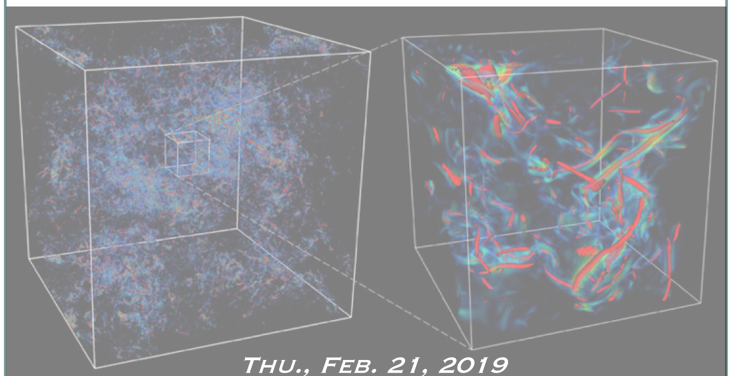
Atms 502, CSE 566

Numerical Fluid Dynamics



Isotropic turbulence, Donzis and Yeung, www.tacc.utexas.edu/scivis-gallery/isotropic-turbulence

ATMS 502
CSE 566

Thursday,
21 February 2019

Class #12

- I owe you grades!
- Pgm3 due Mar. 1
- Programming review?

Plan for Today

- 1) NESTING
  - Terms; Flow of information; BCs
  - Koch/McQueen paper: Survey of methods
- 2) PHASE / GROUP VELOCITY
  - Example – Leapfrog *dispersion party*
- 3) SHELL SCRIPTING
  - Shells, background, use; example
- 4) PROGRAM 3
  - Deformational flow; Staniforth paper
- 5) METHODS WORKSHOP
  - Introduction to Straka paper

Grid nesting

OVERVIEW, CONTINUED

Reference pages for this section:

- C009 – Resolution
- C010 – AMR / nesting
- C050 – Nesting: boundary conditions
- C051 – Nesting: grid placement, movement

Nesting: Flow of information

- Nesting means ...
  - Running at least *two* domains, one wholly contained in other
  - The outer / coarse grid is sometimes called the *parent* domain
  - The inner grid is called the *nested grid* or *child* domain
- Information flow
  - The *parent* domain provides
    - The *initial conditions* for the nest when first placed;
    - The *boundary conditions* to nest as the integration continues.
  - The nested grid provides *feedback* to the parent domain, in the region of overlap between the two grids.
- Terminology
  - The *refinement ratio* is factor by which **dx** (and perhaps dt) are decreased for the nested grid, relative to the outer grid.

Nested grid BCs

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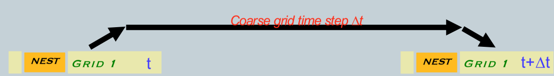
- <u>Nested grid</u>:
  - Shown below: grid-1 time step, *q1 to q2*



Parent grid: uses a single "large" Δt.

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Nested grid BCs

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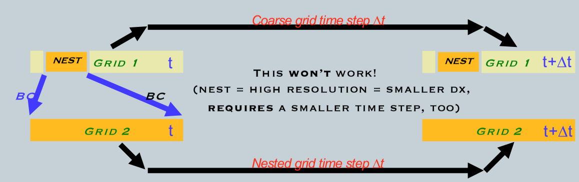
- <u>Nested grid</u>:
  - Shown below: grid-1 time step, *q1 to q2*
  - Added: nested grid step, refinement factor → 1



Nested grid: "refinement" of "1" = same as coarse grid.

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Nested grid BCs

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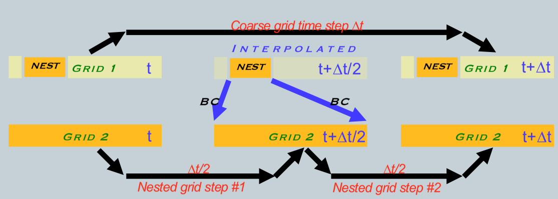
- <u>Nested grid</u>:
  - Shown below: grid-1 time step, q1 to q2
  - Added: nested grid step, refinement factor → 2



Nested grid steps: requires time-dependent BC from grid 1

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Survey of nested grid techniques

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KOCH AND MCQUEEN (1987)

Reference pages for this section:

- C009 – Resolution
- C010 – AMR / nesting
- C050 – Nesting: boundary conditions
- C051 – Nesting: grid placement, movement

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Nested grid techniques

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Notes from the paper.

- Introduction:
  - *Gradual* nest reduction: smoother near boundary
  - One way nesting
    - Waves can enter fine mesh grid (FMG)
    - FMG waves cannot affect coarse mesh grid (CMG)
  - 1-way nesting: *inherent assumption is that large scale motions determine small-scale motions without significant feedback*

1- vs. 2-way nesting: errors

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- Causes of errors from nesting:
  1. Different mesh sizes act like different *propagation media*
     - *Differences in phase velocity generate false waves @ grid boundary*
     - *False waves reflected back into fine mesh grid*
  2. Aliasing of waves due to resolution change
     - *Waves resolvable on FMG but not CMG: aliased*
     - *Results in loss of amplitude entering CMG*

Optimum grid nesting?

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Zhang et al. (1986) suggested:

1. All *resolvable* waves must cross boundary w/o generating noise
   - Requires noise control
   - "Sponge" boundary
     - "Tendency bleeding"
   - Explicit smoothing
     - not *too* strong
2. Conserve the following, exchanged between the grids:
   - Mass
   - Momentum
   - Total energy
     - Suggests this requires *interpolation formula* be reversible as an *averaging formula*

Phase vs. Group velocity

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Phase vs. group velocity

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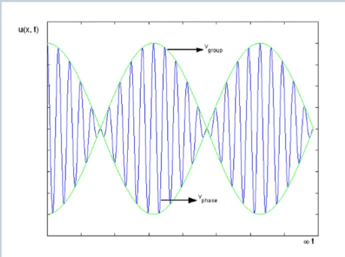
- Nice discussion of concepts can be found at this link at [George Mason University]



Try [this app]*!

*http://galileoandeinstein.physics.virginia.edu/more_stuff/Applets/wavepacket/wavepacket.html

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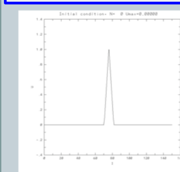
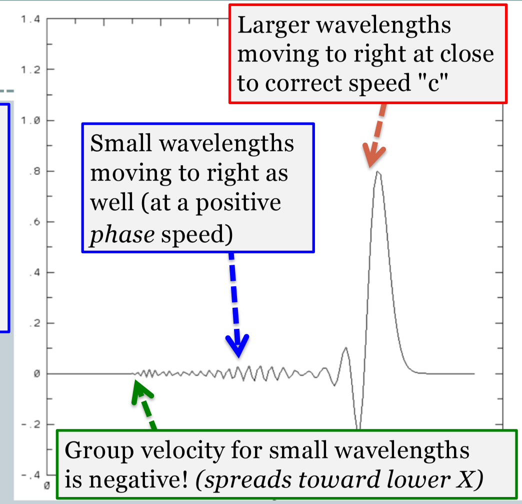
Phase vs. group velocity

Leapfrog method applied to 1-way wave equation with cone IC *(initial condition)*
- it isn't pretty
- but it **is** 2nd-order accurate in x, t !!
- large phase errors





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Shell scripting

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THE BASICS

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Shells & scripting

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- Shell
  - A Linux *shell* is a command interpreter.
    - when you type "cd" it is handled directly by the shell
  - Popular shells:
    - tcsh or csh – "C-shell" – has syntax like C programming language
    - bash – more popular, in some ways more robust language
    - sh (Bourne) shell – older default shell for many centers
    - many High Performance Computing (HPC) centers use *tcsh* as the default. TACC prefers *bash*. Macintoshes use *bash* as default.
    - Windows 10 has an Ubuntu-based bash shell.
  - You can change your (default, login) shell.
    - Login to TACC user portal and ask consulting to change your shell. *portal.tacc.utexas.edu*

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Making a shell script

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- Shell scripting
  - Any shell can be *scripted* – that is, run a shell script (program).
  - A shell script is a plain text file.
  - You *do* have to tell the Linux operating system (OS) that a file contains *executable* commands, using *change mode (chmod)*

```
chmod   u+x   script-file-name
```

  - this adds *execute (x)* permission to the *user (u)* - you.
  - Now you can run the script, by typing the file name (if you have bash, you may need "./" before the file name)

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Linux: variables vs. *environment* variables

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- To **set** a local variable:
  - tcsh:
    - **set** variable_name = value_of_variable *"set" is required!*
  - bash:
    - variable_name = value_of_variable
- **Using** a variable value: "$"
  - tcsh *or* bash: $variable_name ... gives the value of it.
- Environment variables
  - maintained by the system. "Seen" by programs you run.
  - "setenv" (tcsh) or "export" (bash) sets those variables for use outside of use by just your local script or login shell.

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Shell scripting: **tcsh** example

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```
#!/bin/csh                                      tells Linux which shell to use
# This is a comment.  At least put your name here!
foreach  ratio  ( values separated by spaces )  foreach … end is the loop
   pgm4 > output << EOF                         runs pgm4, results to "output"
         ... input stuff ...                      … all of this
         $ratio                                   … is taken as input
         ... more input stuff ...                 … to my program4.
EOF                                             this word canNot be indented!
   grep Error output
   mv gmeta plot$ratio.meta                     An example of renaming the
   mv output output$ratio.txt                   output files based on your
end                                             loop variable.
```

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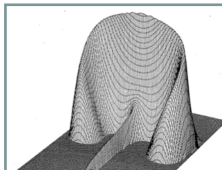

Program 3

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CONE PROBLEM
DEFORMATIONAL FLOW

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Examples of 2D flow

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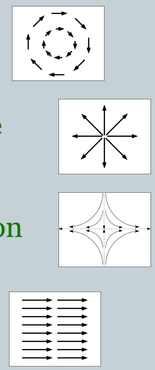
- Rotation
- Divergence
- Deformation
- Constant



- Creates sharp gradients:
  - Convergence
  - Deformation
  - Rotation acting on gradient
- Our deformation case is an excellent test for evaluating handling of sharp gradients by a numerical scheme.

Deformation test

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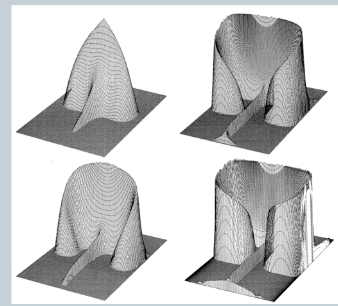
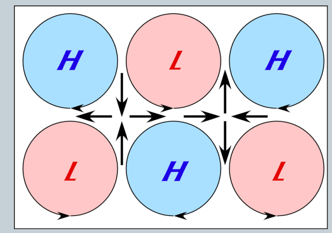


Staniforth et al. 1987



After Bluestein Vol. 1, p. 109

Deformation test

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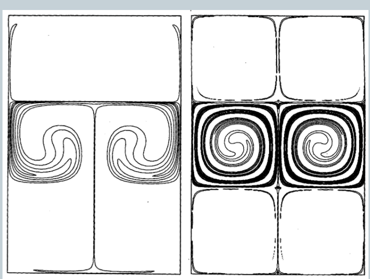

Fig. 4. Isolines of the distribution at (a) $t = T/50$ and (b) $t = T/10$. Sampling interval: $\Delta x = \frac{1}{50}$. Same contours as Fig. 1.

Staniforth et al. 1987

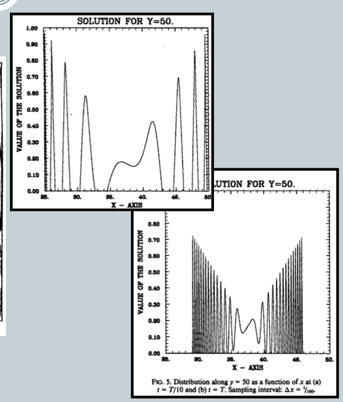

Fig. 5. Distribution along $y = 50$ as a function of x at (a) $t = T/10$ and (b) $t = T$. Sampling interval: $\Delta x = \frac{1}{100}$.

Staniforth et al. 1987

Program 3: U field

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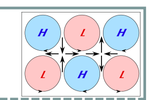
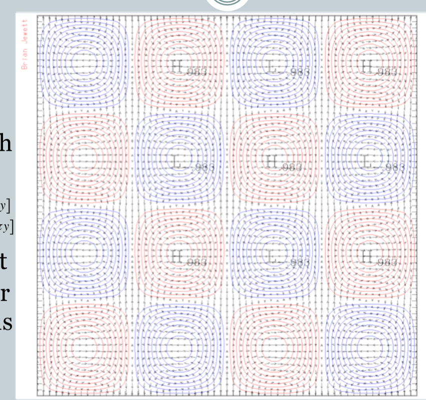


Program 3

Flow field plotted with *ezvec*.

$u(x,y) = \sin[4\pi x]\sin[4\pi y]$
$v(x,y) = \cos[4\pi x]\cos[4\pi y]$

Every point has a vector plotted; this is 61x61.



Contours of **U** are added with positive in red, < 0 shown blue.

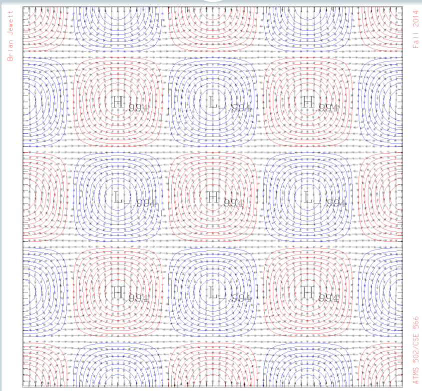
Program 3: V field

Program 3

Flow field plotted with *ezvec*.

$u(x,y) = \sin[4\pi x]\sin[4\pi y]$
$v(x,y) = \cos[4\pi x]\cos[4\pi y]$

Every point has a vector plotted; this is 61x61.



Contours of **V** are shown with positive in red, < 0 shown blue.

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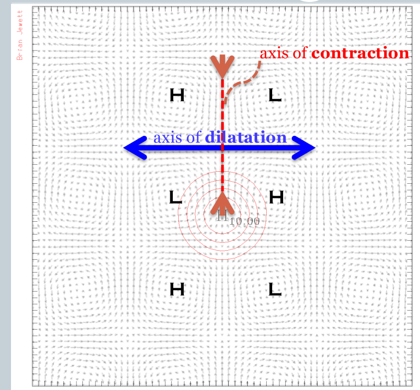
Program 3: Initial *q*



Contours of **q** are shown for T=0, the initial condition.

The center is just below the V max.

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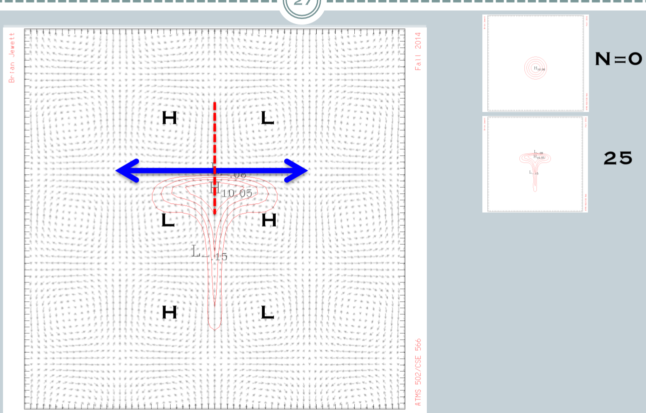
Program 3: N = 25



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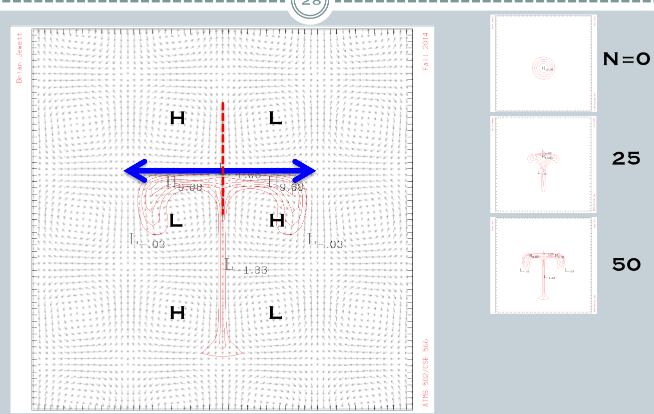
Program 3: N = 50



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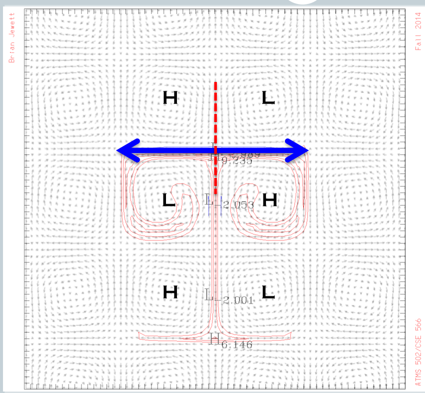
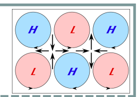
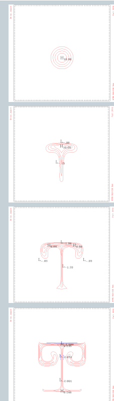
Program 3: N = 100







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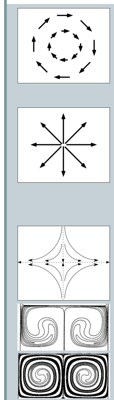
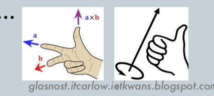
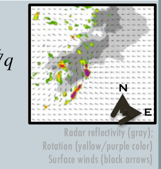
Generating sharp gradients

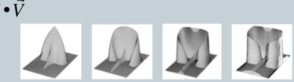


- Rotation (vorticity)
  - sharp gradients if acts on a gradient $\vec{\nabla}q$
  - *vertical* vorticity is $\hat{k}\bullet\vec{\nabla}\times\vec{V}$
  - right hand rule …





- Divergence
  - figure at above left. *con*vergence shrinks area
  - computed as $\vec{\nabla}\bullet\vec{V}$
- Deformation



  - Program #3. shrinks / stretches area. This flow lets us assess the generation of unphysical phenomena as smaller scales are produced.

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Straka paper

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A COMPARISON OF VARIED METHODS APPLIED TO A 2-D OUTFLOW PROBLEM

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Introduction: Straka paper

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- Straka workshop paper
  - *Problem:* density current in 2-D
    - *other attributes:* compressible, nonlinear
  - *Exact* solution:
    - taken from one scheme run at very high (25 meter) grid spacing
  - Solution comparison
    - (perturbation potential) temperature field at final time
    - structure of Kelvin-Helmholtz rotors
    - position of leading edge of the density current
    - L2 norm of perturbation potential temperature
    - Also examined: total kinetic energy and total enstrophy
      - enstrophy = vorticity squared

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