2','put n3=3 n4=3 | patch inv=y weight=y')
```

Split the input data along the 3rd axis

MPI

Installation

MPI (Message-Passing Interface) is dominant framework for parallel processing including distributed-memory system. Several implementations (such as Open MPI and MPICH are available)

In Madagascar, you can do parallel programming with the MPI either internally or externally as well

Internal usage

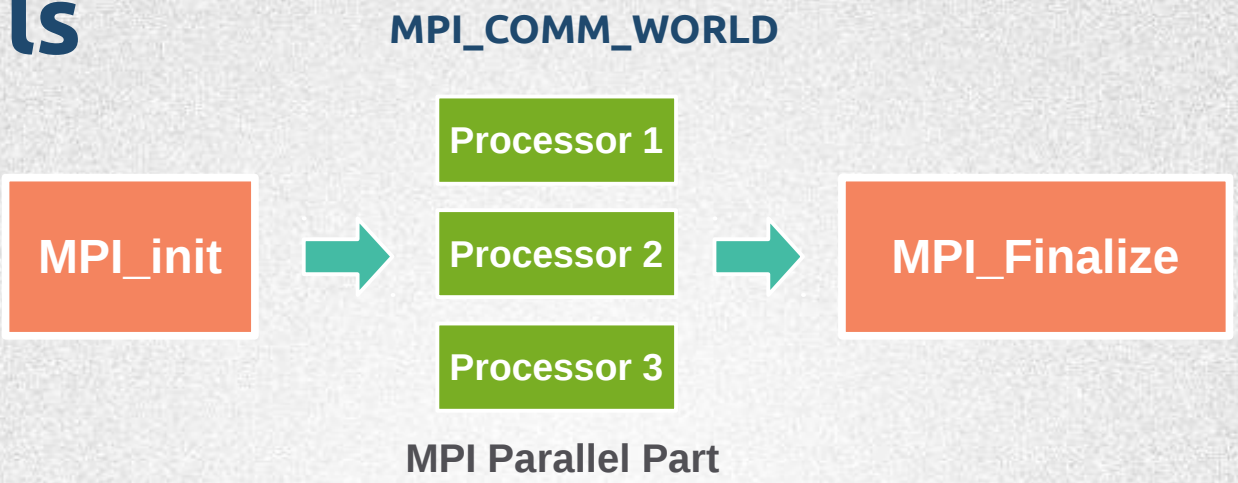
Mmpihelloworld.c:

The name starts with mpi

```
#include <mpi.h>
#include <rsf.h>
#include <stdio.h>
#include <math.h>

int main(int argc, char *argv[])
{
        int myid, numprocs;
        int namelen;
        char processor_name[MPI_MAX_PROCESSOR_NAME];

        sf_init (argc, argv);

        MPI_Init(&argc,&argv);
        MPI_Comm_rank(MPI_COMM_WORLD,&myid);
        MPI_Comm_size(MPI_COMM_WORLD,&numprocs);
        MPI_Get_processor_name(processor_name,&namelen);

        fprintf(stderr,"Hello World! Process %d of %d on %s\n", myid, numprocs, processor_name);

        MPI_Finalize();
        exit(0);
}
```

```
from rsf.proj import *

if not WhereIs('mpirun'):
    sys.stderr.write("\nNo MPI.\n")
    sys.exit(1)

NP = int(ARGUMENTS.get('NP','4'))

Flow('out',None,
        '''
        sfmpihelloworld -hostfile=hostfile
        ''',np=NP,stdin=0,stdout=-1)

End()
```

Tutorials



MPI_COMM_WORLD is a handle points to all the resource

- MPI_Send and MPI_Recv
- MPI_Datatype

Exercise 1

Mmpihellocommu.c:

Send a message from master to slave

```
#include <mpi.h>
#include <rsf.h>
#include <stdio.h>
#include <string.h>
#include <math.h>

int main(int argc, char *argv[])
{
        int myid;
        char message[30];
        MPI_Status mpi_status;

        sf_init (argc, argv);
        MPI_Init(&argc,&argv);
        MPI_Comm_rank(MPI_COMM_WORLD,&myid);
        if (myid==0)
        {
                strcpy(message,"Hello processor 1!");
                MPI_Send(message, strlen(message), MPI_CHAR, 1, 99, \
                        MPI_COMM_WORLD);
        }
        else if(myid == 1)
        {
                MPI_Recv(message, 30, MPI_CHAR, 0, 99, \
                        MPI_COMM_WORLD, &mpi_status);
                fprintf(stderr, "received: %s\n", message);
        }

        MPI_Finalize();
        exit(0);
}
```

Exercise 2

A+B=C

Mmpihello.c:

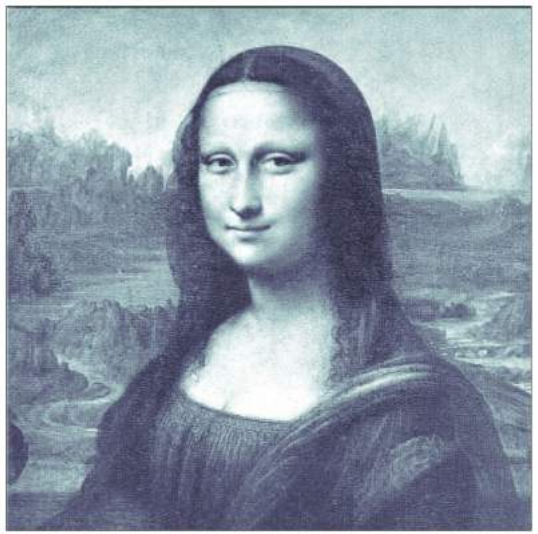
Collect results

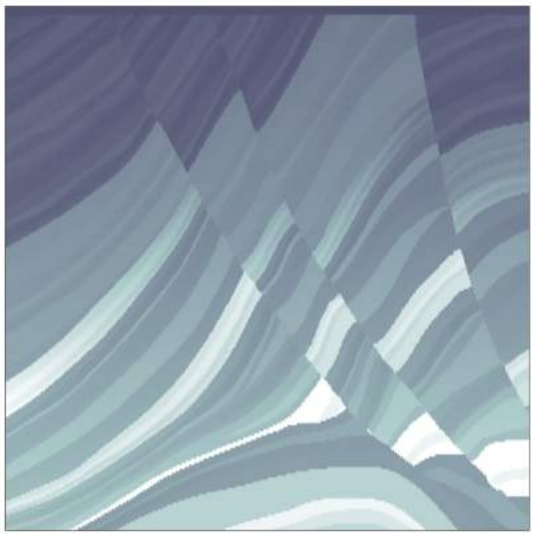
Splits the data along the slowest axis

```
                    ......
/* Input vectors in memory */
        a = sf_floatalloc (n1);
        b = sf_floatalloc (n1);
        /* How many vectors per CPU */
        nc = (int)(n2/(float)ncpu + 0.5f);
        c = sf_floatalloc2 (n1, nc);
        /* Starting position in input files */
        sf_seek (ain, n1*cpuid*esize, SEEK_CUR);
        sf_seek (bin, n1*cpuid*esize, SEEK_CUR);
        for (i = cpuid; i < n2; i += ncpu, k++) {
                /* Read local portion of input data */
                sf_floatread (a, n1, ain);
                sf_floatread (b, n1, bin);
                /* Parallel summation here */
                for (j = 0; j < n1; j++)
                        c[k][j] = a[j] + b[j];
                /* Move on to the next portion */
                sf_seek (ain, n1*(ncpu - 1)*esize, SEEK_CUR);
                sf_seek (bin, n1*(ncpu - 1)*esize, SEEK_CUR);  }
        }
```

```
if (0 == cpuid) { /* Collect results from all nodes */
        for (i = 0; i < n2; i++) {
                k = i / ncpu; /* Iteration number */
                j = i % ncpu; /* CPU number to receive from */
                if (j) /* Receive from non-zero CPU */
                        MPI_Recv (&c[k][0], n1, MPI_FLOAT, j, j,
                                MPI_COMM_WORLD, &mpi_stat);
                sf_floatwrite (c[k], n1, cout);
        }
        sf_fileclose (cout);
} else { /* Send results to CPU #0 */
        for (i = 0; i < k; i++) /* Vector by vector */
                MPI_Send (&c[i][0], n1, MPI_FLOAT, 0, cpuid,
                        MPI_COMM_WORLD);
}
sf_fileclose (ain); sf_fileclose (bin);
MPI_Finalize ();
return 0;
```

Exercise 2

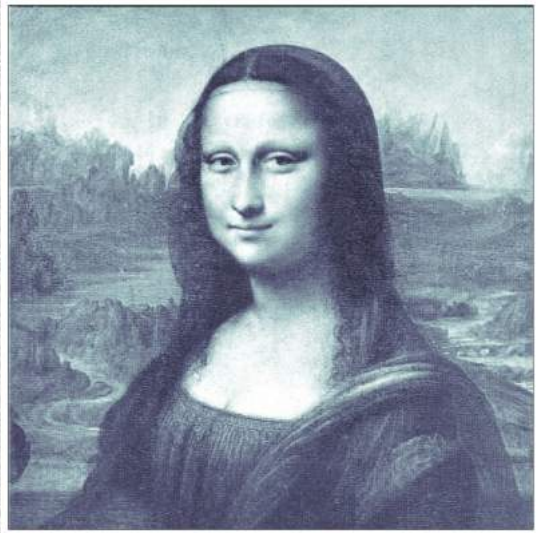




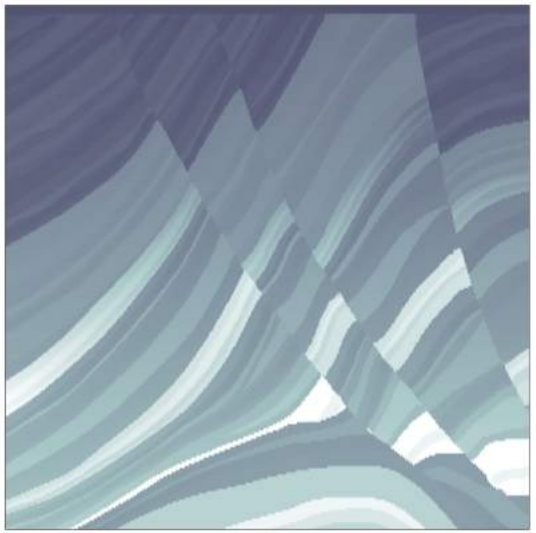
Mona Lisa + **Marmousi** = **Monamousi**

Exercise 2

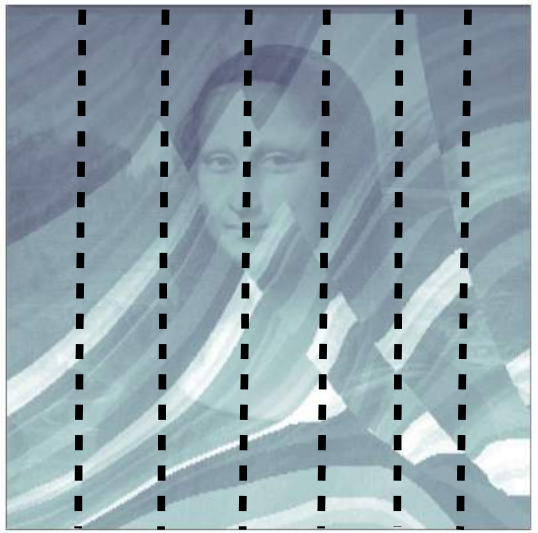
np



Mona Lisa



Marmousi



Monamousi

Mona Lisa + **Marmousi** = **Monamousi**

external usage

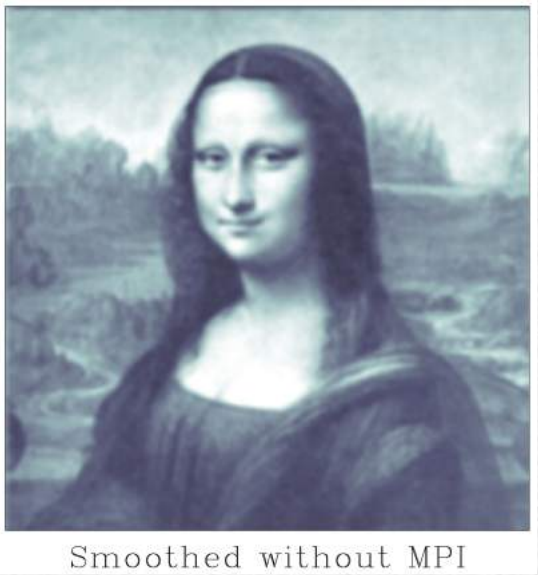
If the input data is supposed to be parallel, sfmpi command splits the data along the given axis and runs it through parallel threads

MPI wrapper for embarassingly parallel jobs.			
sfmpi input=inp.rsf output=out.rsf split=ndim join=axis			
string	**input=**		auxiliary input file name
int	**join=axis**		axis to join
file	**output=**		auxiliary output file name
int	**split=ndim**		axis to split

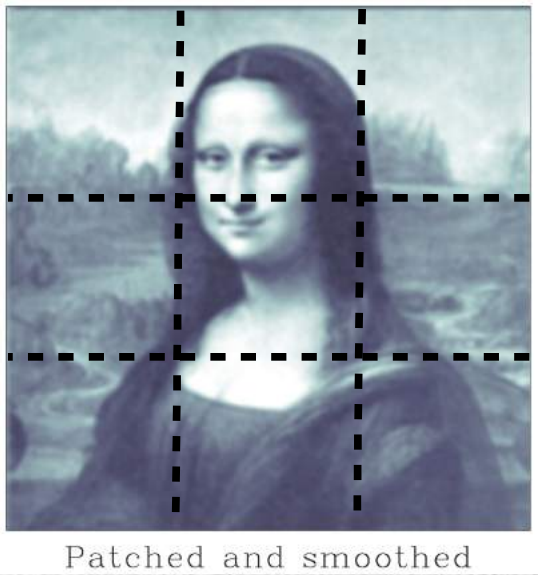
```
mpirun -np 4 sfmpi split=3 sfsmooth rect1=5 rect2=5  input=in.rsf output=out.rsf
```

Smoothing Mona

Mona Lisa



Without MPI



With MPI

Smoothing Mona

```
Flow('patch','mona','patch w=200,200 p=3,3 | put n3=9 n4=1')

Flow('patch2','patch','smooth rect1=%d rect2=%d repeat=2' \
     % (rect,rect), split=[3,'mpi',[0]],reduce='cat',np=4)

Flow('pmona2','patch2','put n3=3 n4=3 | patch inv=y weight=y')
```

Run smoothing function with parallel threads

How many processors involved

Split the input data along the 3rd axis

How to reduce (add or cat axis=1)

Pscons

Pscons

The SCons can execute the script in parallel by splitting input data or splitting commands

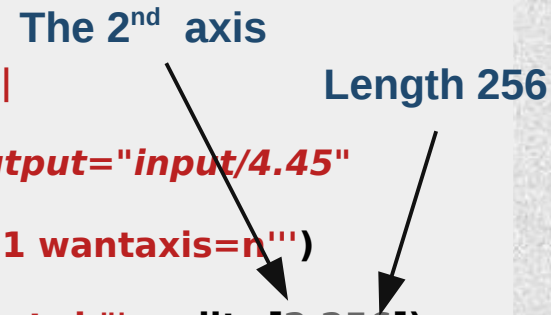
Unlike the OpenMP or MPI utilities, this has fault tolerance -- in case of a node failing, restarting the job will allow it to complete.

Try

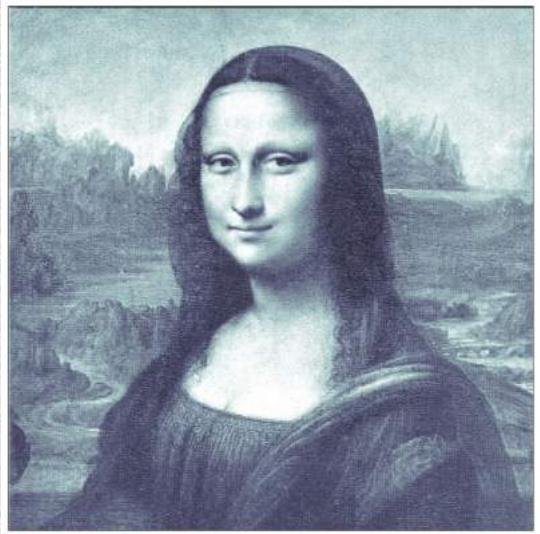
```
pscons / scons -j num
```

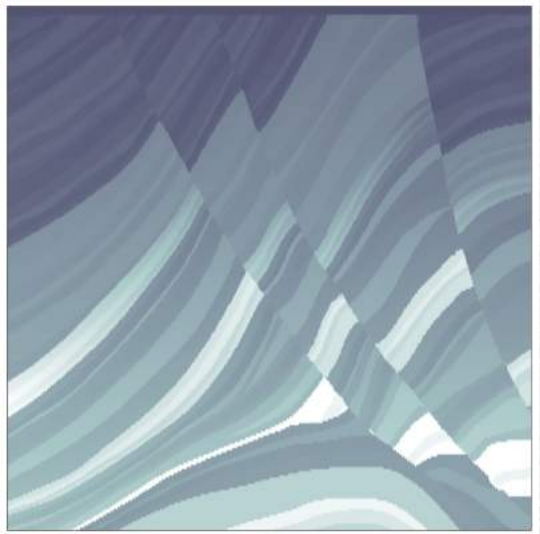
Demo1 – splitting input data

```
from rsf.proj import *

Fetch('mona.img','imgs')
Flow('mona','mona.img',
     '''
     echo n1=512 n2=513 in=$SOURCE data_format=native_uchar | dd type=float |
     window n1=512 n2=512 | sftransp | math output="input/1000"
     ''',stdin=0)
Result('mona', '''grey allpos=y title="Mona Lisa" color=b screenratio=1 wantaxis=n''')

Fetch('marmvel.hh','marm')
Flow('mar','marmvel.hh',
     '''
     dd form=native | window j1=1 j2=2 f2=800 n2=512 f1=0 n1=512|
     scale dscale=0.001 |
     put label1=Depth unit1=km label2=Distance unit2=km | math output="input/4.45"
     ''')
Result('mar', '''grey allpos=y title="Marmousi" color=b screenratio=1 wantaxis=n''')

Flow('monamousi','mar mona','math b=${SOURCES[1]} output="input+b"', split=[2,256])
Result('monamousi', '''grey allpos=y title="Monamousi" color=b screenratio=1 wantaxis=n''')

End()
```



Demo 1





Mona Lisa + **Marmousi** = **Monamousi**

Demo2 – splitting commands

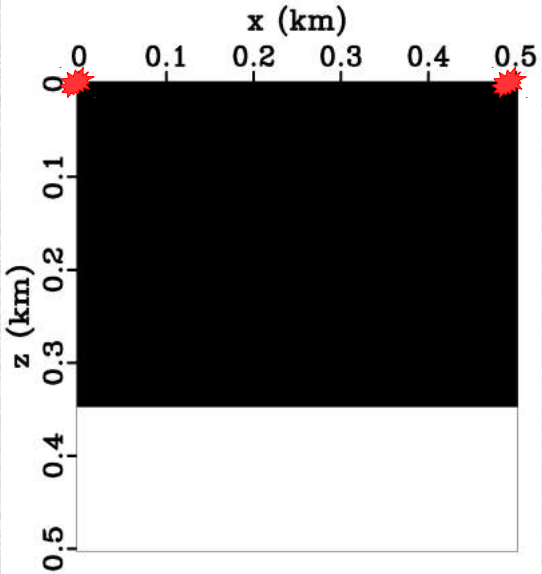
```
from rsf.proj import *
   ......
#shot configuration in coordinate
nshot=2
shot0=0
dshot=0.5
Flow('sz',None,'math n1=1 output=%(sz)g' %par)
for i in range (1,nshot+1):
   isx = shot0 + (i-1)*dshot
   print isx
   Flow('sx-%d'%(i),None,'math n1=1 output=%g'%(isx))
   Flow('source-%d'%(i),'sx-%d sz'%(i),'cat axis=1 ${SOURCES[1]}')
   Flow('erecfield-%d ewavefield-%d'%(i,i),'elasticwavelet density receivers source-%d ccc'%(i),
       '''
       ewefd2d
       den=${SOURCES[1]}
       rec=${SOURCES[2]}
       sou=${SOURCES[3]}
       ccc=${SOURCES[4]}
       wfl=${TARGETS[1]}
       dabc=y snap=y verb=y jsnap=%(jsnap)d jdata=%(jdata)d
       ssou=y nb=20 nbell=11
       ''' %par)
End()
```

```
export OMP_NUM_THREADS=2
```

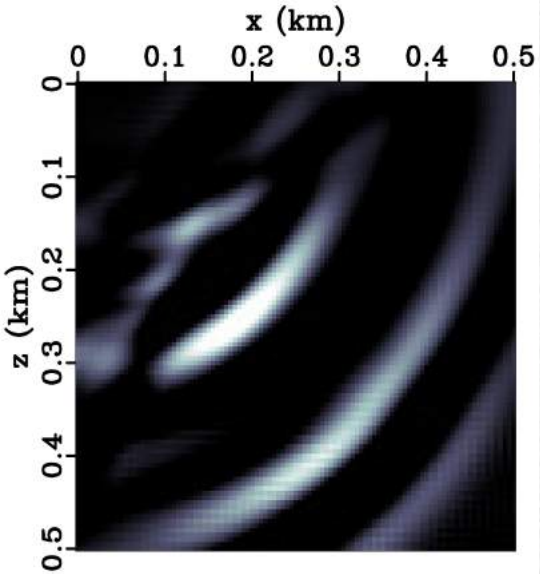
Loop in shots

Elastic wave modeling

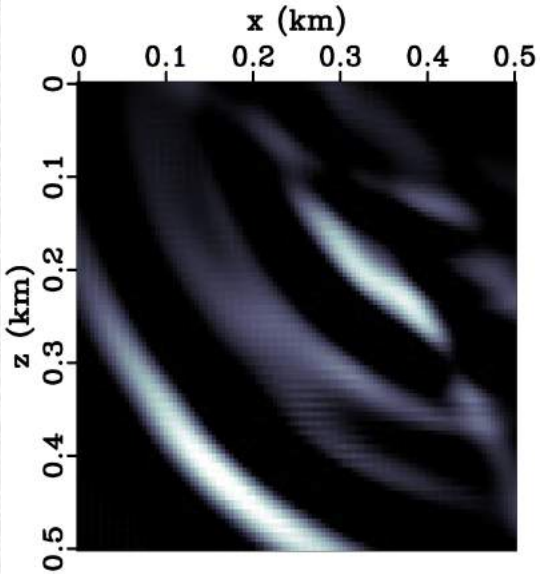
Demo 2



Two shots



Shot 1



Shot 2

Acknowledge

I would like to acknowledge the HPC group in NTNU gave me lectures on parallel programming (https://www.hpc.ntnu.no/display/hpc/NTNU +HPC+GROUP).

Some of the scripts are modified from the Madagascar official website (http://www.ahay.org/wiki/Parallel_Computing)