Using a generalized MPI Interface for Python

MYMPI

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http://nbcr.sdsc.edu/

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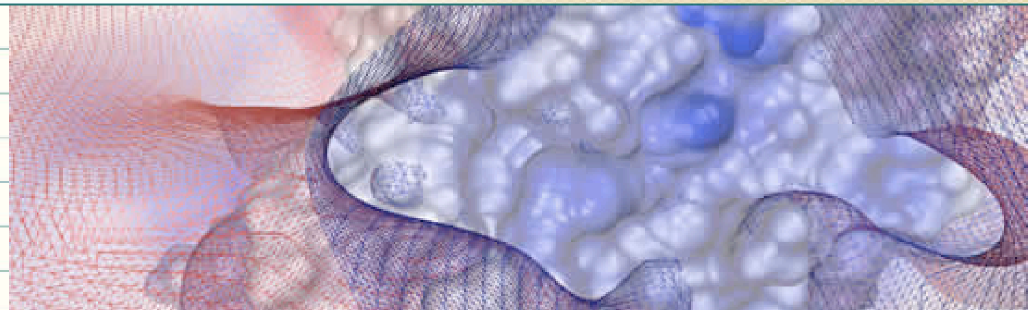

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Jun 25-June 29, 2005: ISMB 2005, Detroit, Michigan.

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Talk Topics

- Discuss MYMPI - MPI Python module
  - What?
  - Why?
- Applications
  - Continuity: cardiac mechanics and electrocardiology
  - Montage: astronomical mosaicking

MYMPI Overview

- A Python module written in C
- Does not require a special version of Python
- Contains calls to many important MPI routines
- Enables writing parallel programs based on the MPI standard
- Enables mixing of Python, C, and Fortran MPI programs

Hasn't this been done?

- Yes
  - pyMPI : http://sourceforge.net/projects/pympi
  - A special Python interpreter
- No
  - MYMPI is a module that works with a standard Python interpreter
  - Many significant differences

Interpreter vs. Module

- pyMPI is actually a custom version of the Python interpreter along with a module
- MYMPI, is a module only that can be used with a normal Python interpreter
  - Can use the same interpreter for serial and parallel applications
  - Don't need to maintain a second interpreter

Interpreter vs. Module

- pyMPI the Python interpreter is the parallel application
    - MYMPI the code executed by the interpreter is the parallel application
    - This can be seen in the start-up procedure

Startup

- Every “normal” MPI application must call MPI_Init
- pyMPI programs don’t not call MPI_Init because it is called when the interpreter starts
- MYMPI, programs explicitly call MPI_Init
- Having better control over when/how MPI_Init is called was one motivation for MYMPI

Syntax and Semantics

- MYMPI follows the syntax and semantics of C and Fortran MPI
- pyMPI has a more OOP flavor
- Knew from the beginning we would be using to write heterogeneous Python and Fortran applications
- Can use our existing training materials. Rewrote examples in Python

Size

- pyMPI is about 1.7 Mb and compiles in minutes
- MYMPI is a single file, 33 Kb, and compiles in < 3 seconds
- pyMPI contains most of MPI-1 (120+ routines)
- MYMPI contains about 30 important routines
- Another motivation was this makes extending and debugging easier, memory leak.

Routines

mpi_alltoall
Sends data from all to all processes
mpi_alltoallv
Sends data from all to all processes, with a displacement
mpi_barrier
Blocks until all process have reached this routine.
mpi_bcast
Broadcasts a message from the process with rank "root" to all other processes of the group.
mpi_comm_create
Creates a new communicator
mpi_comm_dup
Duplicates an existing communicator with all its cached information
mpi_comm_group
Accesses the group associated with given communicator
mpi_comm_rank
Determines the rank of the calling process in the communicator
mpi_comm_size
Determines the size of the group associated with a communictor
mpi_comm_split
Creates new communicators based on colors and keys
mpi_error
Checks for errors (not part of regular MPI)
mpi_finalize
Terminates MPI execution environment
mpi_gather
Gathers together values from a group of processes

Routines

mpi_gatherv
    Gathers into specified locations from all processes in a group
mpi_get_count
    Gets the number of "top level" elements
mpi_group_incl
    Produces a group by reordering an existing group and taking only listed members
mpi_group_rank
    Returns the rank of this process in the given group
mpi_init
    Initialize the MPI execution environment
mpi_iprobe
    Nonblocking test for a message
mpi_probe
    Blocking test for a message
mpi_recv
    Basic receive
mpi_reduce
    Reduces values on all processes to a single value
mpi_scatter
    Sends data from one task to all other tasks in a group
mpi_scatterv
    Scatters a buffer in parts to all tasks in a group
mpi_send
    Performs a basic send
mpi_status
    Return status information (not part of standard MPI)

Data types

- MPI_INT
  - Integer
- MPI_DOUBLE
  - 8 byte floating point number
- We have support for scalars and multiple dimension arrays using the Numeric package.
- Need to add character

Example Call

- Input argument lists closely match the list for C and Fortran MPI routines
- In C we would do a message receive into buffer of count integers from process source using the syntax:

```
MPI_Recv(&buffer,count,     MPI_INT, source, tag,  MPI_COMM_WORLD,&status);
```

Python:

```
buffer=mpi.mpi_recv(        count, mpi.MPI_INT, source, tag,  mpi.MPI_COMM_WORLD    )
status=mpi_status()
```

Where it works

- OSX
    - LAM , MPICH
- IBM - AIX
    - Native
- Redhat
    - LAM, MPICH ethernet
- SuSie
    - MPICH ethernet & MPICH Myrinet

Other uses

- Might be used in place of some F2PY calls
    - Subroutine call becomes a Send and Receive to another process
    - Opinion: Easier to write
- Communication between GUI and worker routines
- Facilitate use of parallel libraries such as SuperLU_DIST

Links

- MYMPI: nbcr.sdsc.edu/tools.php
- MPI: www-unix.mcs.anl.gov/mpi/
  - MPICH: www-unix.mcs.anl.gov/mpi/mpich/
  - LAM: www.lam-mpi.org/
- MPI on OSX (historical): www.sdsc.edu/~tkaiser/mac_stuff/mpi_osx.html
- Lecture notes: peloton.sdsc.edu/~tkaiser/mpi_stuff/workshop/index.html

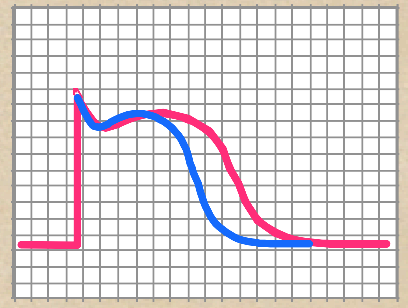
Demo

http://peloton.sdsc.edu/~tkaiser/mympi/Terminal.mov

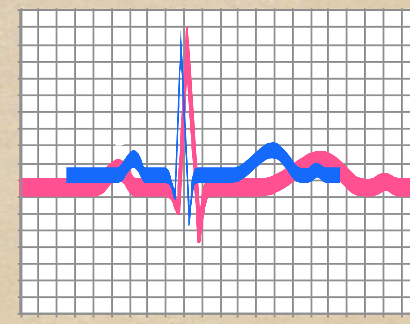
Application: Continuity 6.0

- A problem solving environment for multiscale physiology applications
- Most common applications are cardiac electrophysiogy and biomechanics
- Makes use of Python for:
  - High level object oriented design
  - Scripting and component integration
  - And now, for parallel processing
- Can be downloaded from www.continuity.ucsd.edu

Functional Interactions



Electrophysiology

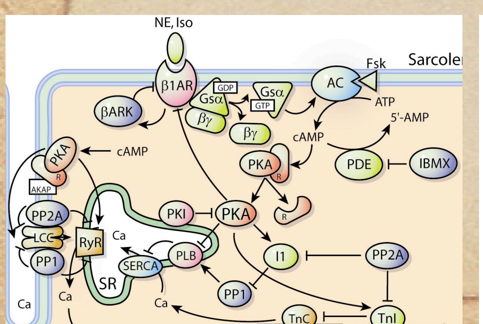


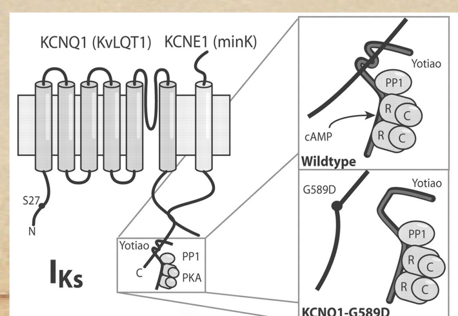
Neurohormonal Control

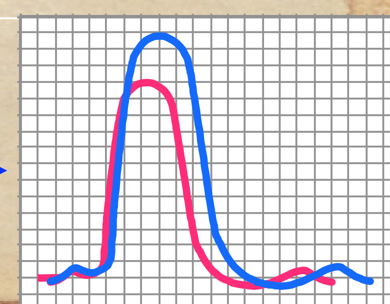
Genetic Mutations

Mechanics

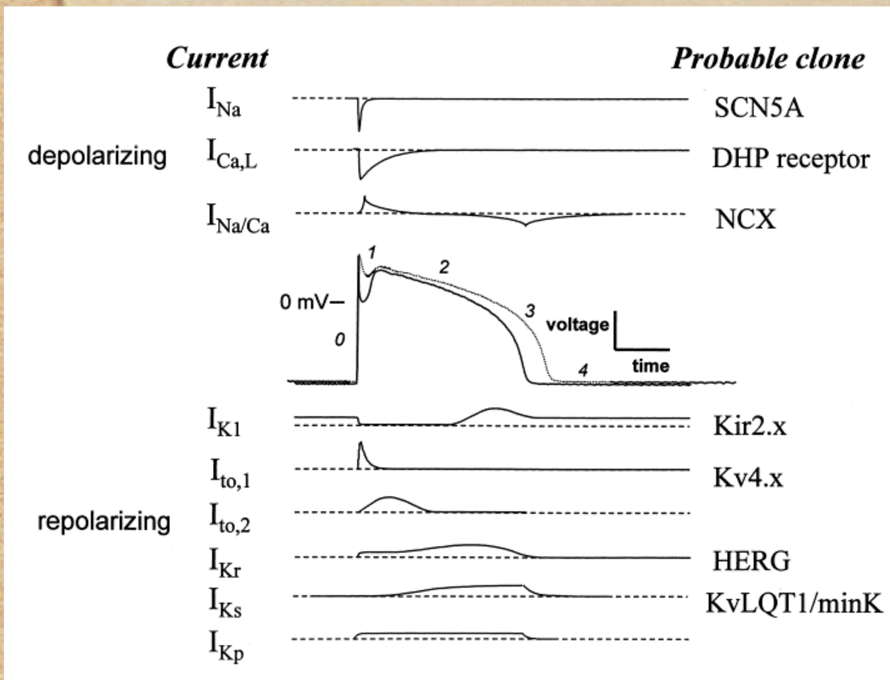
Ca²⁺ Handling

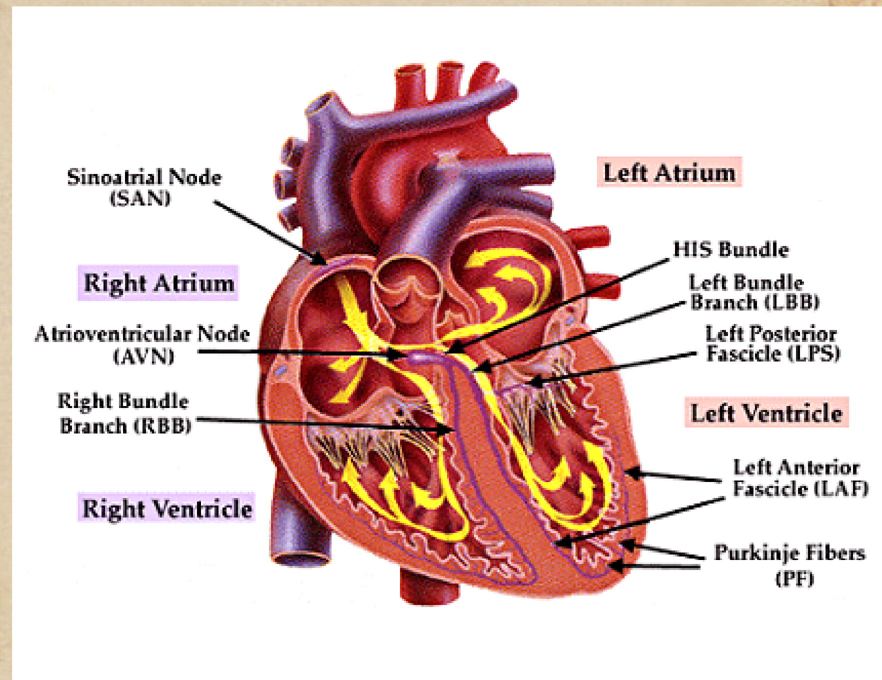






Cardiac Electrophysiology

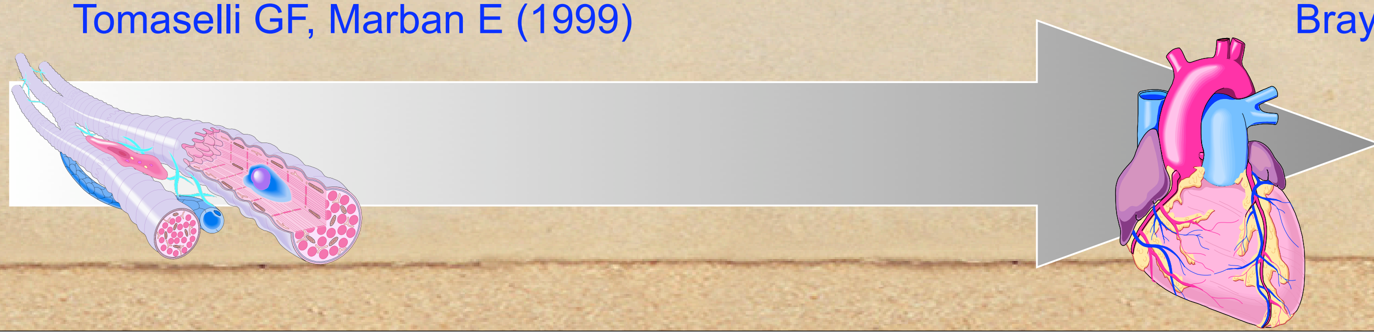




Tomaselli GF, Marban E (1999)

Bray (1994)

Cell



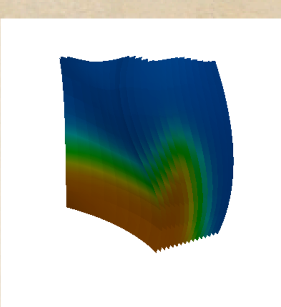
Organ

Some Results

- What we are going to see:
  - A preview from Thinkwell
  - See also: http://butler.cc.tut.fi/~malmivuo/bem/bembook/06/06.htm
- Normal
- Arrhythmia: When things go wrong

Modeling Cardiac Electrophysiology

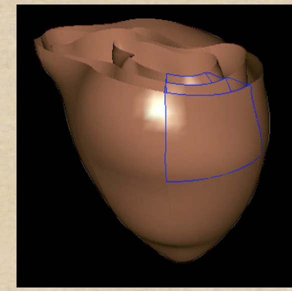
- Solution domain:
  - Wedge of tissue
  - Hopefully soon whole heart!



- Solution Method:
  - Collocation-Galerkin finite elements,
  - Crank-Nicholson time stepping
- Solver packages: RADAU (ODEs), SuperLU (PDEs)

Subcellular → Cellular → **Organ**

Operator Splitting Technique



Time Integration Loop – Crank Nicholson

t = 0

t = Δt/2

t = Δt

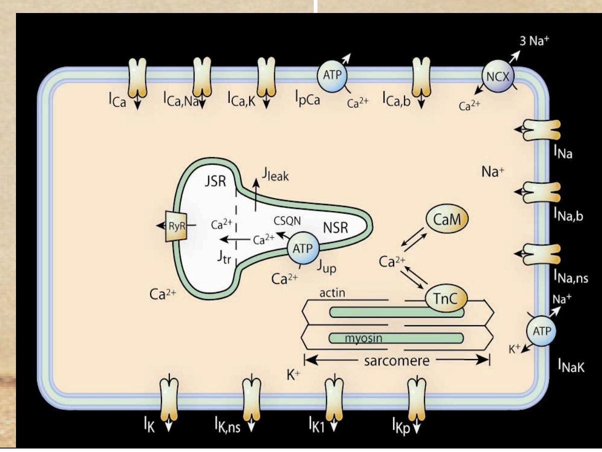
t = 3Δt/2

t = 2Δt

Reaction-diffusion equation (PDE)

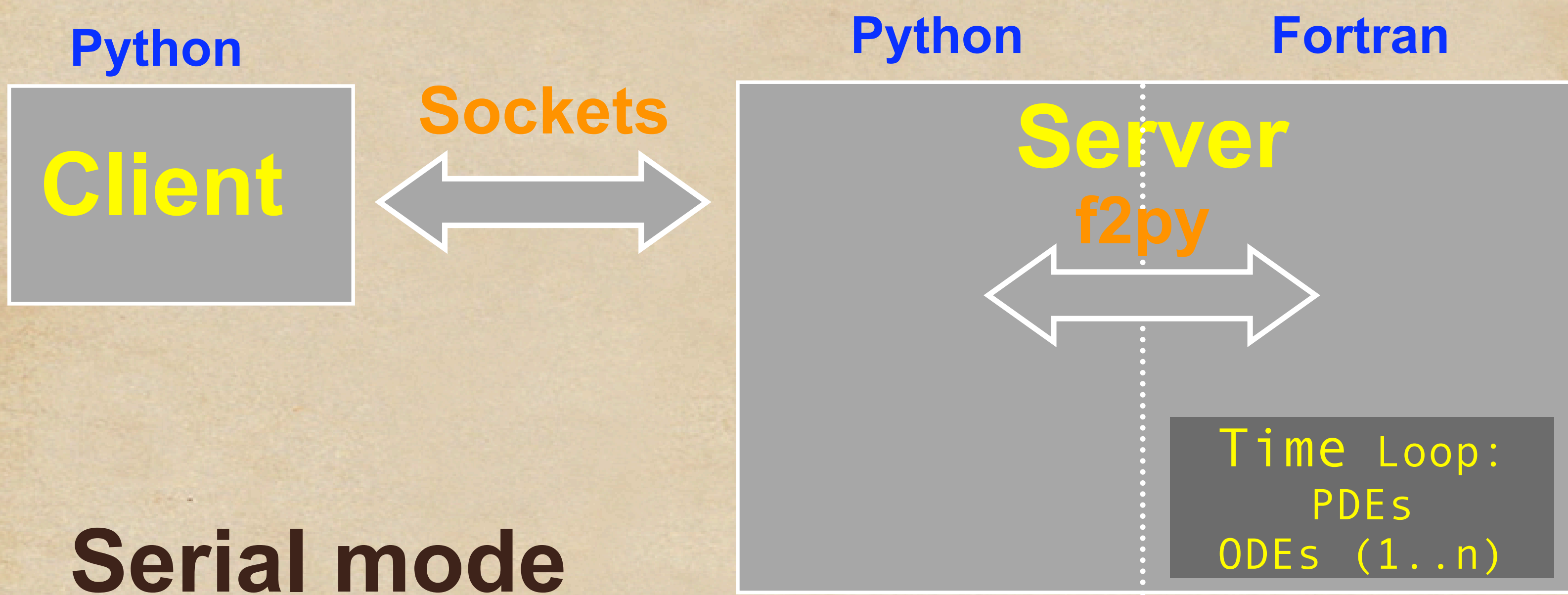
$$\frac{dV_m}{dt} = -\frac{1}{C_m} I_{ion} + \frac{1}{SC_m} \nabla \cdot \mathbf{D} \nabla V_m$$

Ionic model (ODEs)



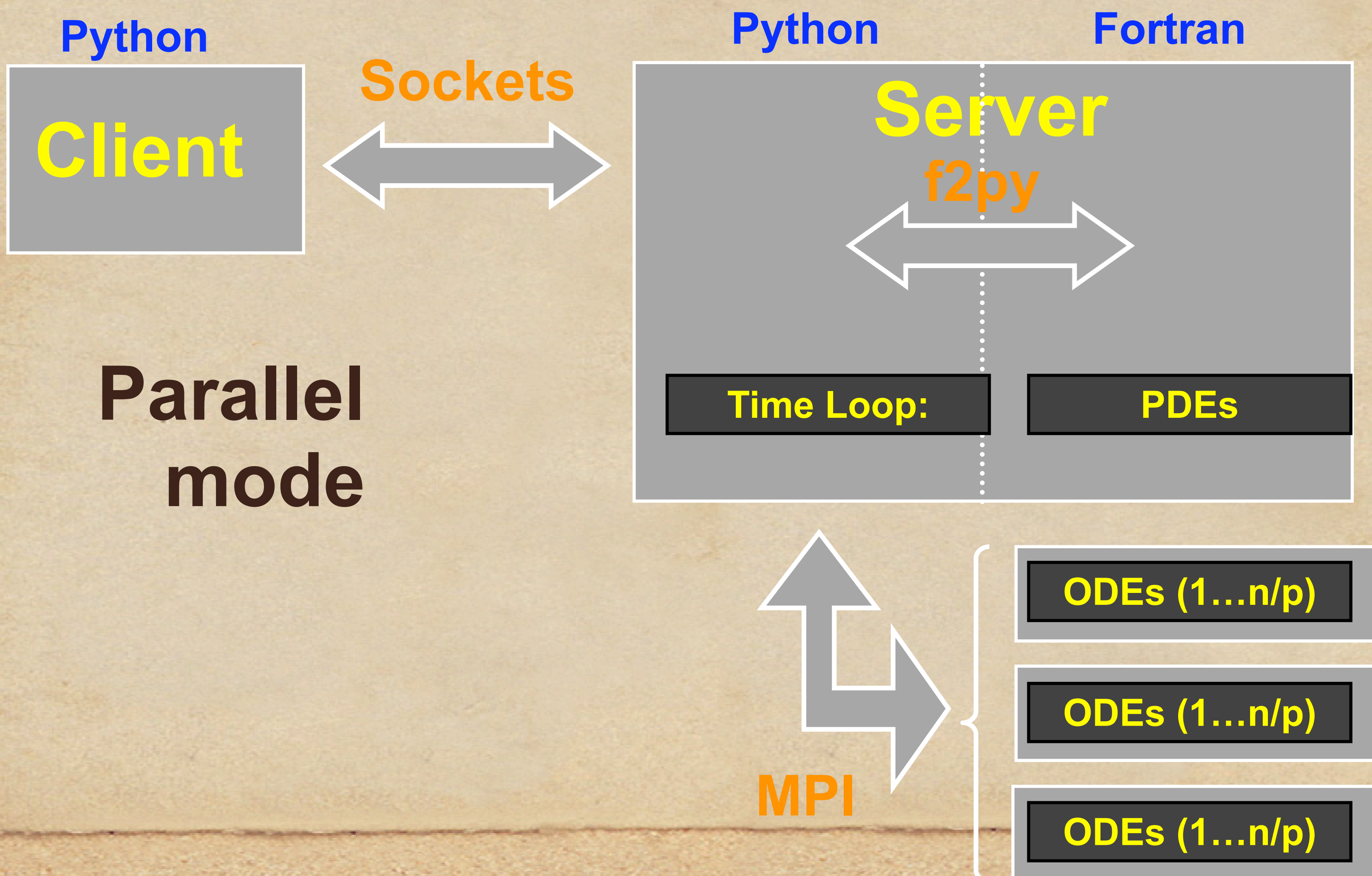
Qu Z, Garfinkel A (1999) *IEEE Trans Biomed Eng 46(9):1166-8*

The Old (Slow) Way

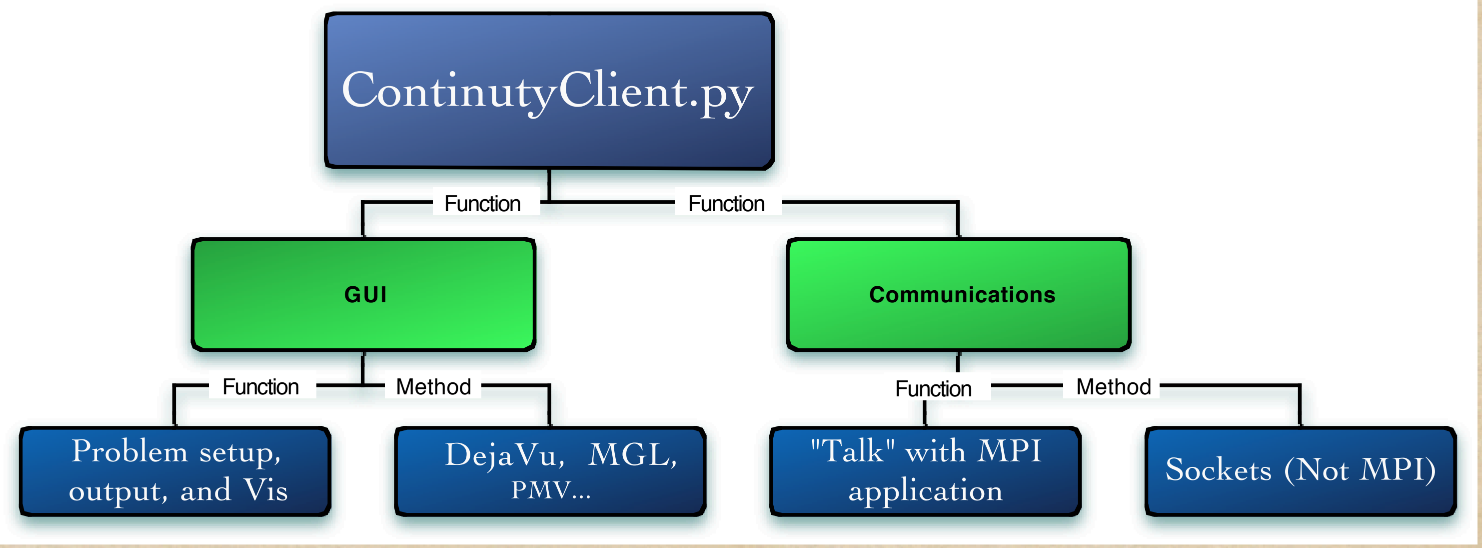


ODEs take 95-99% of
the execution time

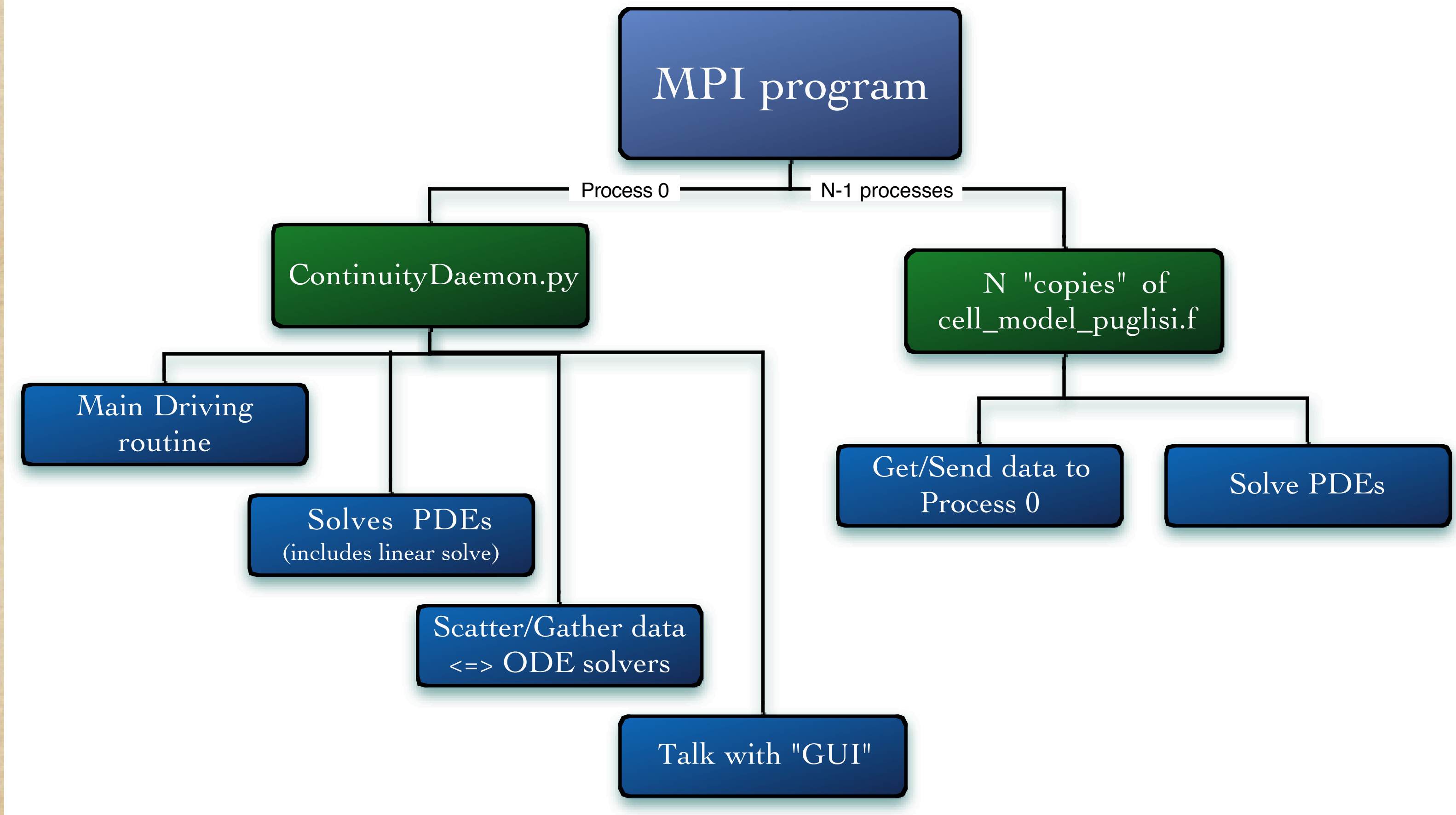
New Faster Way with Parallelization of ODEs



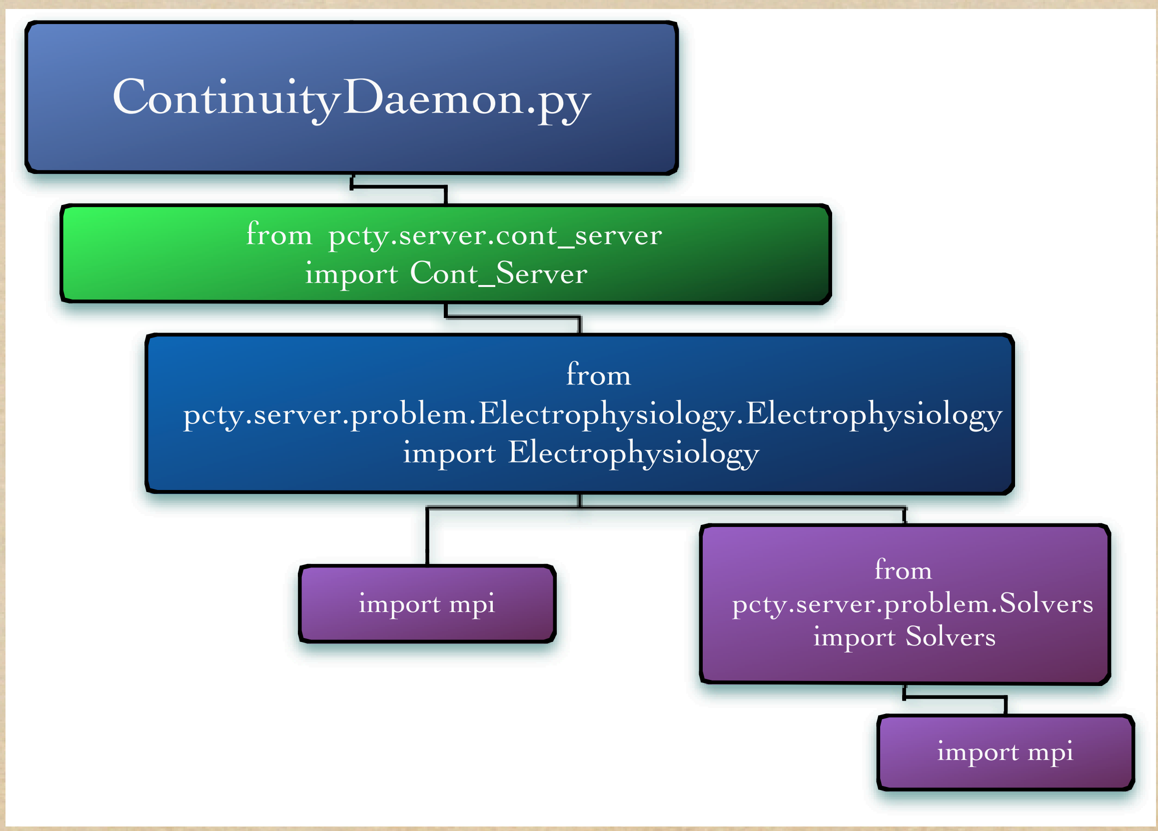
ContinuityClient



Continuity Server



Continuity Server (process 0)



Electrophysiology Setup routine

```
def _cgint_mpi_init (self):
  import mpi
  data = {}
  data['myid'] = mpi.mpi_comm_rank(mpi.MPI_COMM_WORLD)
  data['numprocs'] = mpi.mpi_comm_size(mpi.MPI_COMM_WORLD)
  # Data to broadcast: dt - timestep
  #                    stimon - stimulus time
  #                    stimlen - stimulus length
  data['icount'] = 1
  mpi.mpi_bcast(self.N_gauss_pts,data['icount'],mpi.MPI_INT,0,mpi.MPI_COMM_WORLD)
  data['dt'] = self.control.intprm_dtout
  mpi.mpi_bcast(data['dt'],data['icount'],mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)
  stimon = self.control.intprm_stimon
  mpi.mpi_bcast(stimon,data['icount'],mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)
  stimlen = self.control.intprm_stimlen
  mpi.mpi_bcast(stimlen,data['icount'],mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)

  # Gather local_gps to here.
  data['local_gps'] = zeros(data['numprocs'],"i")
  data['local_gps'] = mpi.mpi_gather(data['local_gps'][0],1,mpi.MPI_INT,1,mpi.MPI_INT,0,mpi.MPI_COMM_WORLD)
  # Data to scatter: iPar - k_rel
  #                  param_set_list - epi/M/endo
  #                  rPar - stim, trigger, t1_rel
  self.times = zeros(self.N_gauss_pts,'f')
  data['disps'] = zeros(data['numprocs'],"i")
  data['odesdisps'] = zeros(data['numprocs'],"i")
  data['newdisps'] = zeros(data['numprocs'],"i")
  data['odeslocal_gps']= zeros(data['numprocs'],"i")
  for i in range(1,len(data['local_gps'])):
    data['disps'][i] = data['disps'][i-1]+ data['local_gps'][i-1]
  result = mpi.mpi_scatterv(self.param_set_list.astype('i'),data['local_gps'],data['disps'],mpi.MPI_INT,0,mpi.MPI_INT,0,mpi.MPI_COMM_WORLD)
  result = mpi.mpi_scatterv(self.iPar.astype('i'),data['local_gps'],data['disps'],mpi.MPI_INT,0,mpi.MPI_INT,0,mpi.MPI_COMM_WORLD)
  mpi.mpi_bcast(self.num_fields,data['icount'],mpi.MPI_INT,0,mpi.MPI_COMM_WORLD)
  self.bcl = 1000.0  #SNH must fix to stim form data
  mpi.mpi_bcast(self.bcl,data['icount'],mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)
  result = mpi.mpi_scatterv(self.rPar,data['local_gps'],data['disps'],mpi.MPI_DOUBLE,0,mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)
  for i in range(data['numprocs']):
    data['newdisps'][i] = data['disps'][i] + self.N_gauss_pts
  result = mpi.mpi_scatterv(self.rPar,data['local_gps'],data['newdisps'],mpi.MPI_DOUBLE,0,mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)
  for j in range(self.num_fields):
    for i in range(data['numprocs']):
      data['newdisps'][i] = data['newdisps'][i] + self.N_gauss_pts
    result = mpi.mpi_scatterv(self.rPar,data['local_gps'],data['newdisps'],mpi.MPI_DOUBLE,0,mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)
  for i in range(data['numprocs']):
    data['odeslocal_gps'][i] = data['local_gps'][i] * self.Num_ODEs
    data['odesdisps'][i] = data['disps'][i] *  self.Num_ODEs

  return data
```

Electrophysiology
Time step loop

```
while (finished == 0):
  if (not fmod(round(t_now,2),1)):    # Print time every second
    print 'Tnow = ', t_now
# Part 1: Evaluate ODEs at collocation points via Fortran processes
  start = time()

  odeSolver(odedata, t_now)  #_cgint_mpi_odesolver

  if(t_now >= t_stop):
    finished = 1
  odeSolverFinish(finished, odedata)
  #ODE_time = ODE_time + t_odes


  self._cgint_pack_source(source)

  end = time()
  elapsed_time = end-start
  ODE_time = ODE_time + elapsed_time

# Part 2: Solution of PDEs through an Ax=b linear solve
  start = time()

  self.PDEs_now,elapsed_time = self.EP_module.p_cont2axb(self.global_equa,coefA,coefB,dt, \
                               source,self.PDEs_now,self.control.assemblers.int_assemble_callback,elapsed_time)

  end = time()
  elapsed_time = end - start
  PDE_time = PDE_time + elapsed_time

# Part 3: Evaluate PDE solution at gauss points to update ODEs for next step
  start = time()

  self._cgint_eval_soln()

  end = time()
  elapsed_time = end - start
  Eval_time = Eval_time + elapsed_time

  ren.rmout_callback(self.gbl_vars,self.ODEs_now,t_now, self.mesh.deriv_per_var,self.mesh.depen_var,self.mesh.global_nodes, \
                     self.Num_ODEs*self.mesh.gaus_per_elem*self.mesh.elements)
  t_now = t_now + dt

# end while loop
print 'Total Integration Time = ', ODE_time+ PDE_time +Eval_time
print 'ODE Time = ', ODE_time
print 'PDE_Time = ', PDE_time
print 'Evaluation Time', Eval_time

if (parallel):
  self._cgint_mpi_finalize(odedata)
```

Electrophysiology Other MPI routines called from main loop

```
def _cgint_mpi_odesolver(self, data, t_now):
  # Scatter current ODE solution
  import mpi
  result = mpi.mpi_scatterv(self.ODEs_now,data['odeslocal_gps'],data['odesdisps'],mpi.MPI_DOUBLE,0,mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)
  # Gather ODE solution and dvdt once fortran processes are done.
  self.ODEs_now = mpi.mpi_gatherv(result,0,mpi.MPI_DOUBLE,data['odeslocal_gps'],data['odesdisps'],mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)
  self.DVoltDt = mpi.mpi_gatherv(result,0,mpi.MPI_DOUBLE,data['local_gps'],data['disps'],mpi.MPI_DOUBLE,0,mpi.MPI_COMM_WORLD)

def _cgint_mpi_odesolver_finish(self, finished, data):
  import mpi
  mpi.mpi_bcast(finished,data['icount'],mpi.MPI_INT,0,mpi.MPI_COMM_WORLD)
```

cell_model_puglisi.f

Set up

```
 call mpi_bcast(num_gps,icount,MPI_INTEGER,0,MPI_COMM_WORLD,ierr)
 call mpi_bcast(dt,icount,MPI_DOUBLE_PRECISION,0,MPI_COMM_WORLD,ierr)
 call mpi_bcast(stimon,icount,MPI_DOUBLE_PRECISION,0,MPI_COMM_WORLD,ierr)
 call mpi_bcast(stimlen,icount,MPI_DOUBLE_PRECISION,0,MPI_COMM_WORLD,ierr)
! Calculate how many gauss pts this process is getting
! Assume only  1 python process.
 fprocs = numprocs - 1
 fid = myid - 1
 local_num_gps = num_gps/fprocs
 rem = num_gps - (num_gps/fprocs)*fprocs
 if (fid < rem) then
  local_num_gps = local_num_gps + 1
 endif
! Gather local_num_gps to Python process for scattering
 write(*,*) 'Proc = ', myid, ' sent ', local_num_gps !Crashes here???
 call mpi_gather(local_num_gps,1,MPI_INTEGER,local_gps,numprocs,MPI_INTEGER,0,MPI_COMM_WORLD)
! Now receive scattered data relevant to local gauss points:
! param_set_list, rPar,iPar
 allocate(param_set_list(local_num_gps),iPar(local_num_gps))
 call mpi_scatterv(param_set_list,num_gps,num_gps,MPI_INTEGER,
&  param_set_list,local_num_gps,MPI_INTEGER,0,MPI_COMM_WORLD,ierr)
 call mpi_scatterv(iPar,num_gps,num_gps,MPI_INTEGER,iPar,
&    local_num_gps,MPI_INTEGER,0,MPI_COMM_WORLD,ierr)
 call mpi_bcast(num_fields,icount,MPI_INTEGER,0,MPI_COMM_WORLD,ierr)
 call mpi_bcast(bcl,icount,MPI_DOUBLE_PRECISION,0,MPI_COMM_WORLD,ierr)
 allocate(rPar((2+num_fields)*local_num_gps))
 call mpi_scatterv(rPar,num_gps,num_gps,MPI_DOUBLE_PRECISION,
& rPar(1),local_num_gps,MPI_DOUBLE_PRECISION,0,MPI_COMM_WORLD,ierr)
 call mpi_scatterv(rPar,num_gps,num_gps,MPI_DOUBLE_PRECISION,
& rPar(local_num_gps + 1),local_num_gps,MPI_DOUBLE_PRECISION,
& 0,MPI_COMM_WORLD,ierr)
 do j = 1,num_fields
  call mpi_scatterv(rPar,num_gps,num_gps,MPI_DOUBLE_PRECISION,
& rPar((j+1)*local_num_gps+1),local_num_gps,MPI_DOUBLE_PRECISION,
& 0,MPI_COMM_WORLD,ierr)
 enddo
```

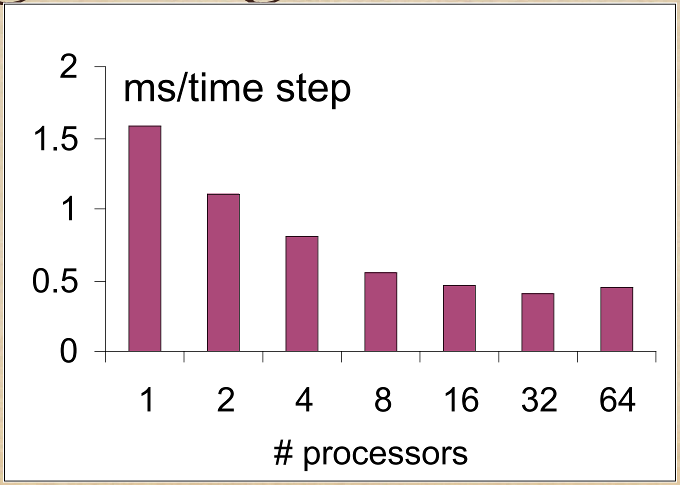
cell_model_puglisi.f

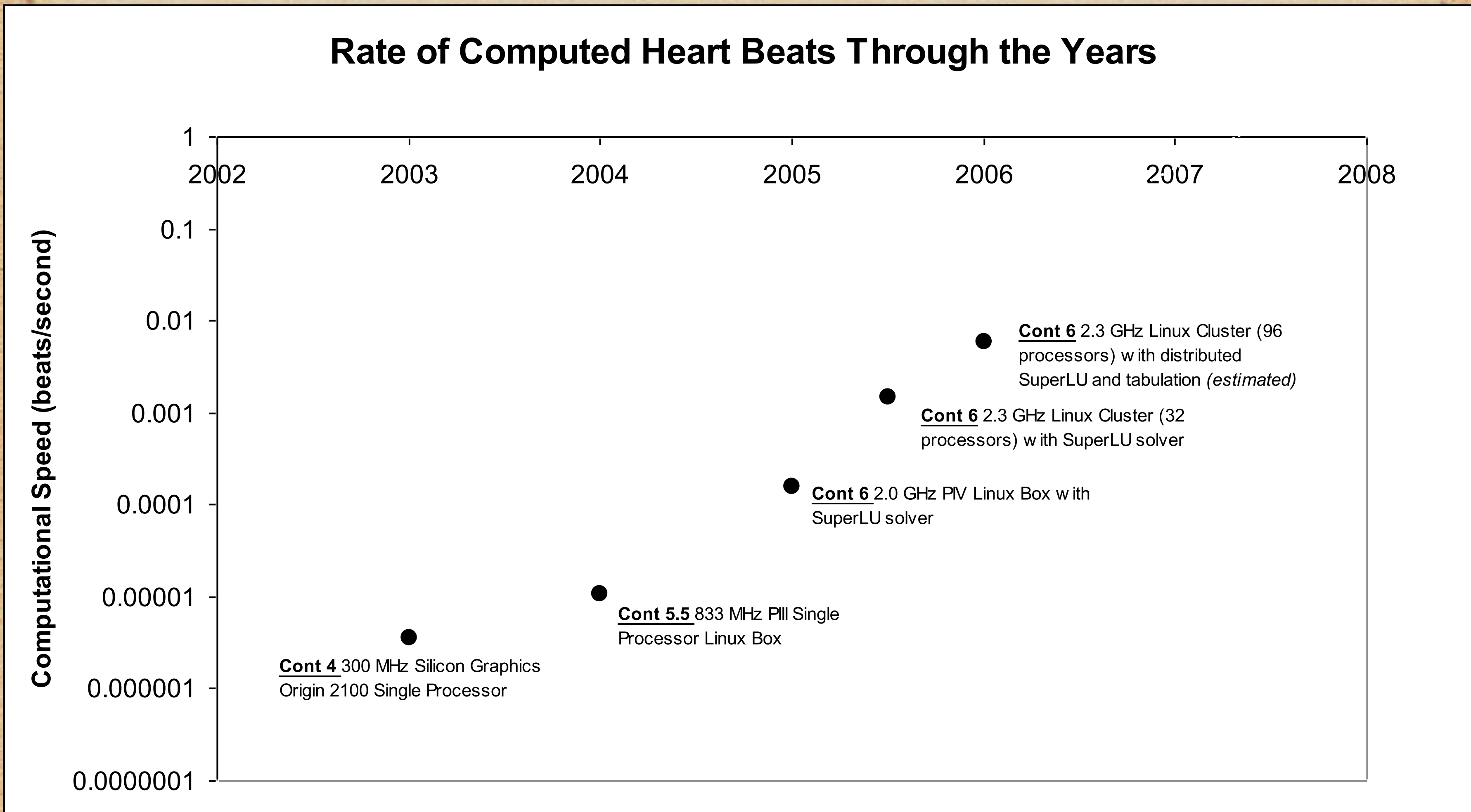
Time step loop

```
do while(finished .eq. 0)
  ! Recv local ode data from python via scatterv
  call mpi_scatterv(local_odes_now,num_gps,num_gps,
 &     MPI_DOUBLE_PRECISION, local_odes_now,local_num_gps*num_odes,
 &     MPI_DOUBLE_PRECISION,0,MPI_COMM_WORLD,ierr)
  ! Solve cell model
  !t1 = etime(ta)
  !write(*,*) 'odes = ', local_ODEs_now(1)
  !write(*,*) 'before cm2odesolver'
  !write(*,*) 'before after= ', local_ODEs_now(1)
  call cm2odesolver(local_ODEs_now,t_now,t_end,local_num_gps,
 & param_set_list,rPar,iPar,local_dvdt,stimon,stimlen,num_fields,
 & bcl,dads,eads,times)
  ! Send current ode and dvdt data back to python via gatherv
  !write(*,*) 'odes after= ', local_ODEs_now(1)
  call mpi_gatherv(local_odes_now,local_num_gps*num_odes,
 &     MPI_DOUBLE_PRECISION,local_odes_now,numprocs,numprocs,
 &     MPI_DOUBLE_PRECISION,0,MPI_COMM_WORLD,ierr)
  call mpi_gatherv(local_dvdt,local_num_gps,
 &      MPI_DOUBLE_PRECISION,local_dvdt,numprocs,numprocs,
 &     MPI_DOUBLE_PRECISION,0,MPI_COMM_WORLD,ierr)
  call mpi_bcast(finished,icount,MPI_INTEGER,0,MPI_COMM_WORLD,
 &   ierr)
  !write(*,*) 'after bcast'
  !t2 = etime(ta)
  !todes = t2-t1
  !write(*,*) 'after reduce'
  t_now = t_end
  t_end = t_end + dt
enddo
```

Parallel Performance

- Communication Limited
- Ethernet not myrinet
- MYMPI is slower than normal MPI but allows a heterogeneous programming environment




Rate of Computed Heart Beats Through the Years
Computational Speed (beats/second)
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
2002
2003
2004
2005
2006
2007
2008
Cont 6 2.3 GHz Linux Cluster (96 processors) w ith distributed SuperLU and tabulation (estimated)
Cont 6 2.3 GHz Linux Cluster (32 processors) w ith SuperLU solver
Cont 6 2.0 GHz PIV Linux Box w ith SuperLU solver
Cont 5.5 833 MHz PIII Single Processor Linux Box
Cont 4 300 MHz Silicon Graphics Origin 2100 Single Processor

Future Work

- Extension to whole heart anatomical model -- parallelization of the PDEs
- Parallel SuperLU
- Electro-mechanical model

Montage Mosaicking

Leesa Brieger

International Virtual Observatory Alliance

Aus-VO

AVO
ASTROPHYSICAL VIRTUAL OBSERVATORY

China-VO

Astro Grid

vo-i

RVO

CVO

NVO
NATIONAL VIRTUAL OBSERVATORY

IVOA

SVO
Spanish Virtual Observatory

DRACO

JVO
JAPANESE VIRTUAL OBSERVATORY

France

HVO
Hungarian Virtual Observatory

GERMAN ASTROPHYSICAL
GAVO
VIRTUAL OBSERVATORY

URL's

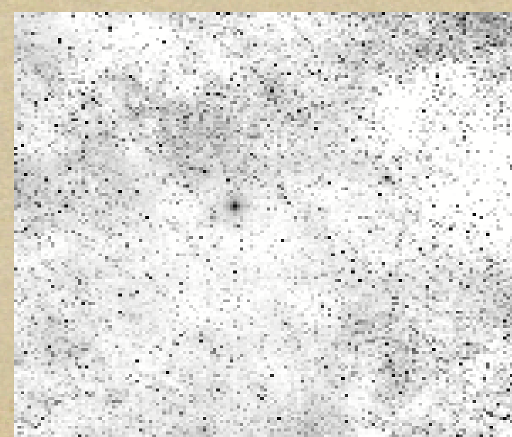
- Montage:
  - http://montage.ipac.caltech.edu/
- Montage gallery:
  - http://montage.ipac.caltech.edu/gallery.html
- NVO:
  - http://www.us-vo.org/
- IVOA:
  - http://www.ivoa.net/

Montage Mosaicking

2MASS mosaic near galactic center

Without background corrections:

With background corrections:



Montage/NVO

- Build an atlas of surveys
  - standardization
  - comparison and composition of information

- Provide on-demand services
  - science-grade images (cut-outs)
  - user-requested mosaics
  - large-scale mosaicking services

Montage: Caltech/SDSC Collaboration

- Mosaic the entire 2MASS archive
- Reformat the archive
- Create 2MASS addition to the Hyperatlas that is being constructed
- 1734 plates (pages) in the atlas, 3 bands in 2MASS: 5202 6-deg mosaics to produce

Montage: Caltech/SDSC Collaboration

- Create the infrastructure to do large-scale mosaics
- data management –

  Storage Resource Broker (SRB)
- workflow management -

  MYMPI
- computations take place on TeraGrid Itanium2 and IBM Power4 systems

Montage Data

- Atlas mosaics are 6-degree squares
- Input for one mosaic: 1300-4000 raw input files, each of 2MB
- Output for one mosaic: a single 4GB FITS file or subdivided tiles of that, eg. 144 tiles each of 27 MB
- Input archive: around 8 TB,
- Output archive: around 7 TB

Montage Data Flow

- Input data (2MASS archive) stored locally in a parallel, high-performance filesystem (gpfs)
- 2MASS archive replicated locally in SRB and at Caltech on spinning disk, served up from the IRSA server
- Output data archived locally in SRB, accessible from everywhere there is an SRB client

Montage Workflow

- Stand-alone executables compose a mosaic
- Independent steps on input data – currently task-oriented, could be data-oriented
- some serial steps, some parallel (MPI) steps
- Python MPI, Perl, shell scripts

Montage Workflow

Organize many mosaics into a single multi-CPU, MPI job:

- the serial steps done for all mosaics simultaneously, one on each CPU
- the parallel steps done for one mosaic at a time, using all the CPUs of the job

Python Workflow Script

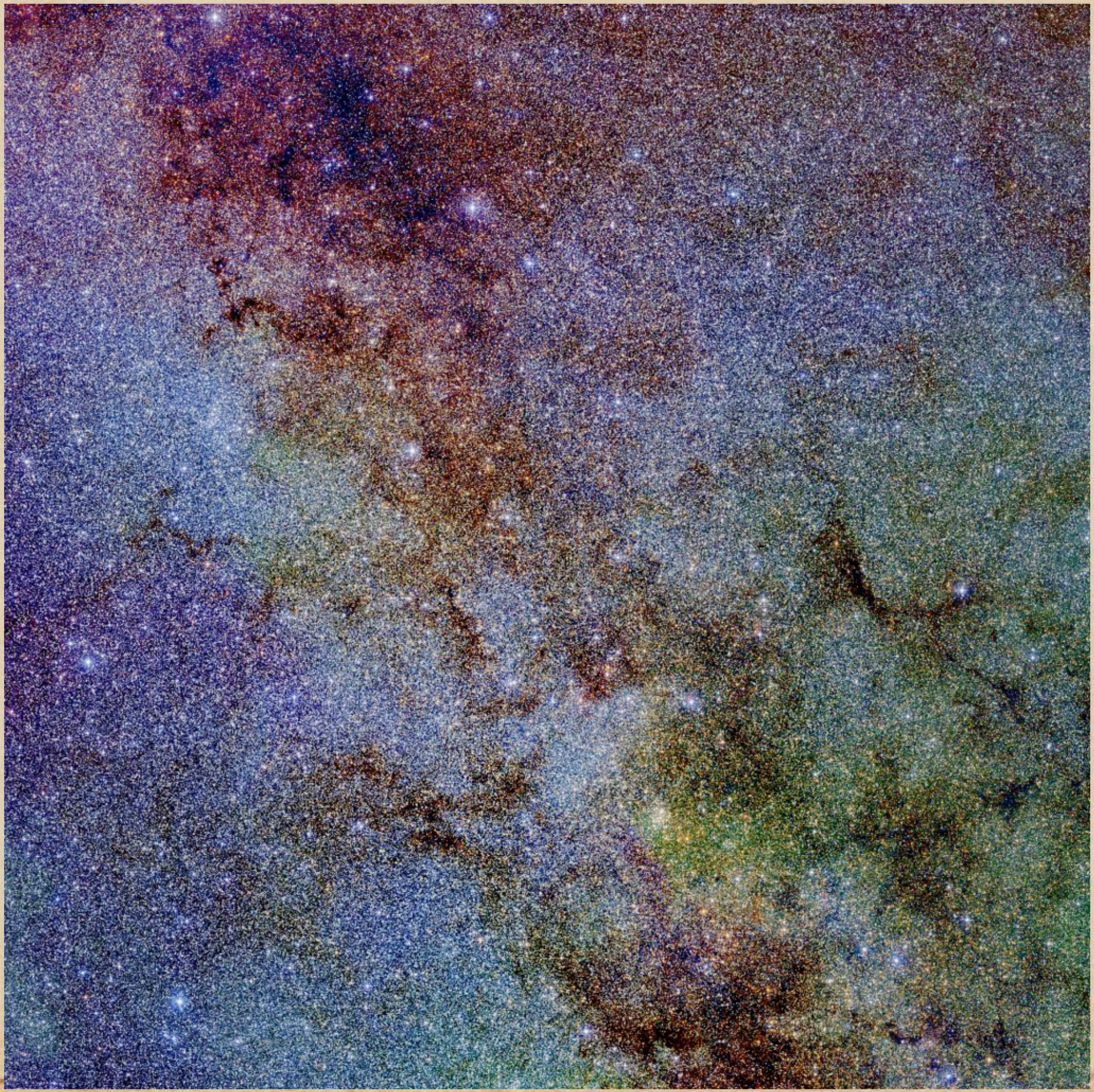
```
#!/usr/local/apps/python/Python2.4.1/bin/python
# Script to run the galactic plane example.
import os
import sys
import string
import subprocess
import Numeric
from Numeric import *
import mpi
import posix
bandlist = ['h','j','k']
cmd=""
for arg in sys.argv:
   cmd=cmd+ arg+" "
print "python command line arguments: " ,cmd
myid_numprocs =  mpi.mpi_start(len(sys.argv),cmd)
myid=mpi.mpi_comm_rank(mpi.MPI_COMM_WORLD)
numprocs=mpi.mpi_comm_size(mpi.MPI_COMM_WORLD)
```

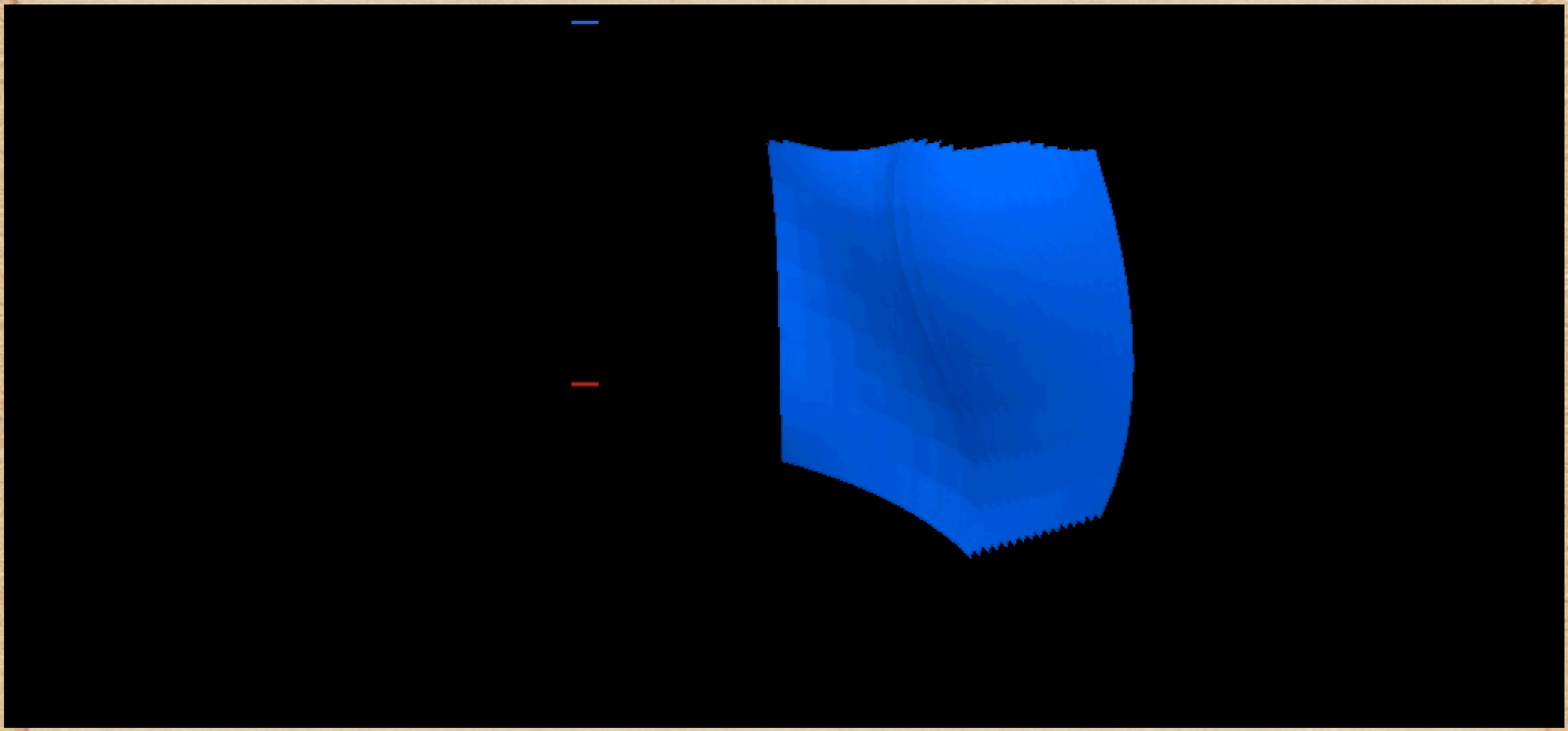
```
# List of plates for the production run
platefile = open('production-pages', 'r')
plates = platefile.readlines()
numplates = len(plates)
platefile.close()

parent_dir = os.getcwd()
#print "top dir: ", parent_dir

myindex = myid

while myindex<numplates:
 myplates = plates[myindex].split()
 myplate = myplates[0]
 plate_dir = "plate."+myplate

 try:
  os.mkdir(plate_dir)
 except OSError:
  pass
```

```
for band in bandlist:

  os.chdir(parent_dir)
  os.chdir(plate_dir)
  try:
   os.mkdir(band+"-tiles")
  except OSError:
   pass
  os.chdir(band+"-tiles")

# Image table for raw data
  res = os.system('mImgtbl -r raw images.tbl')
  if not (res == 0):
   print "Error: Problem with images.tbl for plate "+myplate+", band "+band+"\n"
  else:
   print "OK: images.tbl for plate "+myplate+", band "+band+" \n“

# Make header
  res = os.system('mMakePlateHdr images.tbl plate.hdr')
  if not (res == 0):
   print "Error: Problem with mMakePlateHdr for plate "+myplate+", band "+band+"\n
  else:
   print "OK: mMakePlateHdr for plate "+myplate+", band "+band+"\n"
```

```
# Synchronize before the parallel step
   mpi.mpi_barrier(mpi.MPI_COMM_WORLD)
# Parallel Projections - one at a time
   for i in range(0,numprocs):
     if( myid == i):
       print "Starting projections for plate", myplate," band ",band
       res = os.system("time mpirun -machinefile prod_pbs_nodefile -np "+str
       (numprocs)+"  /usr/local/apps/Montage_v3.0_beta23/bin/mProjPara -p raw -f
       images.tbl plate.hdr projdir stats.tbl")
       if  not (res == 0):
         print "Error: Problem with projections for plate "+myplate+"\n"
       else:
         print "OK: Projections done for plate ", myplate," band ",band
# Synchronize processes as they go through this loop
      mpi.mpi_barrier(mpi.MPI_COMM_WORLD)

# Image table for reprojected data
   res = os.system('mImgtbl -r projdir proj.tbl')
   . . .
# errorfile.close()
mpi.mpi_finalize()
```

Montage: 3 infrared bands => a color image





Back

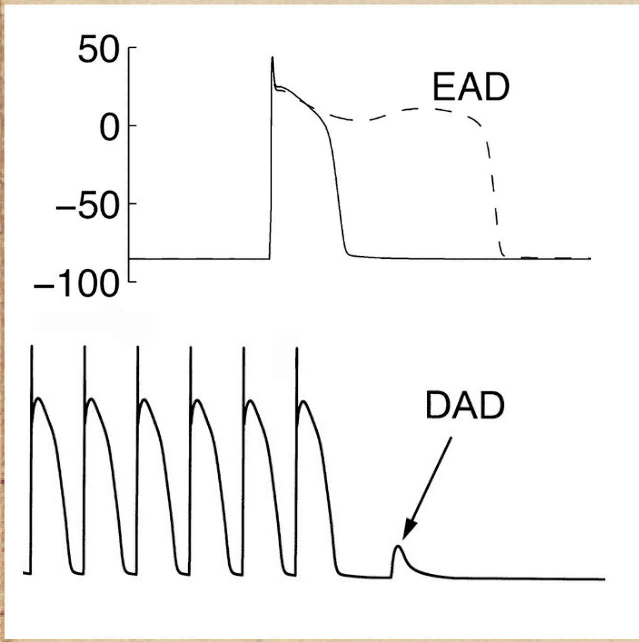
Back

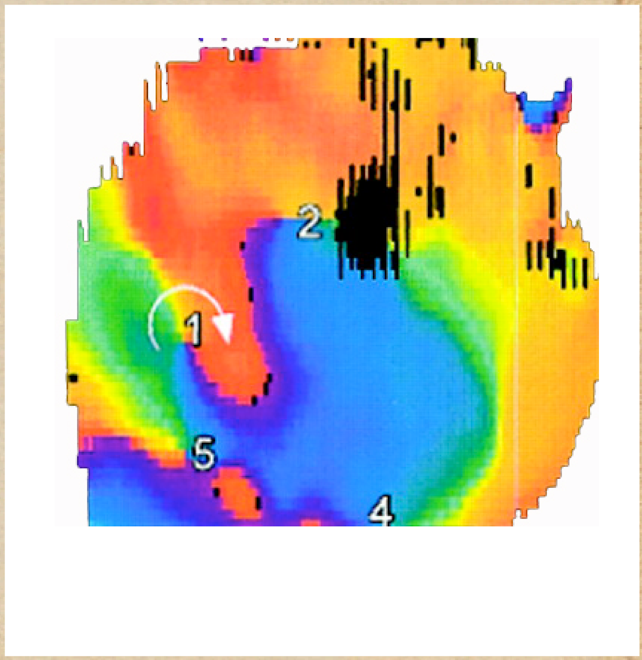
Ventricular Arrhythmia

Triggered Activity

Reentry

↑ Dispersion of repolarization





Saucerman (2004)
Beuckelmann (1998)

Jalife (2000)