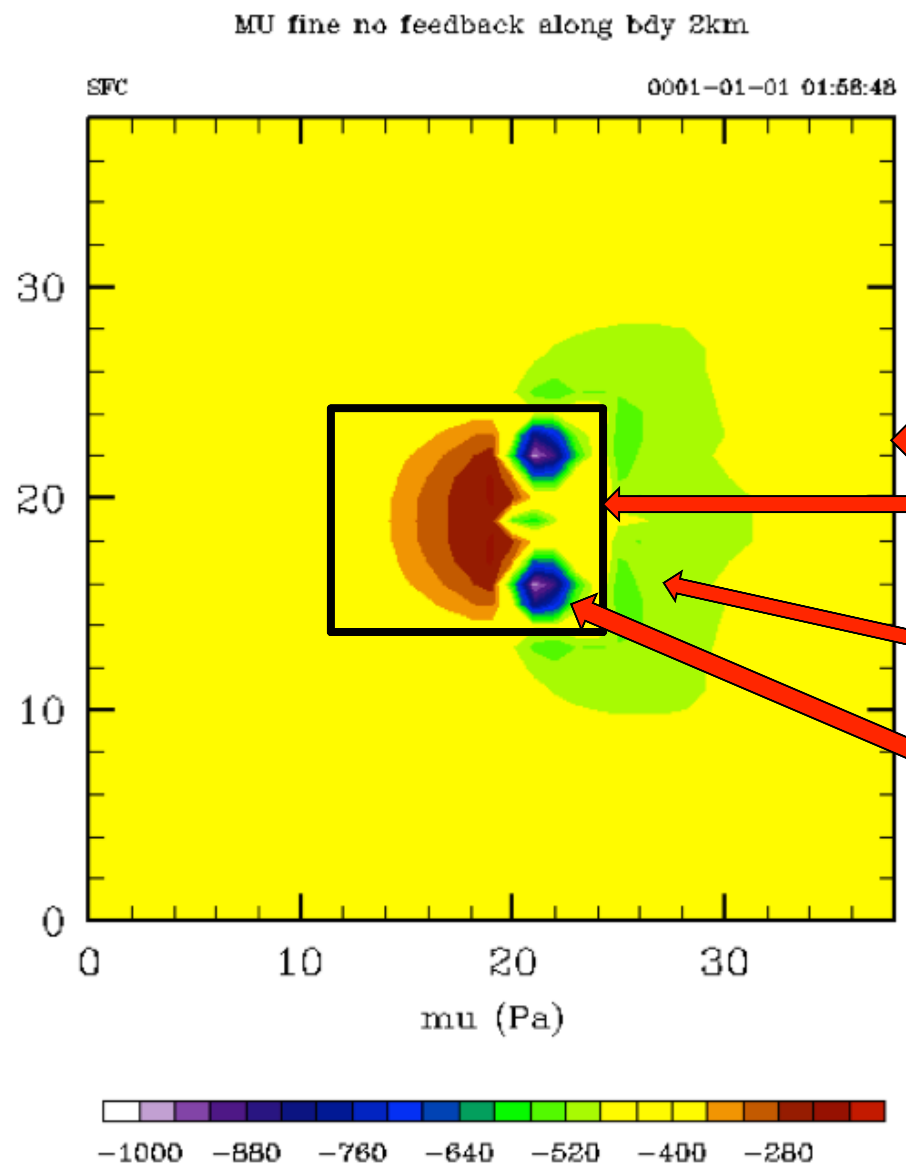
Nesting in WRF

Dave Gill



Super Cell QSS

2-domain run

CG

FG

Feedback: on

Split storm

Overview

- Nesting: Journalism 101: Who, what, why, when, where
- Domains
  - OK *vs* semi-OK *vs* not OK at all
  - Variable staggering CG to FG
  - Lateral forcing
  - Feedback
  - Masked interpolation
  - Time stepping for multi-domain
- Concurrent *vs* Offline Nesting
- Registry
  - U D F S
  - i2
- Some suggestions
  - Performance
  - Location, location, location
  - Inside out, start with inner domain
  - Go big or go home
  - Map factors, stability, time step, domain size

Nesting Basics - What is a nest

- A nest is a ***finer-resolution*** domain used during a model run. This domain may be ***embedded*** simultaneously within a coarser-resolution (parent) model run, or ***run independently*** as a separate model forecast.
- The nest ***covers a portion*** of the parent domain, and is driven along its ***lateral boundaries*** by the parent domain.
- Nesting enables running at finer resolution without the following problems:
  - Uniformly high resolution over a large domain - prohibitively expensive
  - High resolution for a very small domain with mismatched time and spatial lateral boundary conditions

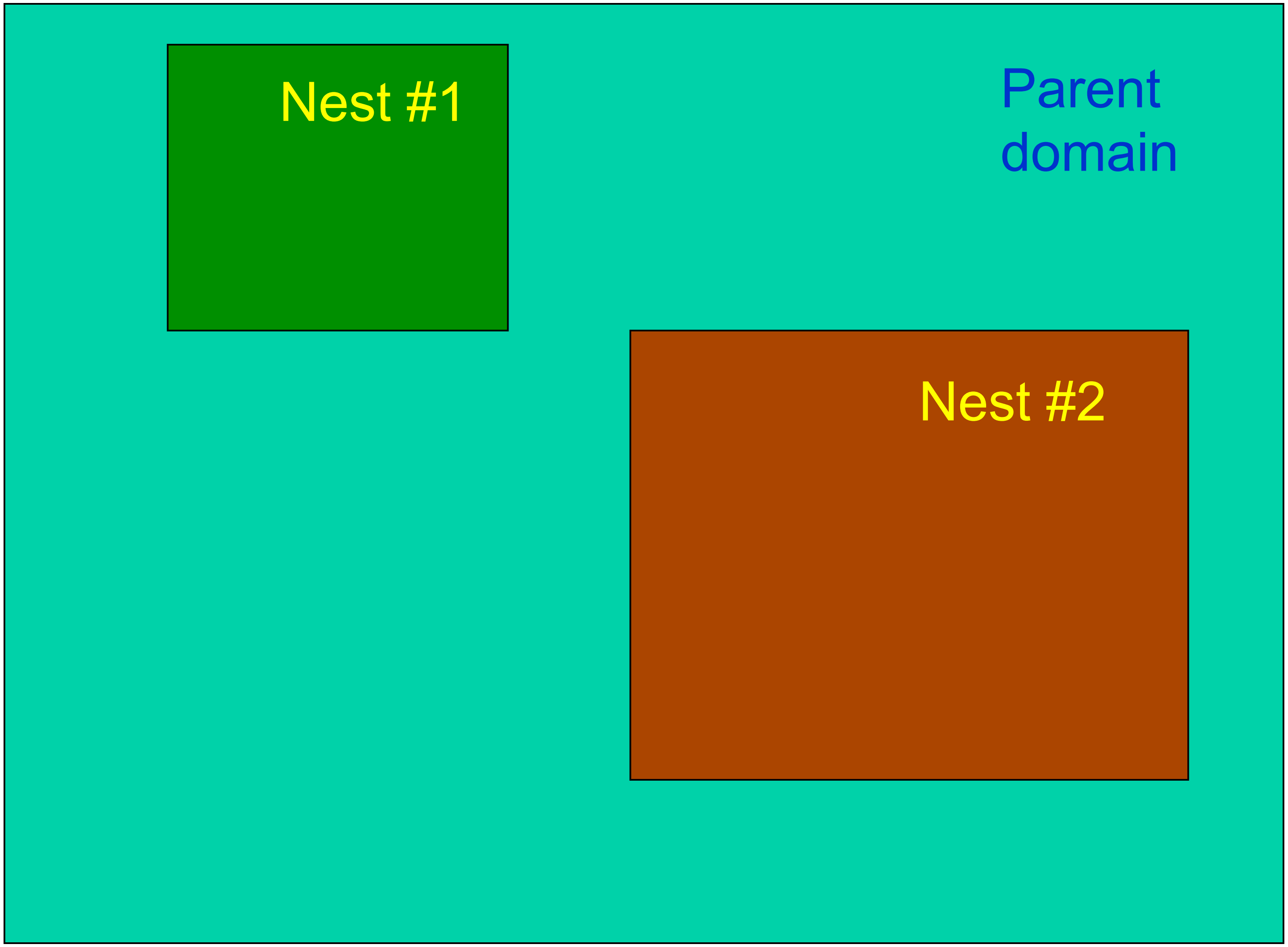
Nesting Basics

- One-way nesting via multiple model forecasts
- One-way nesting with a single model forecast, without feedback

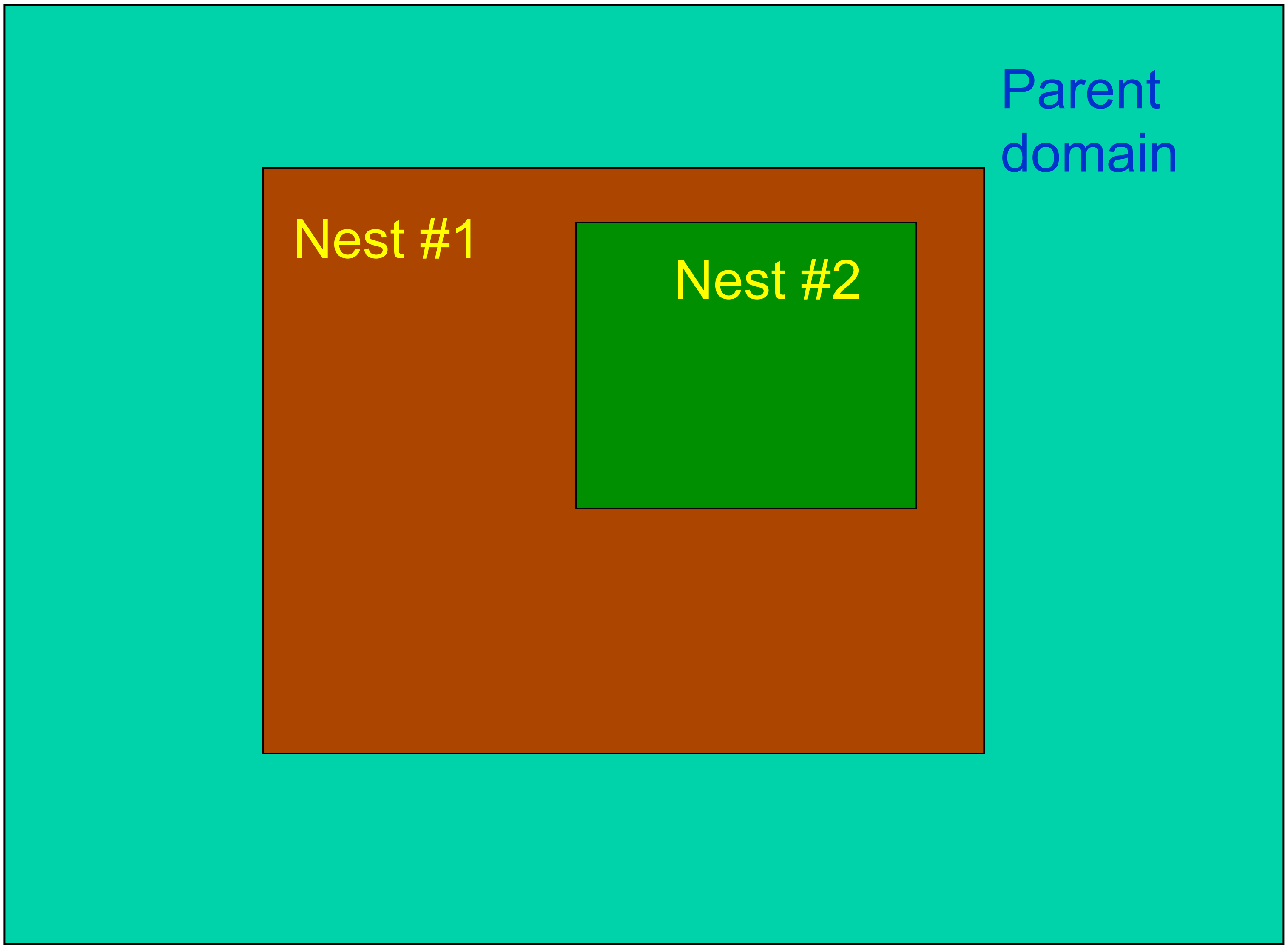
- One-way/two-way nesting with a single input file, all fields interpolated from the coarse grid
- One-way/two-way nesting with multiple input files, each domain with a full input data file
- One-way/two-way nesting with the coarse grid data including all meteorological fields, and the fine-grid domains including only the static files

- One-way/two-way nesting with a specified move for each nest
- One-way/two-way nesting with an automatic move on the nest determined through (usually) 700 hPa low tracking

Two nests on the same “level”, with a common parent domain

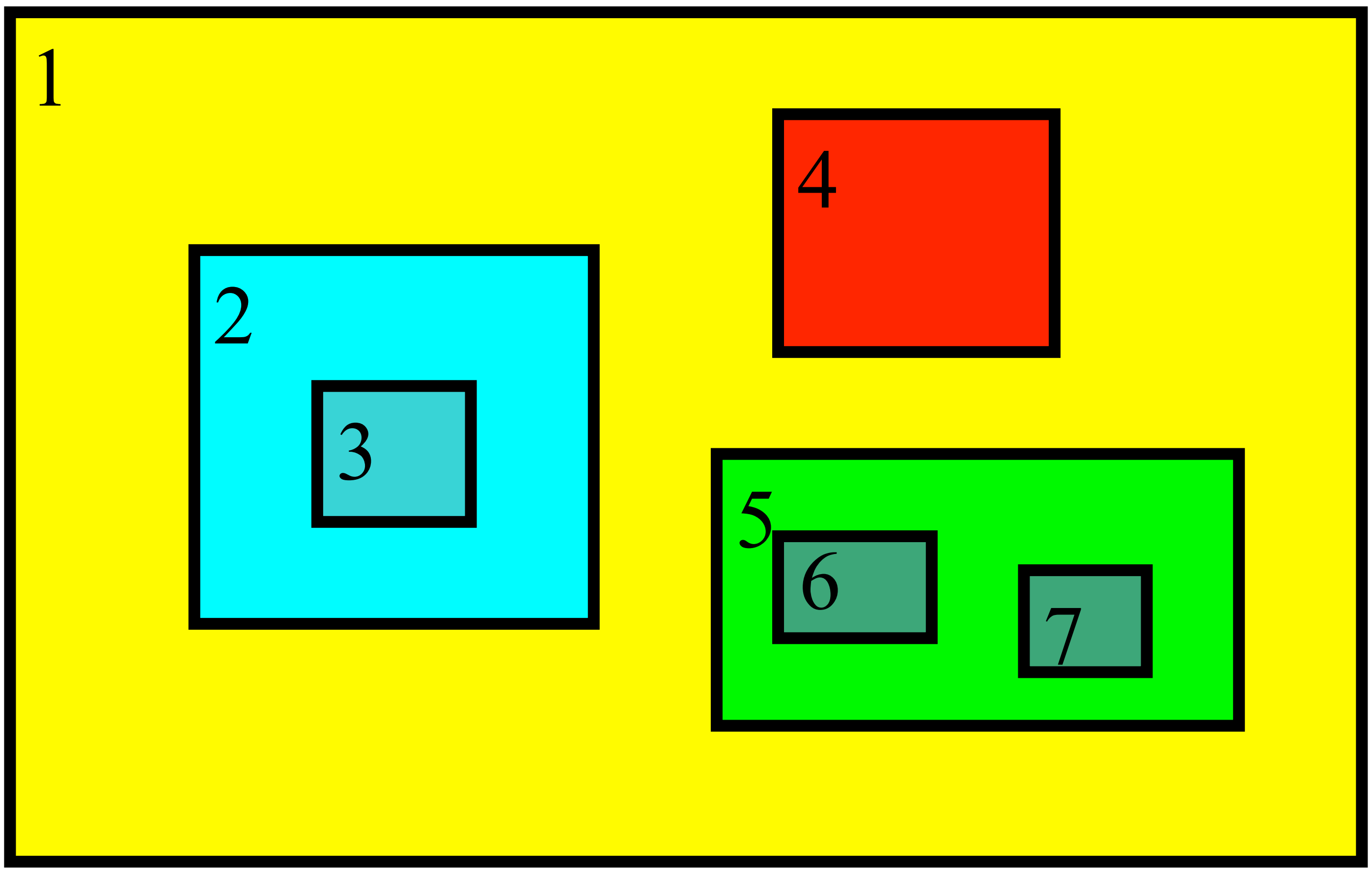


Two levels of nests, with nest #1 acting as the parent for nest #2



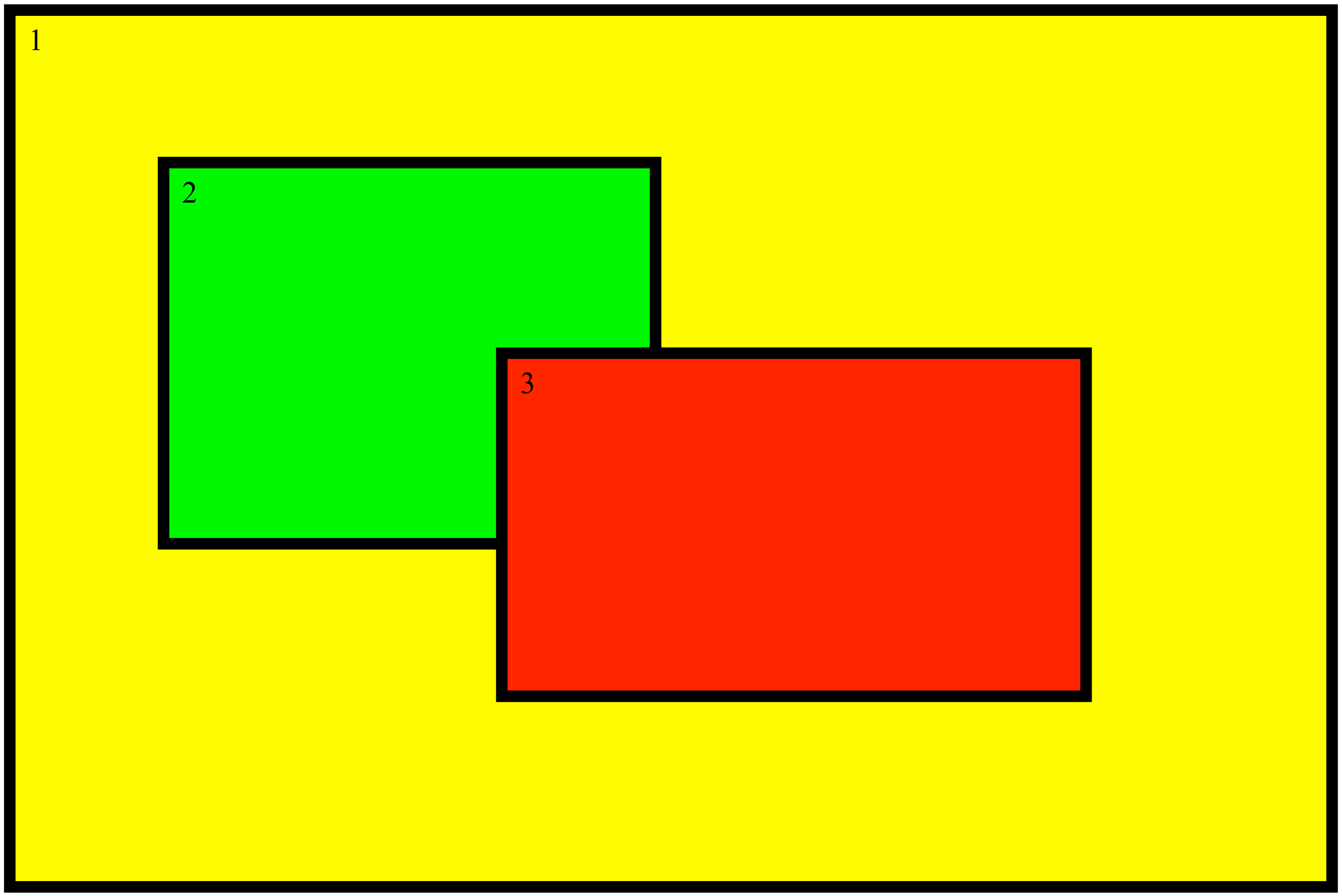
These are all OK

Telescoped to any depth
Any number of siblings



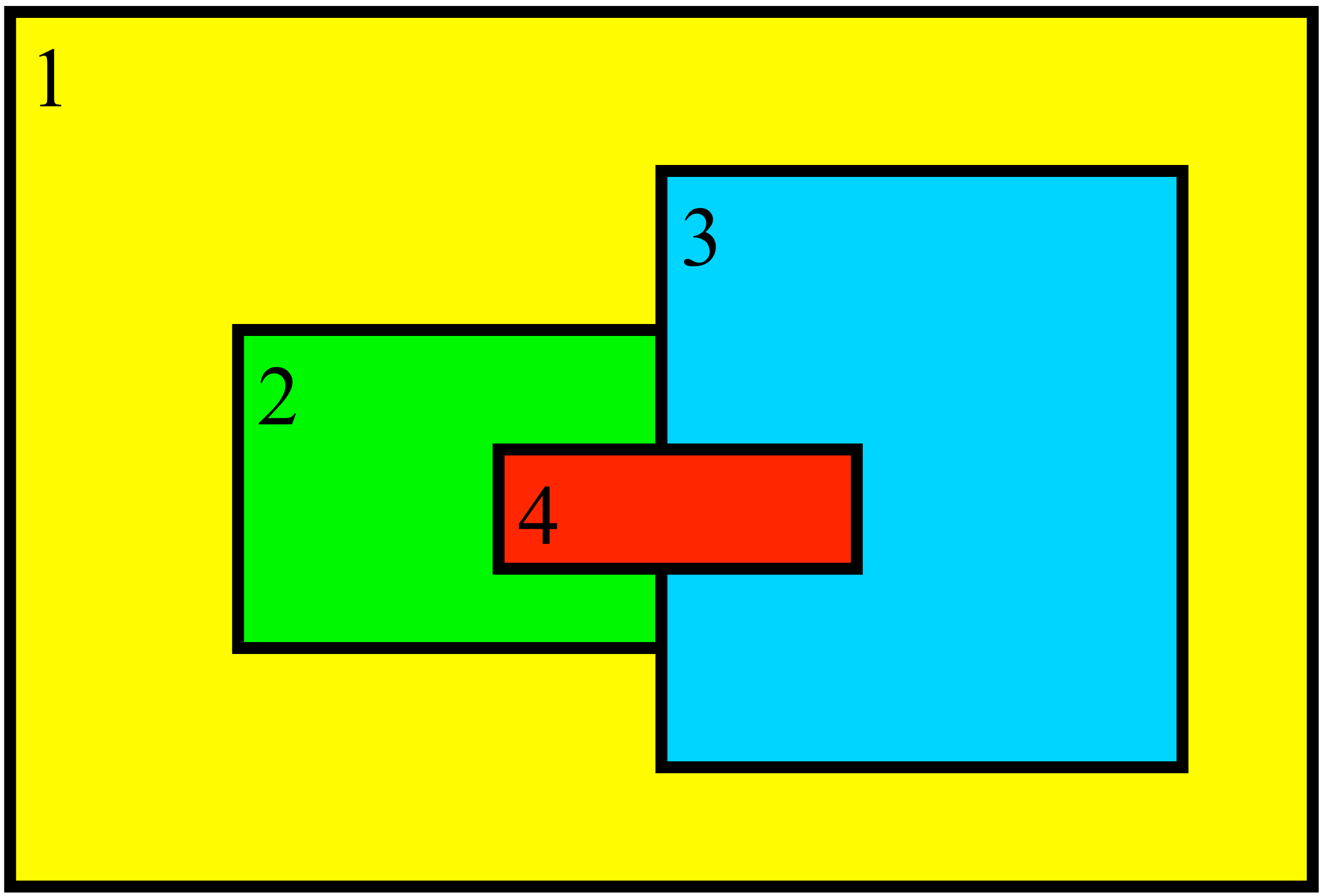
Not OK for 2-way

Child domains *may not* have overlapping points in the parent domain (1-way nesting excluded).



Not OK either

Domains have one, and only one, parent -
(domain 4 is NOT acceptable even with 1-way nesting)

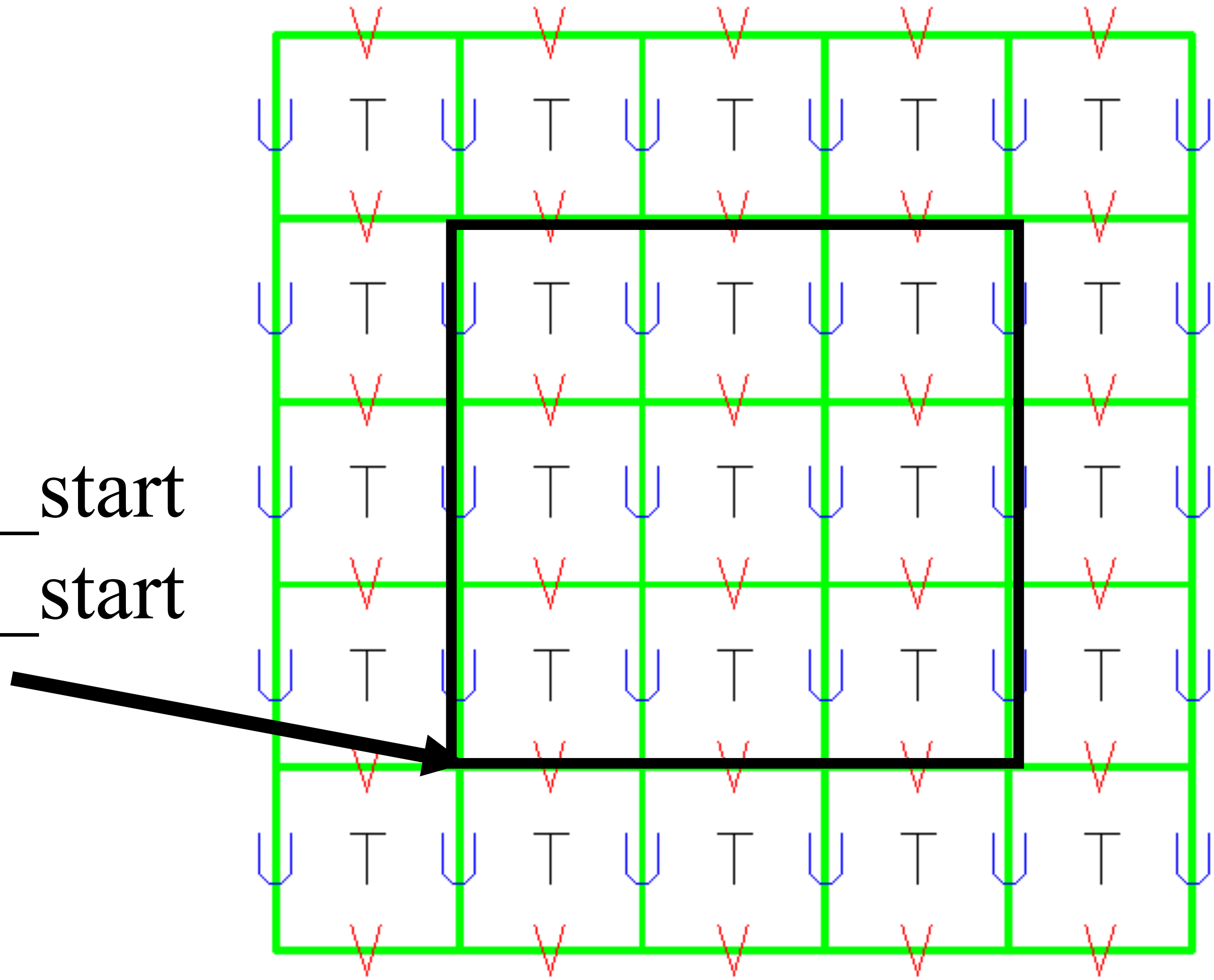


WRF Coarse-Fine Overlap

- The rectangular fine grid is coincident with a portion of the high-resolution grid that covers the entire coarse grid cell

Coarse Grid Staggering

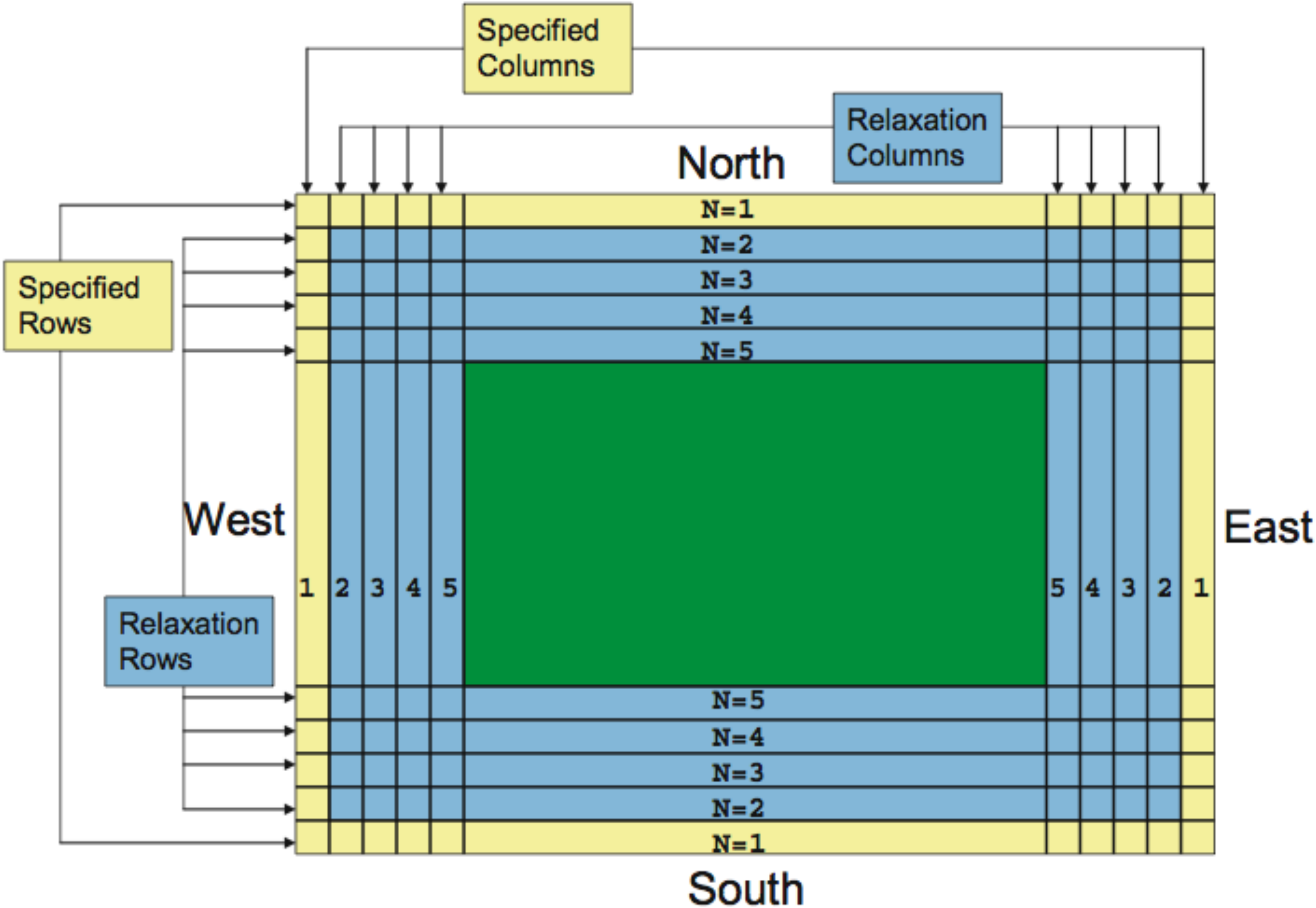
i_parent_start
j_parent_start



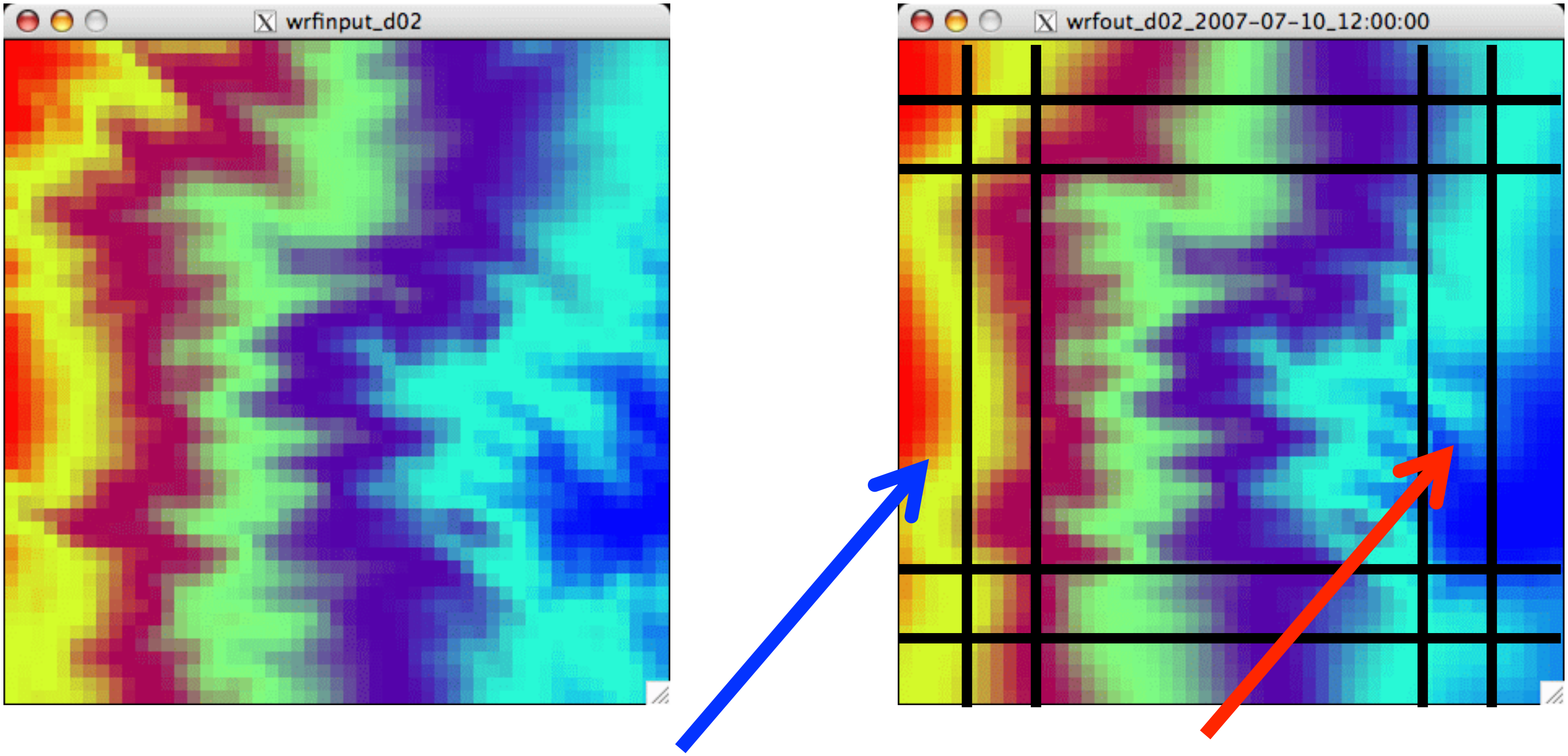
WRF Coarse-Fine Overlap

- The nested domain can be placed anywhere within the parent domain and the nested grid cells will exactly overlap the parent cells at the coincident cell boundaries.
- Coincident parent/nest grid points eliminate the need for complex, generalized remapping calculations, and enhances model performance and portability.

Real-Data Lateral Boundary Condition: Location of Specified and Relaxation Zones



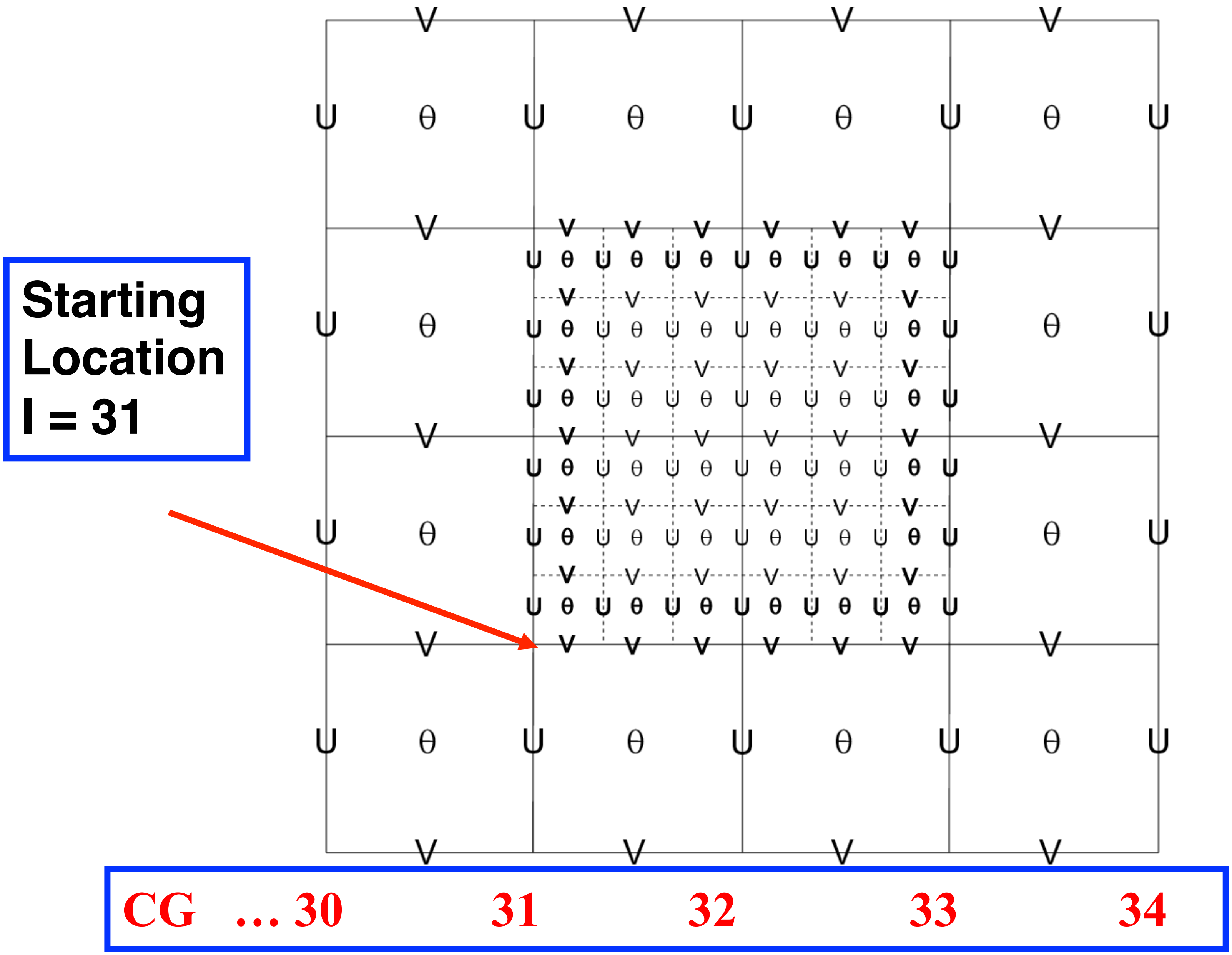
Lateral Smoothing



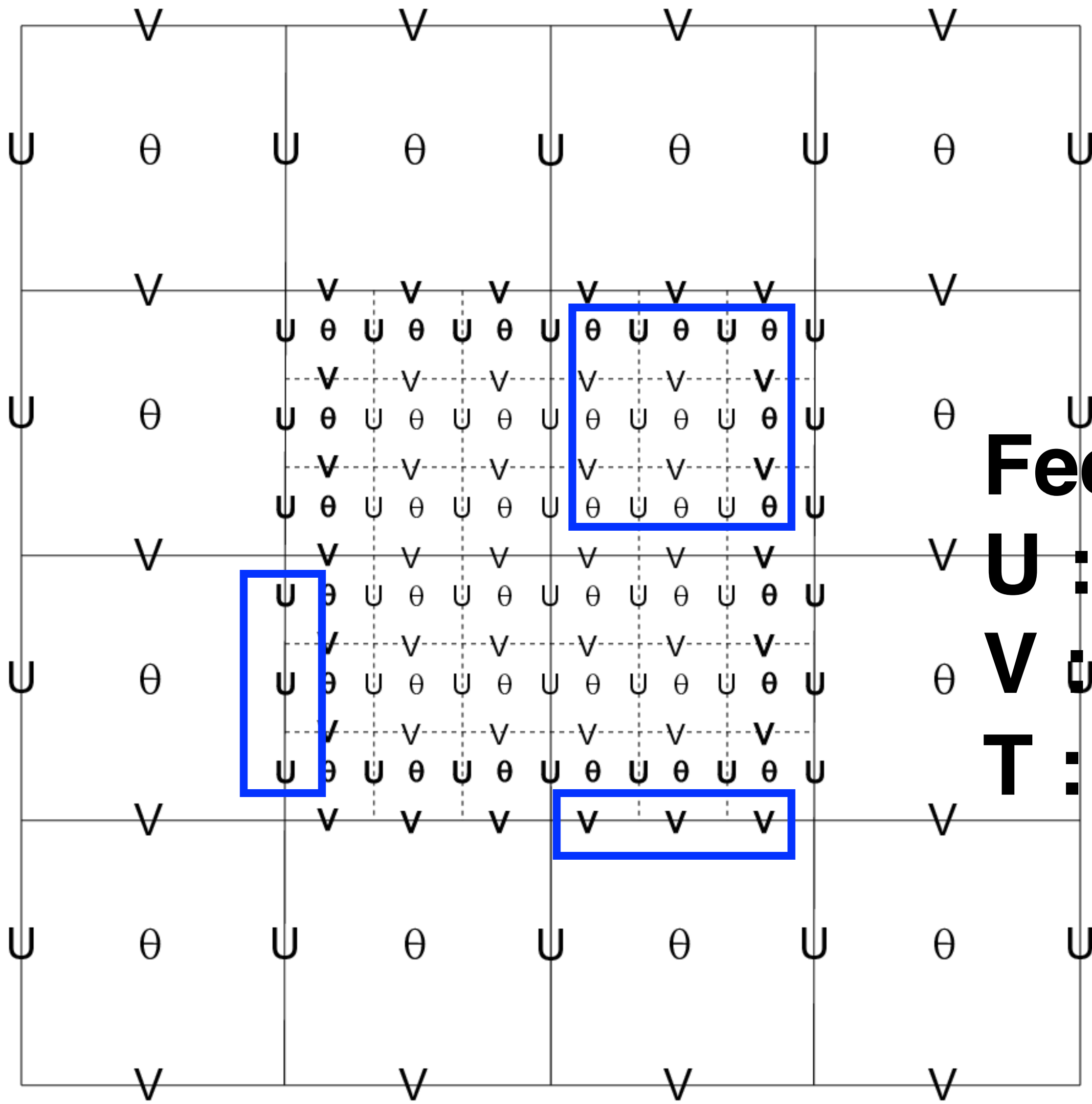
First spec_bdy rows and columns interpolated from CG

Second spec_bdy rows and columns weighted avg from CG and the FG domains

Coarse Grid Staggering 3:1 Ratio



Coarse Grid Staggering 3:1 Ratio



Feedback:
U : column
V : row
T : cell

Coarse Grid Staggering 3:1 Ratio

Feedback:
U : column
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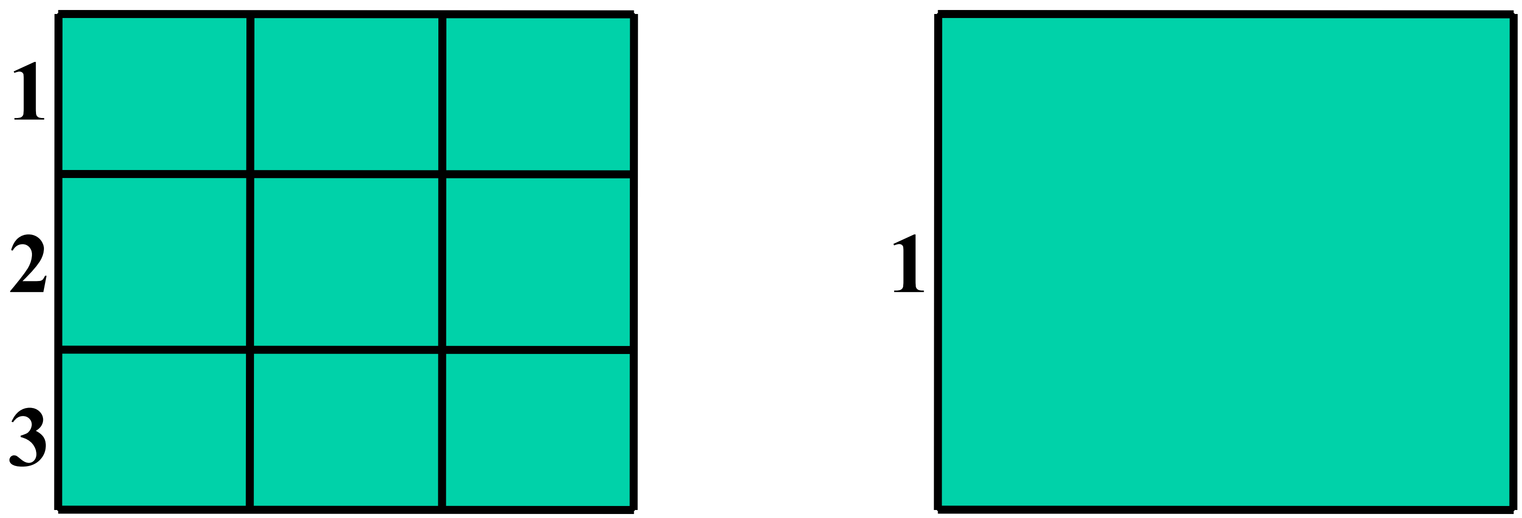
T : cell



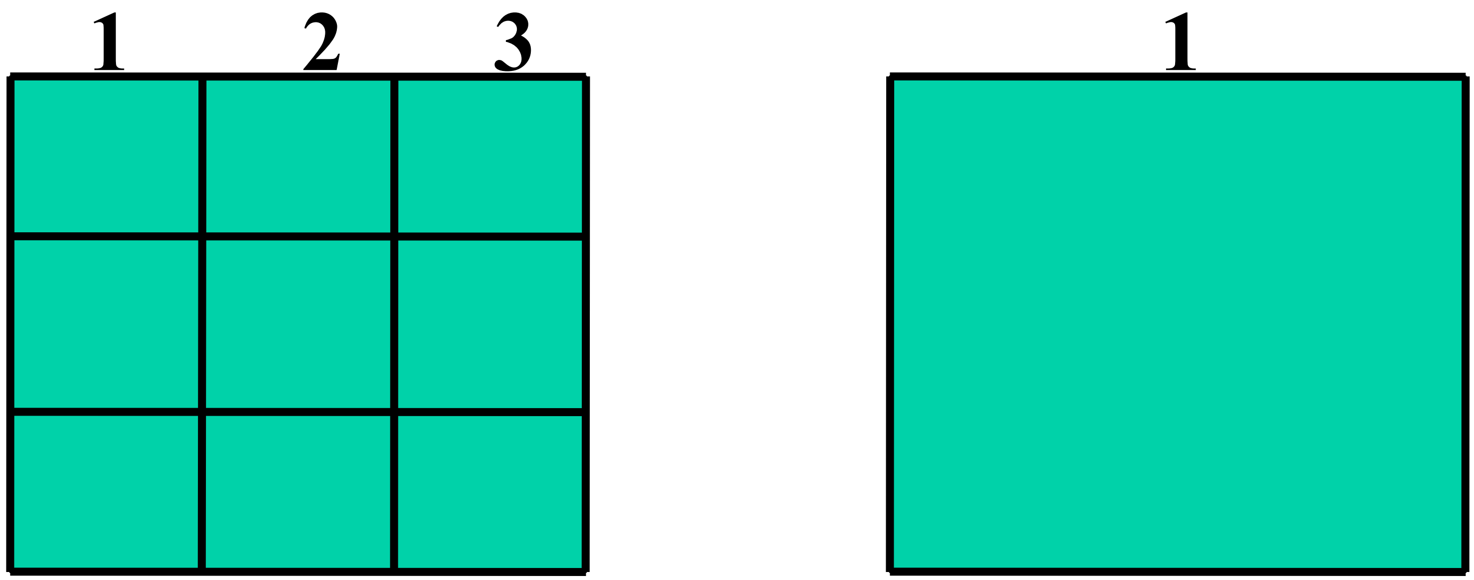
Coarse Grid Staggering 3:1 Ratio

Feedback:

U : column

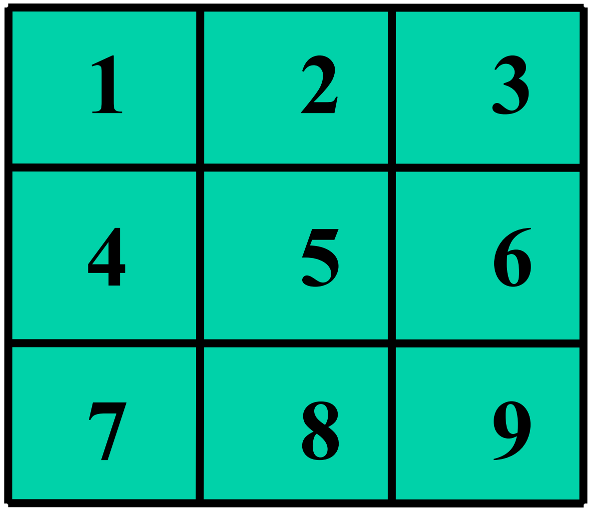
V : row

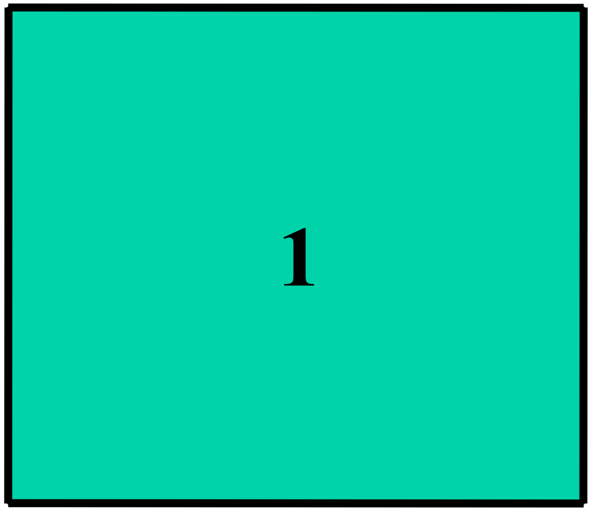
T : cell



Coarse Grid Staggering 3:1 Ratio

Feedback:
U : column
V : row
T : cell

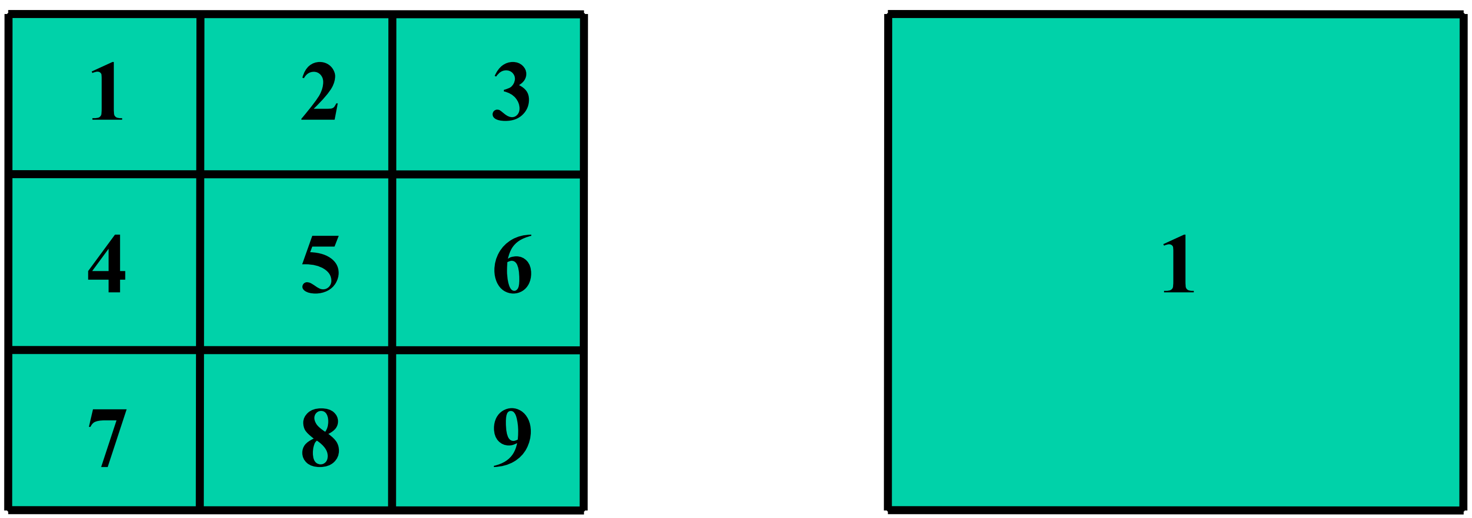




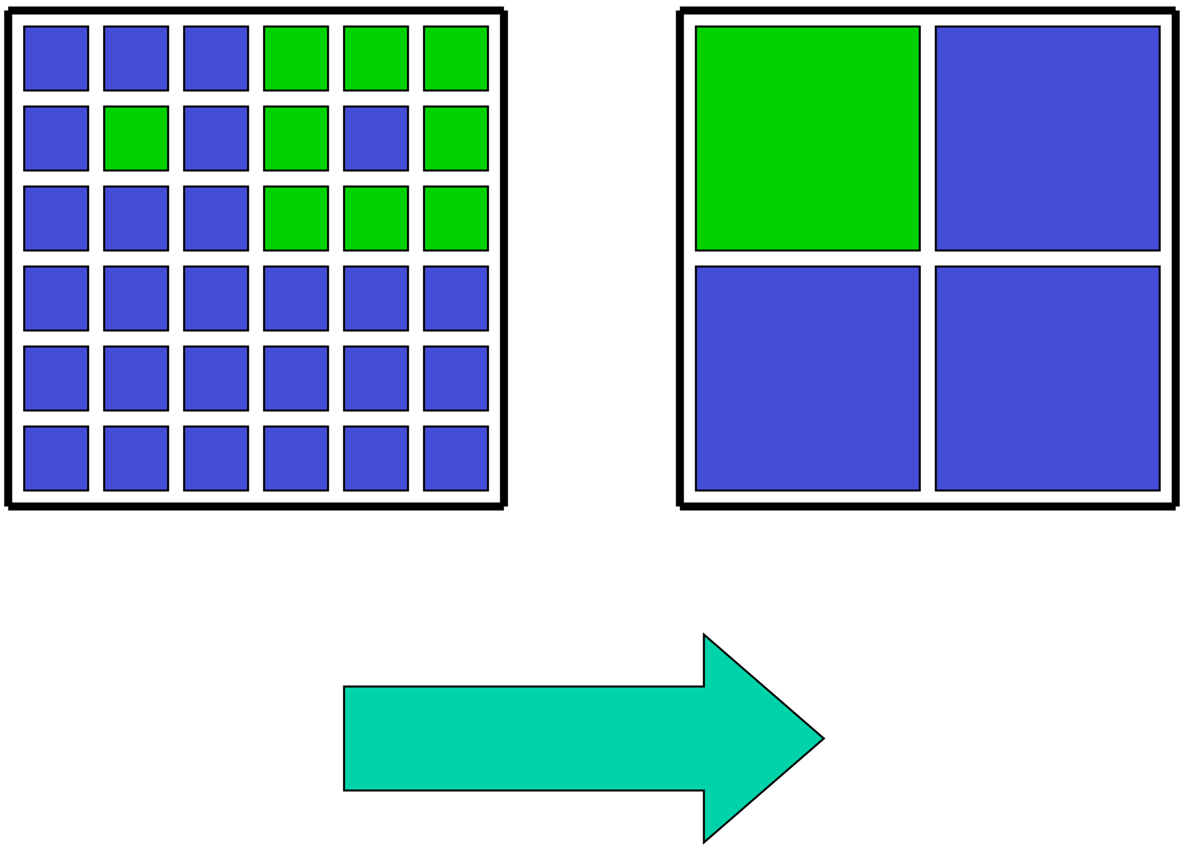
Coarse Grid Staggering 3:1 Ratio

Able to deal with these average values since dealing with continuous and unmasked fields

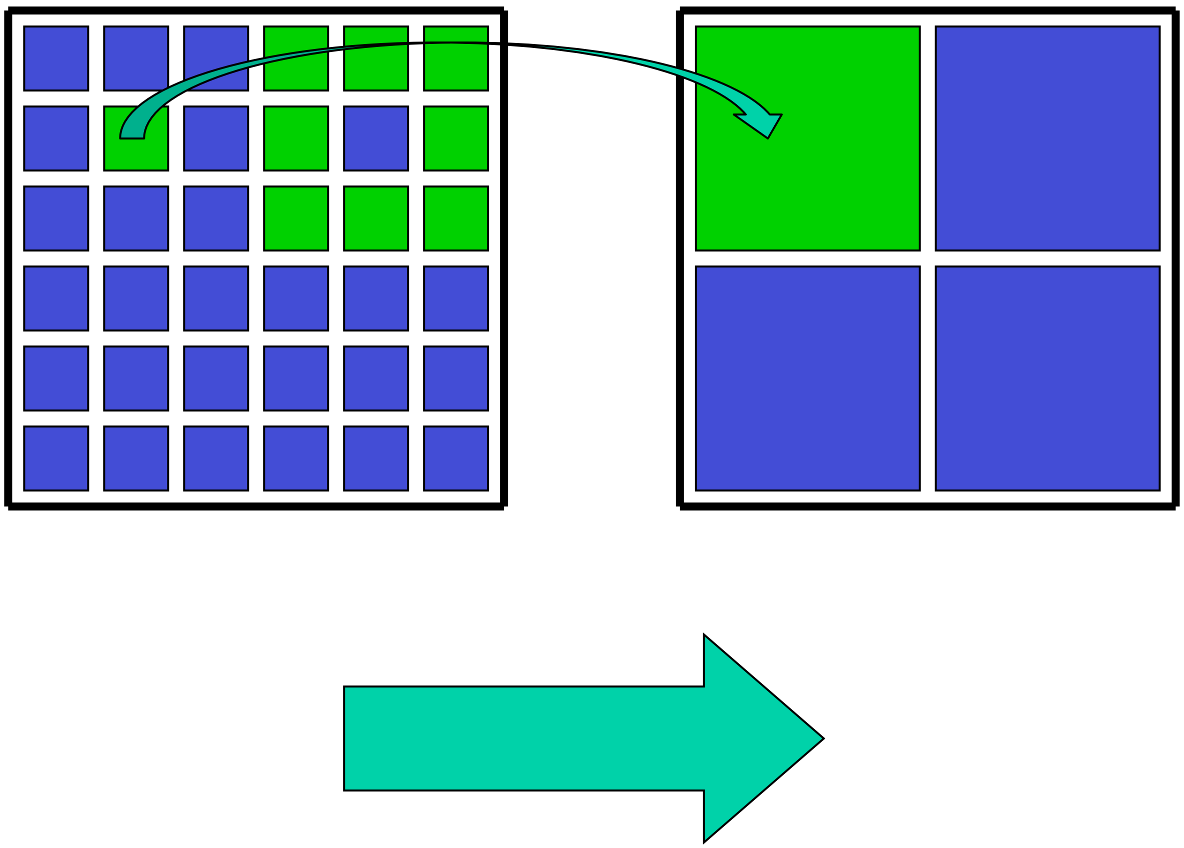
Feedback:
U : column
V : row
T : cell



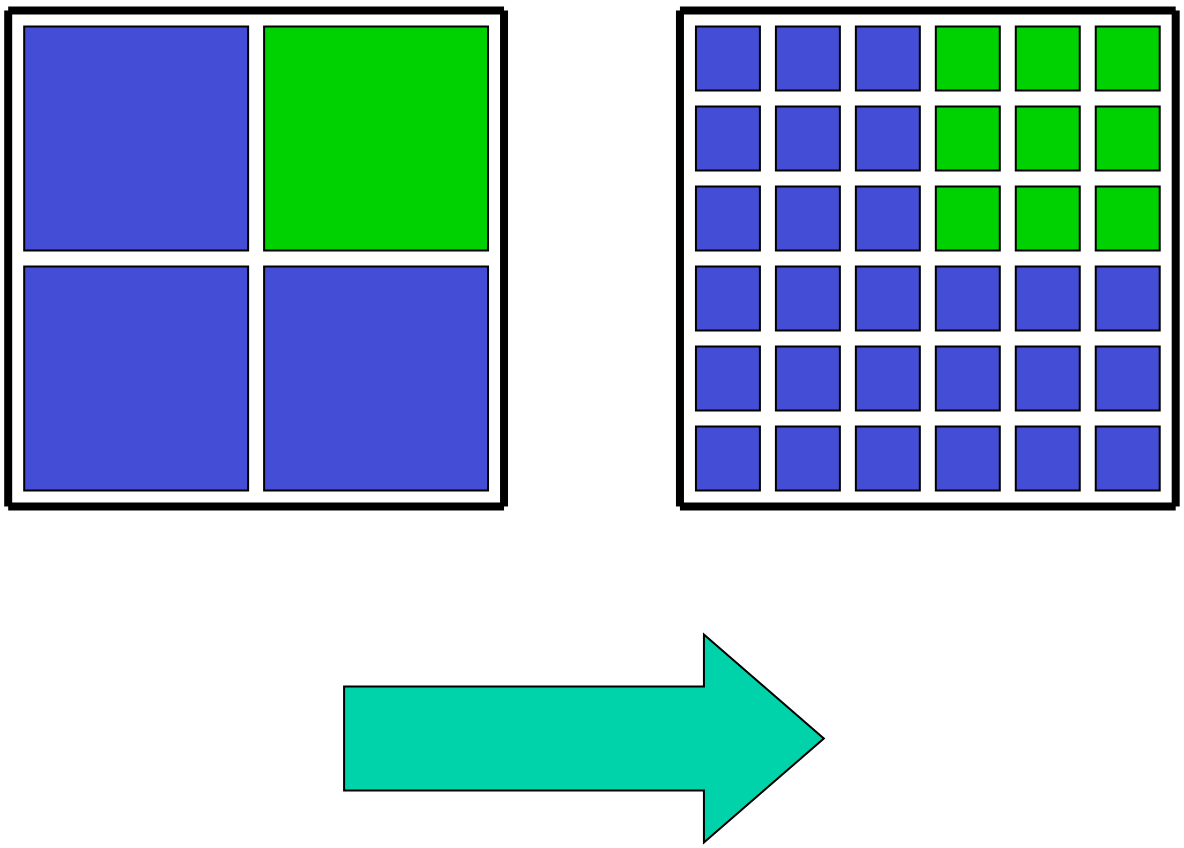
Masked Feedback
Center point – Odd preference



Masked Feedback
Center point – Odd preference

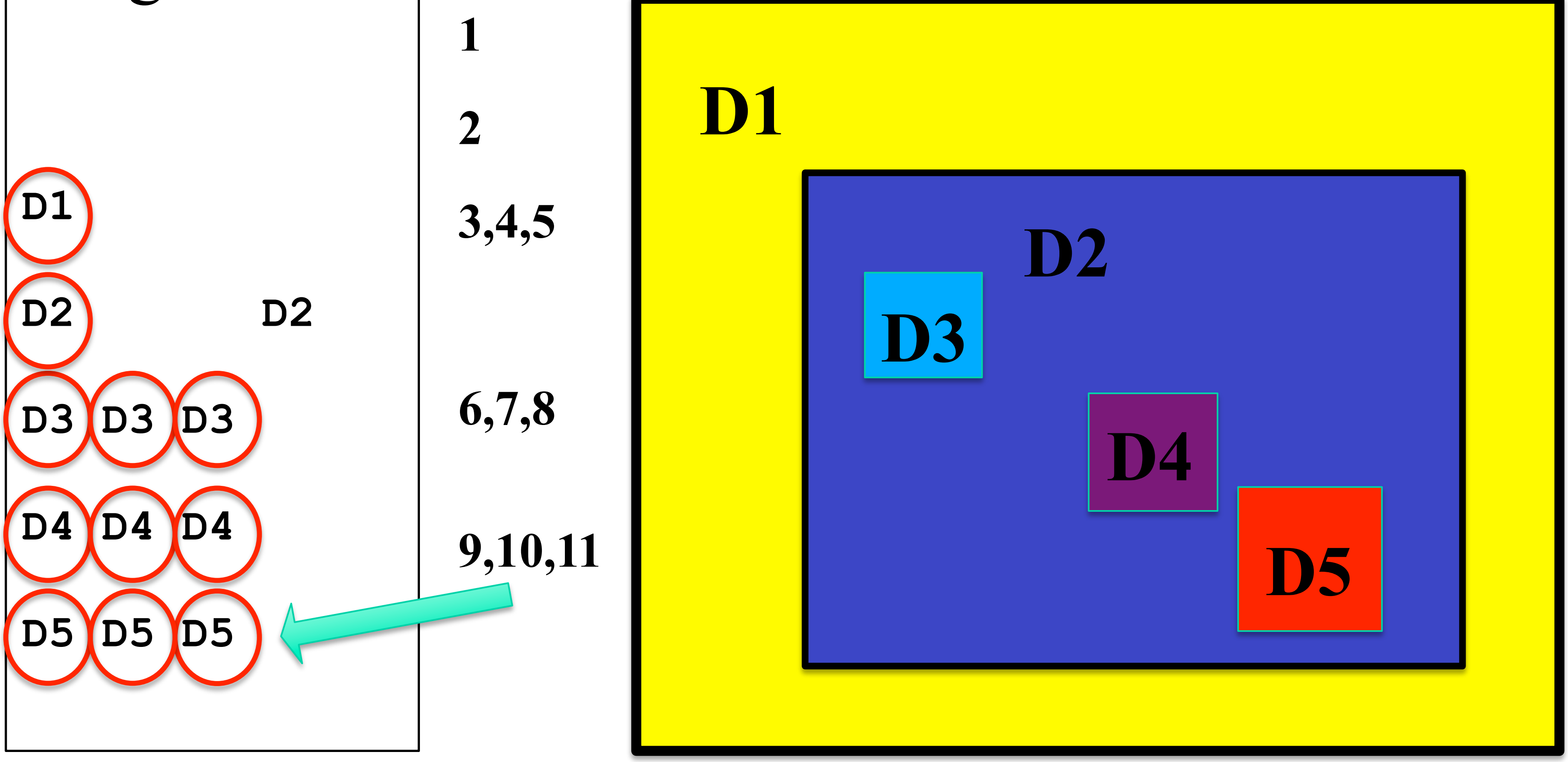


Masked Interpolation

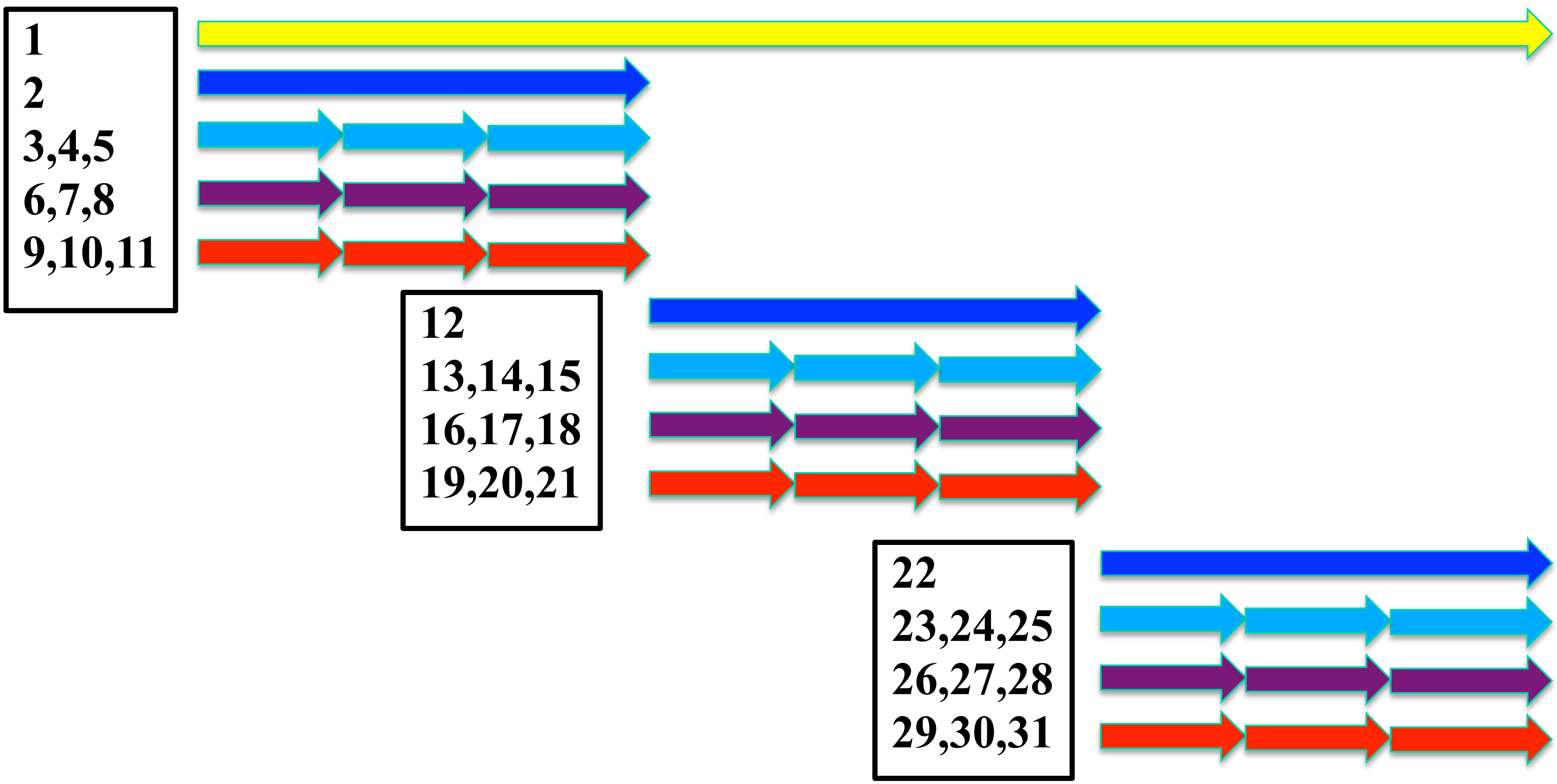


WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.

The order of integration is



WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.



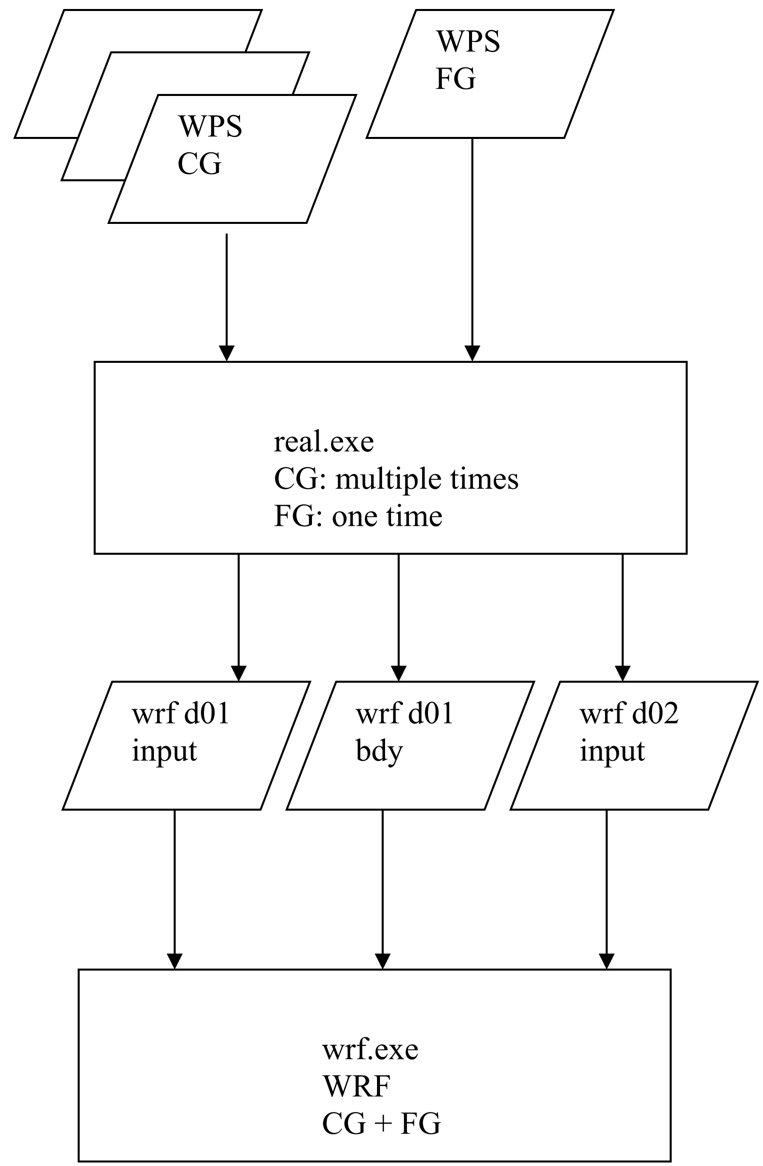
Concurrent Nesting with *n* Inputs

Coarse and fine grid domains must start at the same time, fine domain may end at any time

Feedback may be shut off to produce a 1-way nest (cell face and cell average)

Any integer ratio for coarse to fine is permitted, odd is usually chosen for real-data cases

Options are available to ingest only the static fields from the fine grid, with the coarse grid data horizontally interpolated to the nest



Concurrent Nesting with *n* Inputs

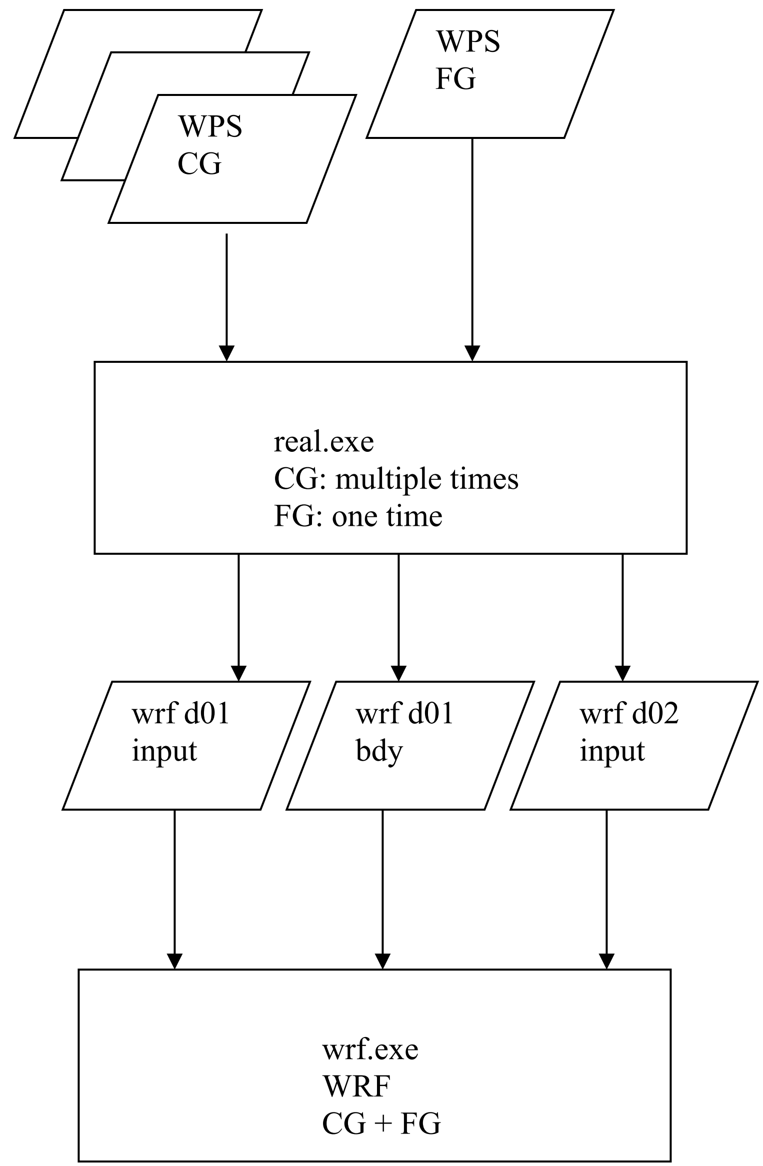
Restricted vertical nesting

Usually the same physics are run on all of the domains (excepting cumulus)

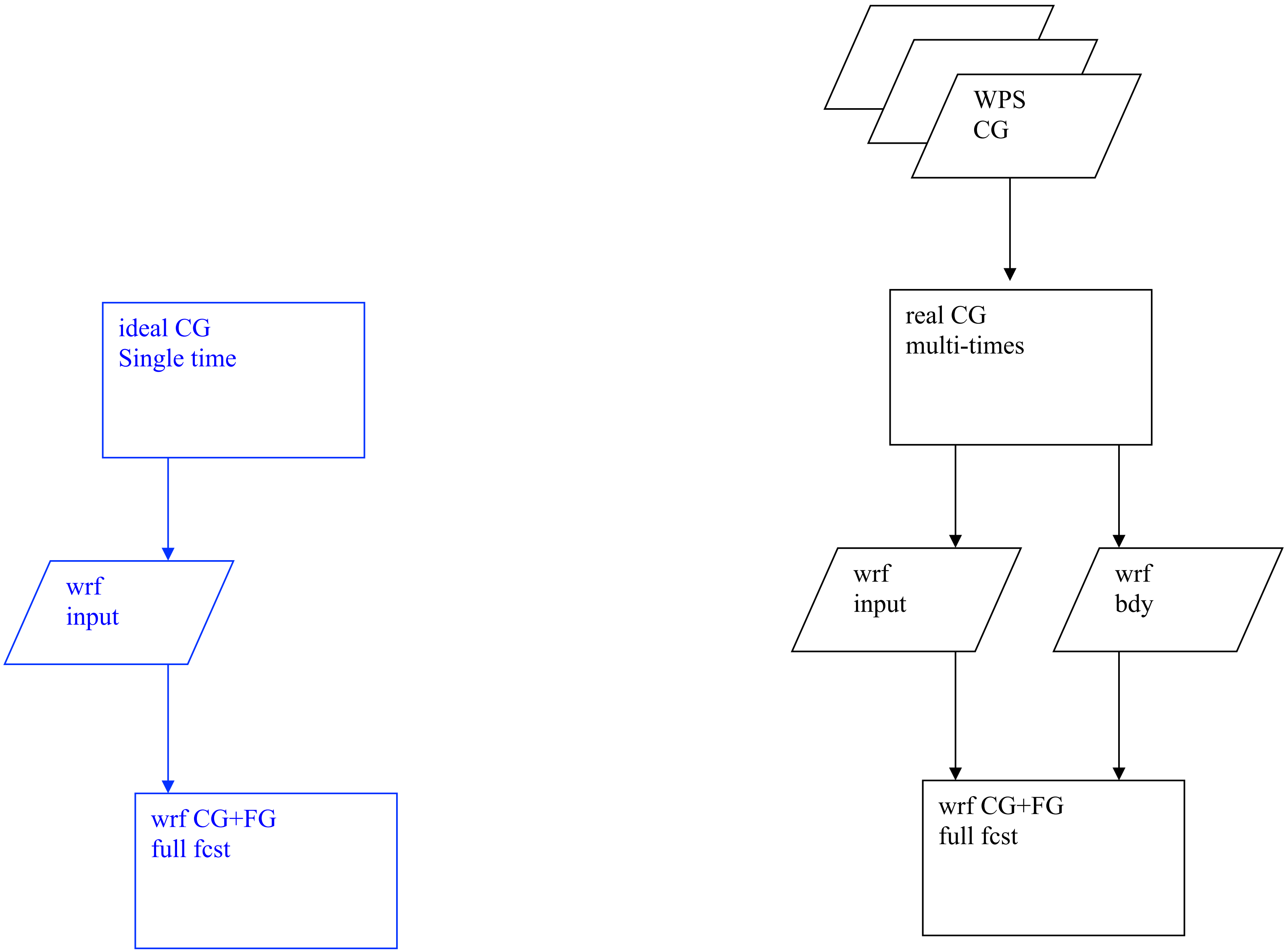
The grid distance ratio is not strictly tied to the time step ratio

Topography smoothly ramps from coarse grid to the fine grid along the interface along the nest boundary

All fine grids must use the nested lateral boundary condition



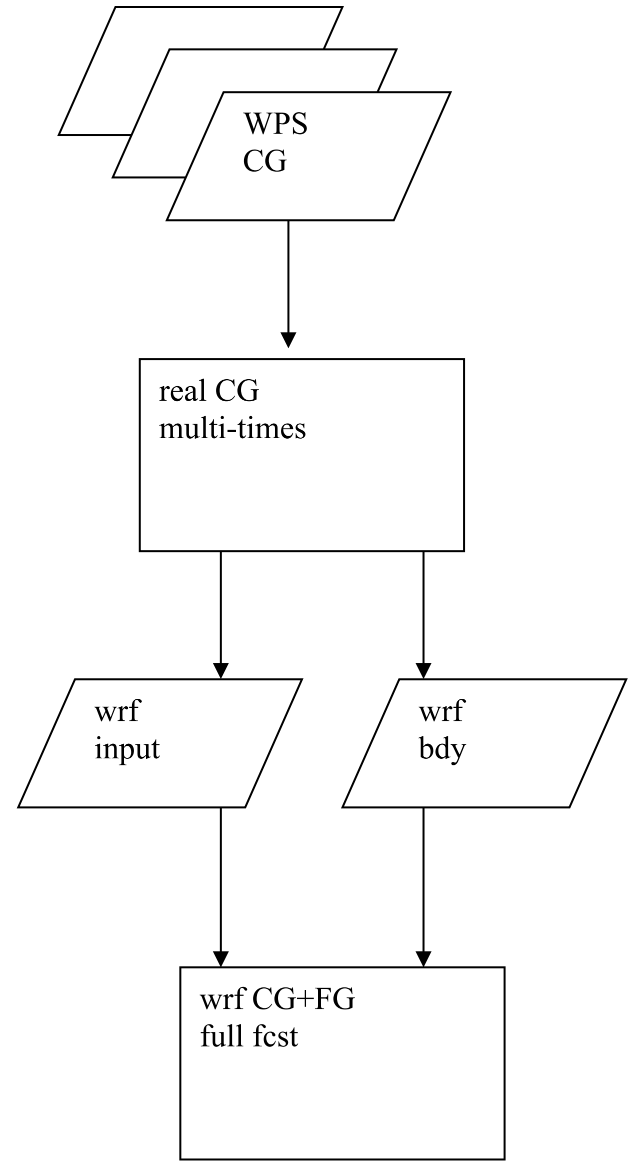
Concurrent Nesting with 1 Input



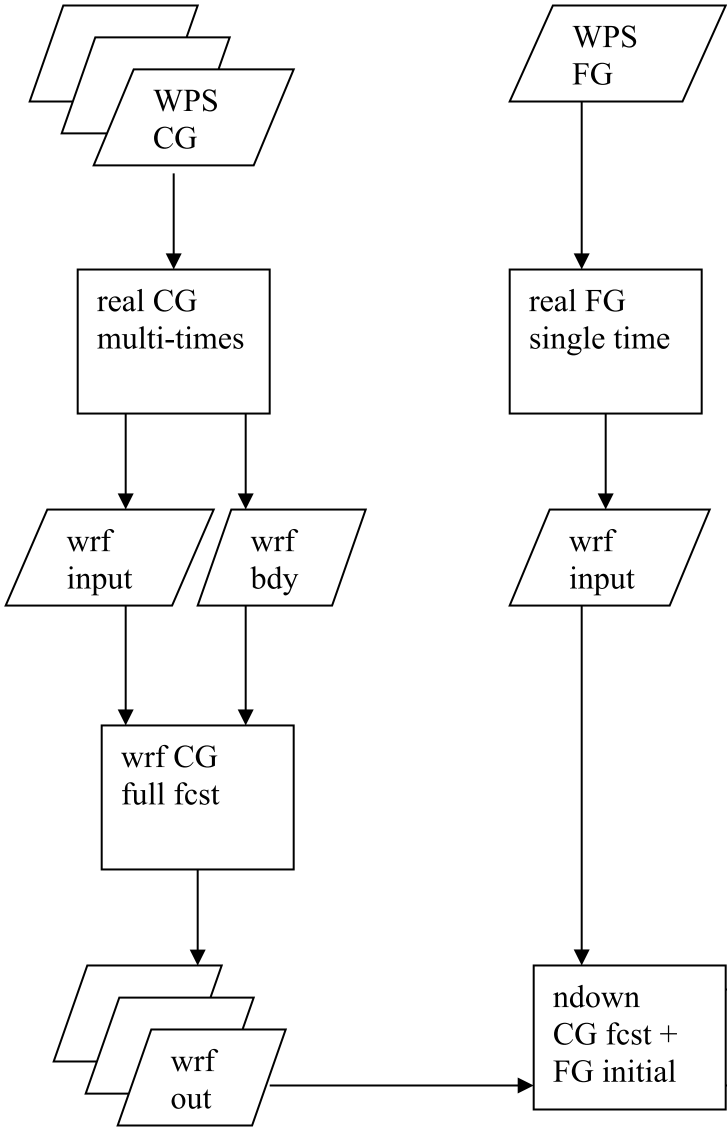
Concurrent Nesting with 1 Input

A single namelist column entry is tied to each domain

The horizontal interpolation method, feedback, and smoothing are largely controlled through the Registry file



ndown: Offline Nesting

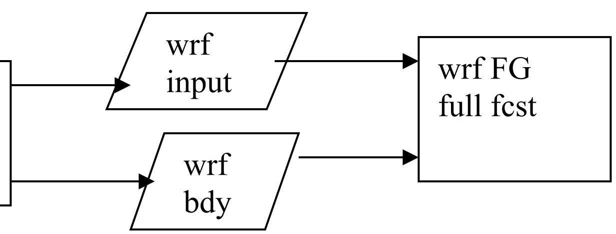


Separate WRF forecast runs, separate real pre-processor runs, intervening **`ndown.exe`** run

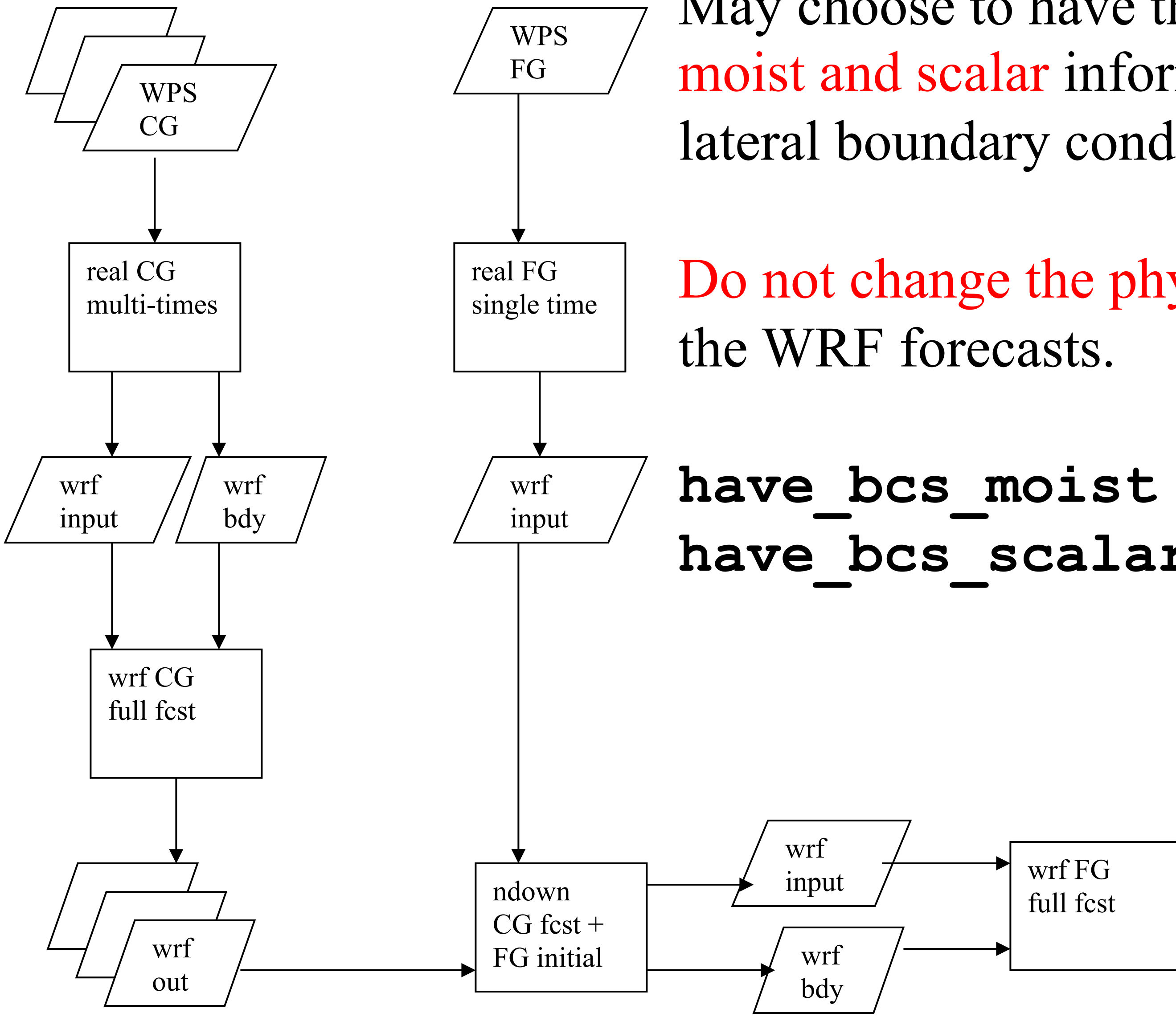
Same restrictions for horizontal nest ratios

Can start at any time that an output time exists from the parent grid

Boundary condition frequency for the fine grid is usually the same as the coarse grid output frequency



ndown: Offline Nesting



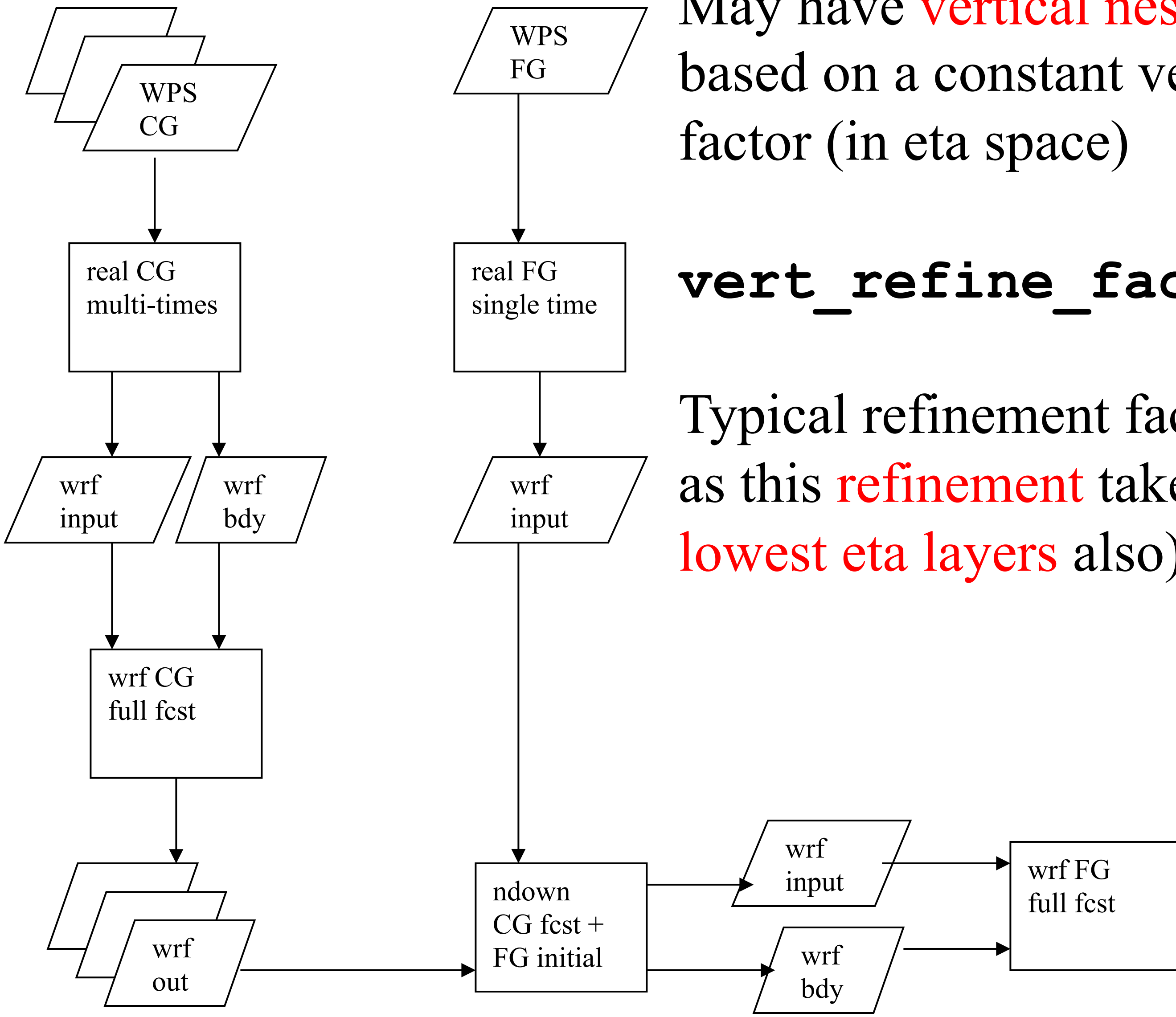
May choose to have the parent WRF model moist and scalar information used for the lateral boundary conditions.

Do not change the physics options between the WRF forecasts.

`have_bcs_moist`

`have_bcs_scalar`

ndown: Offline Nesting



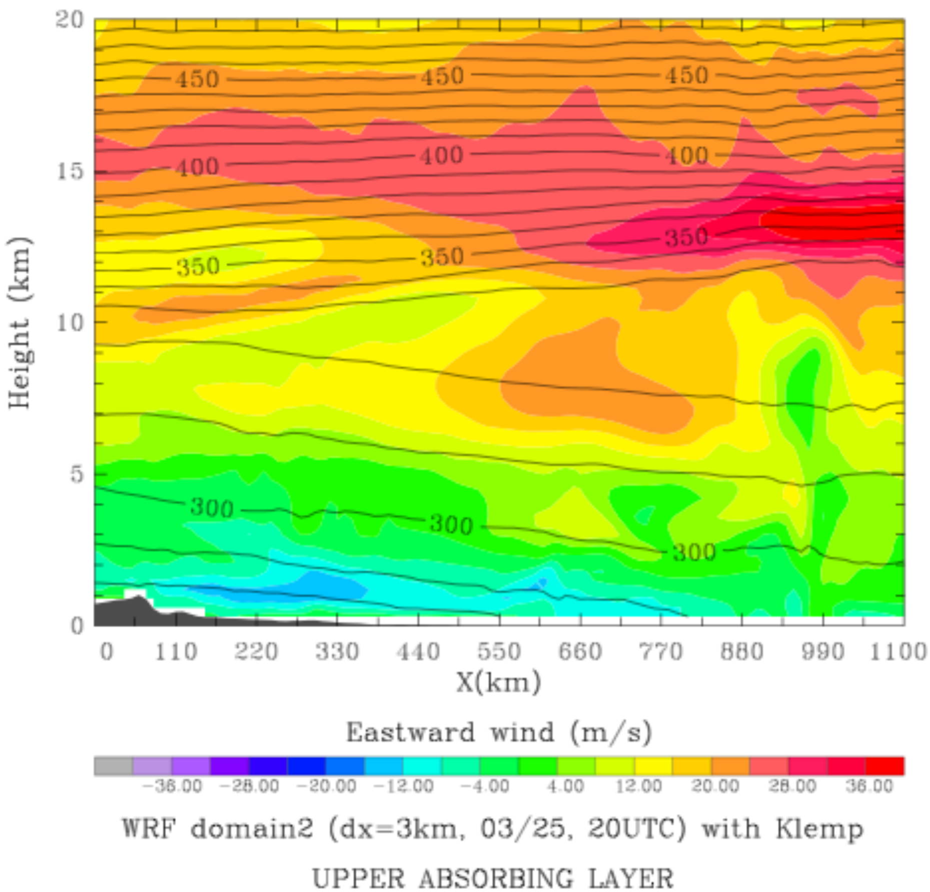
May have vertical nesting on the fine grid based on a constant vertical refinement factor (in eta space)

`vert_refine_fact`

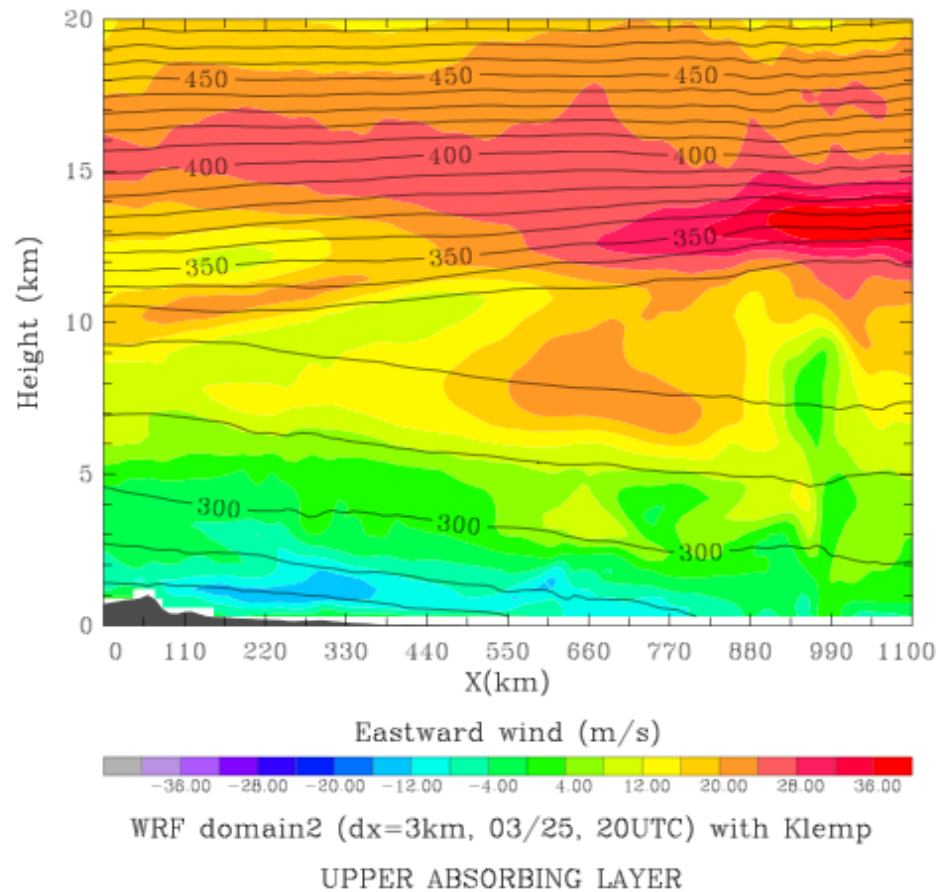
Typical refinement factors 2-5 (be careful, as this refinement takes place in the lowest eta layers also)

West East Cross section
Shaded: v; Contour: theta
6-h Forecast, from Mohamed Moustaoui

Standard Levels



3x Refinement



Vertical Nesting

Starting with V3.7, the model allows **different numbers of vertical levels on different domains**. Usually, this is to include more levels on the inner domains.

This is **a new feature** and needs to be handled cautiously.

Restrictions:

- Only RRTM radiation scheme is available
- Real data cases only
- Static nest locations only

Vertical Nesting

```
&domains
max_dom              = 2,
e_vert               = 35,    45,
vert_refine_method = 0,     2,
```

Vertical Nesting

```
&domains
eta_levels( 1:35) = 1., 0.993, 0.983, 0.97, 0.954, 0.934,
                    0.909, 0.88, 0.8406663, 0.8013327,
                    0.761999, 0.7226653, 0.6525755,
                    0.5877361, 0.5278192, 0.472514,
                    0.4215262, 0.3745775, 0.3314044,
                    0.2917579, 0.2554026, 0.2221162,
                    0.1916888, 0.1639222, 0.1386297,
                    0.1156351, 0.09525016, 0.07733481,
                    0.06158983, 0.04775231, 0.03559115,
                    0.02490328, 0.0155102, 0.007255059, 0.
```

Vertical Nesting

```
&domains
eta_levels(36:81) = 1.0000, 0.9946, 0.9875, 0.9789, 0.9685,
                    0.9562, 0.9413, 0.9238, 0.9037, 0.8813,
                    0.8514, 0.8210, 0.7906, 0.7602, 0.7298,
                    0.6812, 0.6290, 0.5796, 0.5333, 0.4901,
                    0.4493, 0.4109, 0.3746, 0.3412, 0.3098,
                    0.2802, 0.2524, 0.2267, 0.2028, 0.1803,
                    0.1593, 0.1398, 0.1219, 0.1054, 0.0904,
                    0.0766, 0.0645, 0.0534, 0.0433, 0.0341,
                    0.0259, 0.0185, 0.0118, 0.0056, 0.
```

What are those “usdf” Options

```
state real u ikjb dyn_em 2 X \
  i01rhusdf=(bdy_interp:dt) \
  "U" "x-wind component" "m s-1”
```

“f” defines what lateral boundary forcing routine (found in **share/interp_fcn.F**) is utilized, colon separates the additional fields that are required (fields must be previously defined in the Registry)

Called at beginning of each set of child time steps, has parent and child information available – could be used with SST.

What are those "usdf" Options

```
state real landmask ij misc 1 -  \
  i012rhd=(interp_fcnm)u=(copy_fcnm)\
  "LANDMASK" "LAND MASK (1=LAND, 0=WATER)"
```

"u" and "d" define which feedback (up-scale) and horizontal interpolation (down-scale) routines (found in **`share/interp_fcn.F`**) are utilized

Default values (i.e. not a subroutine name listed in the parentheses) assume non-masked fields

What are those “usdf” Options

```
state real ht ij  misc  1  - i012rhdus  "HGT" \
  "Terrain Height"   "m"
```

“s” if the run-time option for smoothing is activated, this field is to be smoothed - only used for the parent of a nest domain, smoothing is in the area of the nest, excluding the outer row and column of the nest coverage

Whether or not smoothing is enabled is a run-time option from the namelist – **smoothing can always be turned off without introducing any problems**

Special IO Stream #2 Fields

```
state real msft ij  misc  1 -  \
  i012rhdu=(copy_fcnm)  "MAPFAC_M"   \
  "Map scale factor on mass grid" ""

state real msfu ij  misc  1 X  \
  i012rhdu=(copy_fcnm)  "MAPFAC_U"   \
  "Map scale factor on u-grid" ""

state real msfv ij  misc  1 Y  \
  i012rhdu=(copy_fcnm)  "MAPFAC_V"   \
  "Map scale factor on v-grid" ""
```

Nesting Suggestions – CG Size

- The size of the nested domain may need to be chosen with computing performance in mind.
- Assuming a 3:1 ratio and the same number of grid cells in the parent and nest domains, the fine grid will require 3x as many time steps to keep pace with the coarse domain.
- A simple nested domain forecast is approximately 4x the cost of just the coarse domain.
- Don' t be *cheap* on the coarse grid, doubling the CG points results in only a 25% nested forecast time increase.

Nesting Suggestions – Cost

- Example: assume 3:1 nest ratio

If the nest has the same number of grid cells, then the **amount of CPU** to do a single time step for a coarse grid (CG) and a fine grid step (FG) is **approximately the same**.

Since the fine grid (3:1 ratio) has 1/3 the grid distance, it requires 1/3 the model time step. Therefore, the FG requires 3x the CPU to catch up with the CG domain.

Nesting Suggestions – Same Area

- Example: assume 3:1 nest ratio

If you try to cover the SAME area with a FG domain as a CG domain, you need **(ratio)^2 grid points**.

With the associated FG time step ratio, you require a **(ratio)^3**.

With a 3:1 ratio, a FG domain covering the same area as a CG domain **requires 27x CPU**.

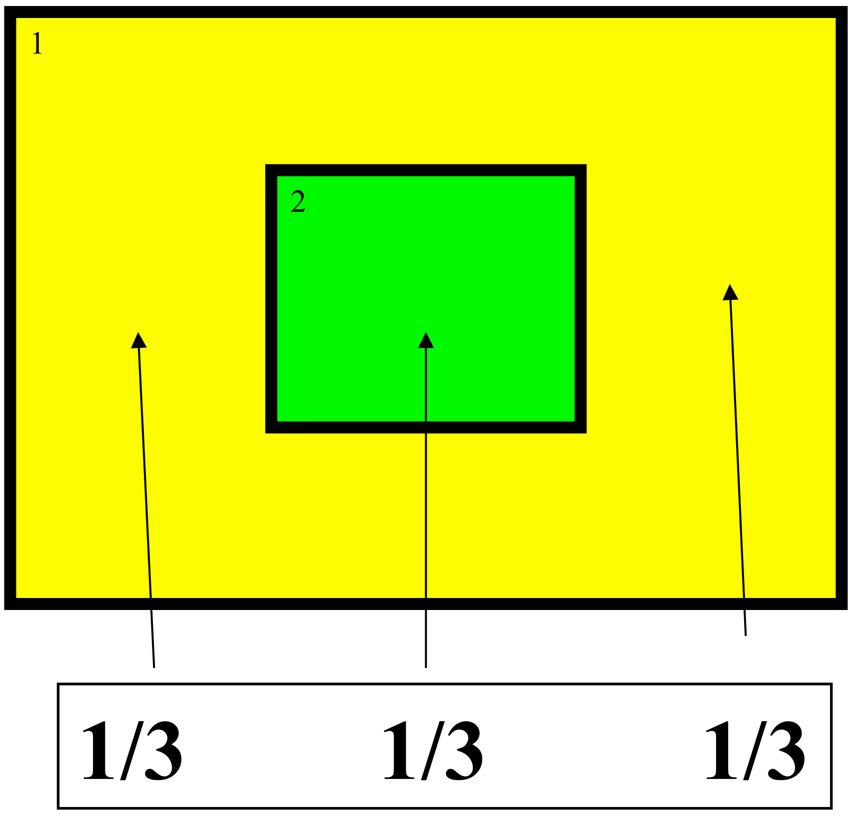
Nesting Suggestions – Same Area

- Example: assume **10:1 nest ratio**

To change your test case from 50-km resolution to a finer 5-km resolution would be at least **1000x more** expensive.

Nesting Suggestions - Location

- The minimum distance between the nest boundary and the parent boundary is FOUR grid cells
- You should have a **MUCH** larger buffer zone
- It is not unreasonable to have approximately 1/3 of your coarse-grid domain surrounding each side of your nest domain



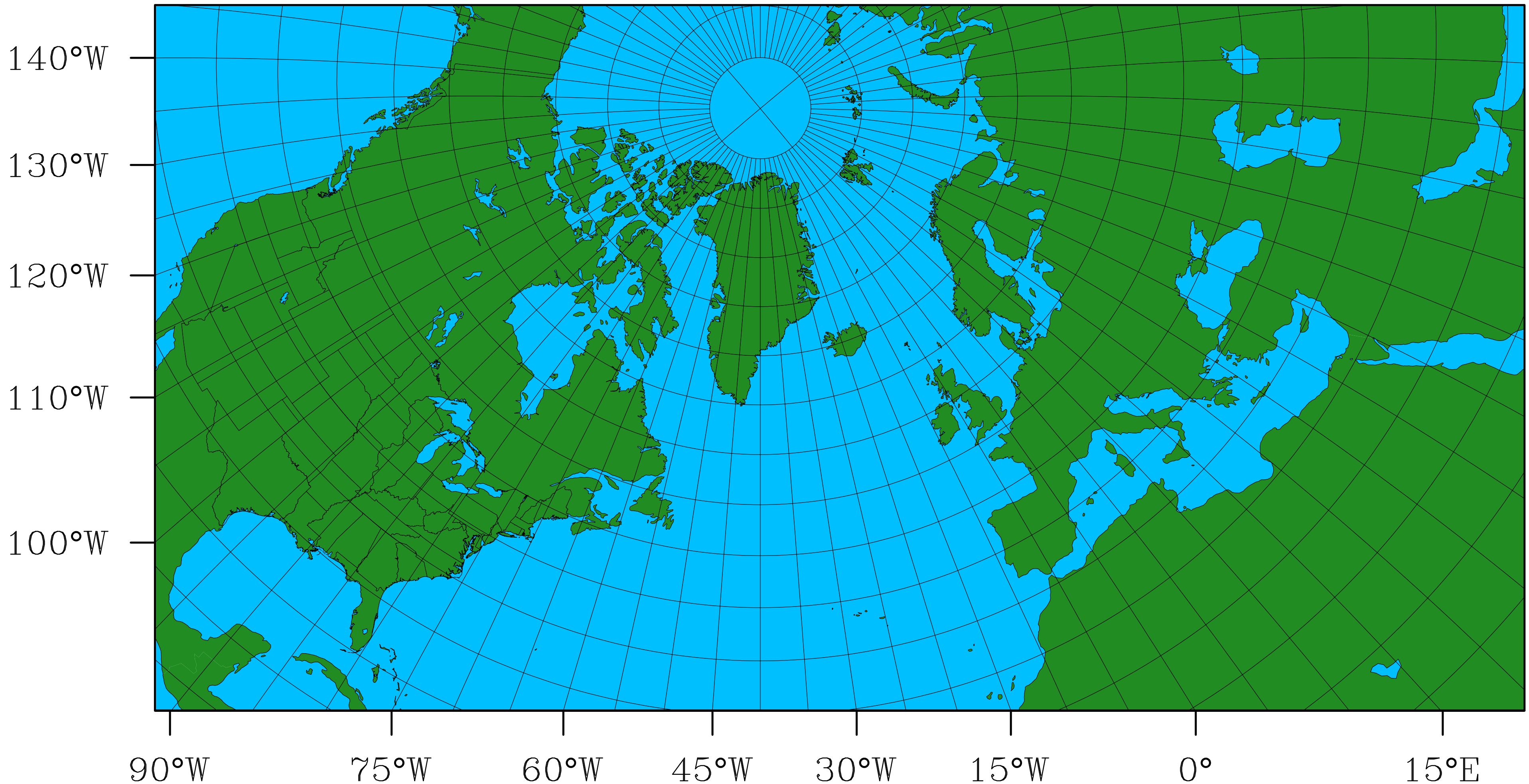
Nesting Suggestions – Inside Out

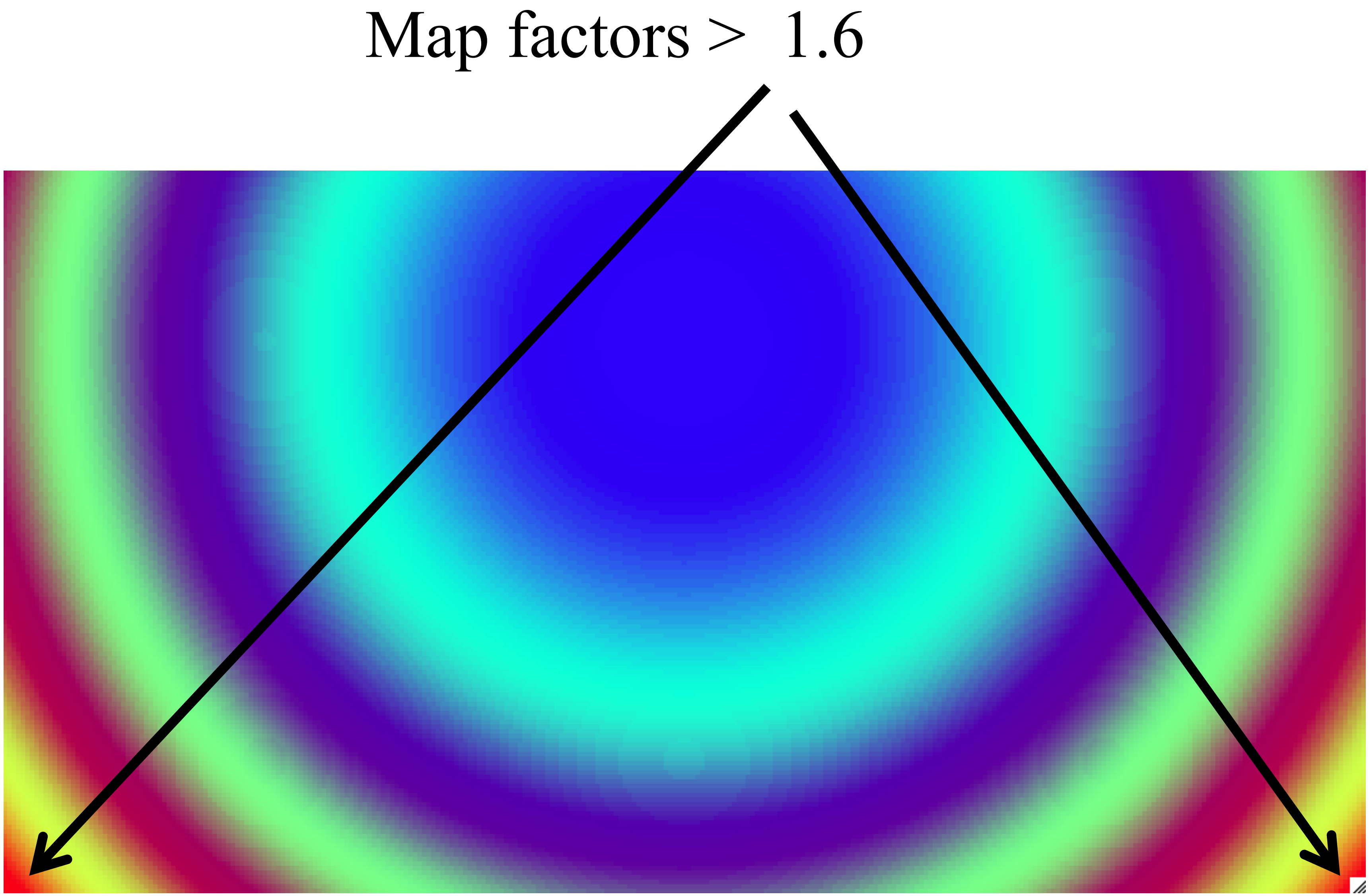
- Start with designing your inner-most domain. For a traditional forecast, you want everything important for that forecast to be entirely contained inside the domain.
- Then start adding parent domains at a 3:1 or 5:1 ratio. A parent should not have a smaller size (in grid points). Keep adding domains until the most coarse WRF grid has no more than a 3:1 to 5:1 ratio to the external model (first guess) data.

Nesting Suggestions – Big CG

- Larger domains tend to be better than smaller domains.
- A 60 m/s parcel moves at > 200 km/h. A 2-km resolution grid with 100x100 grid points could have all of the upper-level initial data swept out of the domain within a couple of hours.

Nesting Suggestions – CG dt




Map factors > 1.6

Nesting Suggestions – CG dt

- The most-coarse domain may have a geographic extent that causes large map factors.

```
time_step                  = 300 (BLOWS UP)
dx                         = 50000,16666,5555
grid_id                    = 1,    ,2     ,3
parent_id                  = 0,    ,1     ,2
parent_grid_ratio          = 1,    ,3     ,3
parent_time_step_ratio     = 1,    ,3     ,3
```

Nesting Suggestions – CG dt

- Reducing the time step so that the coarse grid is stable makes the model too expensive. 1.5x more

```
time_step                  = 200 (STABLE, PRICEY)
dx                         = 50000,16666,5555
grid_id                    = 1,    ,2     ,3
parent_id                  = 0,    ,1     ,2
parent_grid_ratio          = 1,    ,3     ,3
parent_time_step_ratio     = 1,    ,3     ,3
```

Nesting Suggestions – CG dt

- Only reduce the time step on the coarse grid, and keep the fine grid time steps at their approx original values.

```
time_step              = 200 (STABLE, CHEAP)
dx                     = 50000,16666,5555
grid_id                = 1,    ,2     ,3
parent_id              = 0,    ,1     ,2
parent_grid_ratio      = 1,    ,3     ,3
parent_time_step_ratio = 1,    ,2     ,3
```

Nesting Suggestions – CG dt

Domain Number	Original Time Step (s) UNSTABLE	Safe Time Step (s) STABLE EXPENSIVE	BETTER Time Step (s) STABLE CHEAPER
Domain 01 PARENT	300	200	200
Domain 02 CHILD	100	66.6	100

```
time_step               = 300 (UNSTABLE)
parent_time_step_ratio  = 1,   ,3    ,3
```

Nesting Suggestions – CG dt

Domain Number	**Original Time Step (s) UNSTABLE**	**Safe Time Step (s) STABLE EXPENSIVE**	**BETTER Time Step (s) STABLE CHEAPER**
Domain 01 PARENT	300	200	200
Domain 02 CHILD	100	66.6	100

```
time_step                  = 200 (STABLE, PRICEY)
parent_time_step_ratio     = 1,    ,3    ,3
```

Nesting Suggestions – CG dt

Domain Number	Original Time Step (s) UNSTABLE	Safe Time Step (s) STABLE EXPENSIVE	BETTER Time Step (s) STABLE CHEAPER
Domain 01 PARENT	300	200	200
Domain 02 CHILD	100	66.6	100

```
time_step                  = 200 (STABLE, CHEAP)
parent_time_step_ratio     = 1,   ,2    ,3
```

Nesting Suggestions – CG dt

- Model time step is always proportional to the time step of the most coarse grid.
- The coarse grid is the only grid impacted with large map factors: **`dt(s) = 6*dx(km)`**
- The nominal grid distance always needs to be scaled:

  dt(s) = 6*dx(km) **/ MAX (map factor in domain)**
- Reducing the coarse grid time step does not significantly reduce model performance if you can tweak the time step ratio.

Nesting Suggestions – CG dt

- **The take away:**

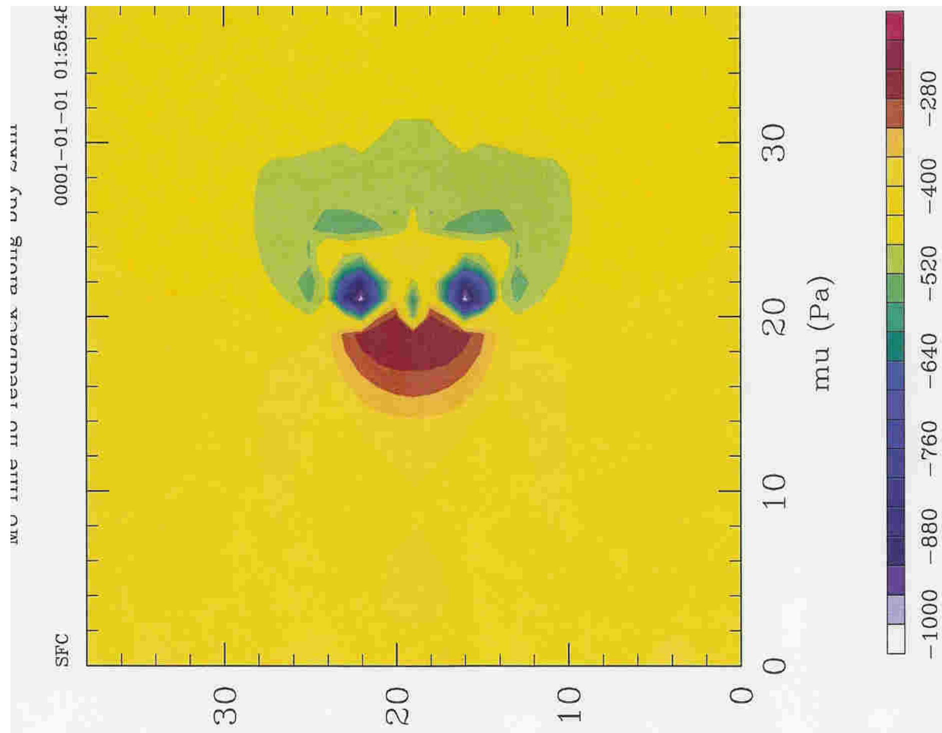
- The time step ratio and grid distance ratio are not necessarily identical, and may used effectively when large map factors in the coarse grid domain force a time step reduction for stability.
- If map factors are causing stability troubles, it is usually only the most coarse grid that is impacted since the fine grid is usually in the middle of the domain.

Nesting Suggestions - Wrap Up

- Set up domain first to provide good valid forecast, then deal with efficiency
- Selecting a set of domains with the reason "it is all I can afford" gets you into trouble
- Numerically stable and computationally expedient do not imply scientifically or physically valid

Review

- Nesting: Journalism 101: Who, what, why, when, where
- Domains
  - OK *vs* semi-OK *vs* not OK
  - Variable staggering CG to FG
  - Lateral forcing
  - Feedback
  - Masked interpolation
  - Time stepping for multi-domain
- Concurrent *vs* Offline Nesting
- Registry
  - U D F S
  - i2
- Some suggestions
  - Performance
  - Location, location, location
  - Inside out, start with inner domain
  - Go big or go home
  - Map factors, stability, time step, domain size



Nesting PART 2

- Nesting steps inside of WRF
- Available source code options
- Choosing the nested interpolation type
- Building automatically accessed routines

Nesting Sequence Inside of WRF

- The WRF model always has the **parent domain integrate a single time step**, then the code checks to see if a child domain exists (valid time)

- The parent has **current** (t+dt) information stored in the _2 variables and the information from the **previous time step** stored in the _1 variables (for example t_1, t_2, etc).

- These two time levels of data allow the lateral boundary conditions for the fine grid to be handled similarly to that of the most coarse grid: an interpolated **initial value** of the nest (the old time, _1) **and a tendency** to get to the next time are required

Nesting Sequence Inside of WRF

- The initial value and the tendency from the parent domain are **horizontally interpolated onto the child domain**
- For a nest ratio of 3:1, then three child time steps are required to get to the parent current time. The **tendency** during these three child time steps **along the lateral boundaries remains constant**
- At the end of the last child time step required to get to the parent's current time, for a two-way nest, the **child information feeds back** to the parent domain

Available Source Code Options

- The nesting inside of WRF requires a few types of routines:
  - **Horizontally interpolate** the parent to the child
  - **Generate the lateral boundary conditions** for the child
  - **Feed back** information from the child to the parent
  - Optionally **smooth** the area in the parent covered by the child domain after feedback

- All of these options are selected through **the Registry**

Available Source Code Options

- In the Registry, the nesting options are located with the I/O flags

```
Latitude: du=(copy_fcnm)
U: usdf=(bdy_interp:dt)
TSK: d=(interp_mask_field:lu_index,iswater)u=(copy_fcnm)
LANDMASK: d=(interp_fcnm_imask)u=(copy_fcnm)
SST: d=(interp_mask_field:lu_index,iswater)
```

- but could be as complicated as

```
SST: d=(interp_mask_field:lu_index,iswater)\
f=(p2c_mask:lu_index,tslb,num_soil_layers,iswater)
```

Available Source Code Options

- The syntax for horizontal interpolation from the parent to the child is **“d” for “down”**

```
d=(subroutine_name: optional arguments, comma separated)
```

- Default is interp_fcn

- The “d” option is handled only **once per domain**, at initialization

Available Source Code Options

- The syntax for feedback from the child back to the parent is **“u” for “up”**

```
d=(subroutine_name: optional arguments, comma separated)
```

- Default is copy_fcn

- The “u” is processed in the WRF model after the **last in the sequence of required fine grid time steps** to bring the child domain up to the same time as the parent

Available Source Code Options

- The syntax for the lateral boundary tendency computation is **`"f" for LBC "forcing"`**

`f=(subroutine_name: optional arguments – typically time step)`

- Default is interp_bdy (but specified because the time step argument is always used)

- Any domain that would like to have the **child domain given information at the end of each parent time step** (such as lateral boundaries), may use the "f=()" Registry option.

- Some developers have subroutines that **interpolate a child domain from the parent at EACH parent time step** (SSTs and perturbations from SKEBS are examples)

Choosing the Nested Interpolation Type

- At run-time, the user **may select the order of the horizontal interpolation** to be used

```
&domains
interp_method_type = 1: bilinear
                     2: sint
                     3: nearest neighbor
                     4: quadratic
/
```

- The same order/type of interpolator is used the initial horizontal interpolation and the subsequent lateral boundary interpolation

Building Automatically Accessed Routines

- The registry program manufactures a default template for the subroutine call.

```
SUBROUTINE interp_fcn                                & SUBR CALL
    ( cfld,                                          & CG
      cids, cide, ckds, ckde, cjds, cjde,            & CG DIMS I
      cims, cime, ckms, ckme, cjms, cjme,            & CG DIMS J
      cits, cite, ckts, ckte, cjts, cjte,            & CG DIMS K
      nfld,                                          & FG
      nids, nide, nkds, nkde, njds, njde,            & FG DIMS I
      nims, nime, nkms, nkme, njms, njme,            & FG DIMS J
      nits, nite, nkts, nkte, njts, njte,            & FG DIMS K
      shw,                                           & STENCIL WIDTH
      imask,                                         & NEST MASK
      xstag, ystag,                                  & STAGGERING X Y
      ipos, jpos,                                    & NEST START LOCATION
      nri, nrj                                       ) NEST RATIO I J
```

Building Automatically Accessed Routines

- The lateral boundary routines (the "f=()" option) always get the eight boundary arrays appended (total of 16 arrays, 8 for parent, 8 for child).

Building Automatically Accessed Routines

```
SUBROUTINE bdy_interp ( &
   cfld, cids, cide, ckds, ckde, cjds, cjde, cims, cime, ckms, ckme, cjms, cjme,   &
   cits, cite, ckts, ckte, cjts, cjte,   &
   nfld, nids, nide, nkds, nkde, njds, njde, nims, nime, nkms, nkme, njms, njme,   &
   nits, nite, nkts, nkte, njts, njte,   &
   shw, imask, xstag, ystag, ipos, jpos, nri, nrj,             &
    cbdy_xs, nbdy_xs,      &  ! CG FG X start
    cbdy_xe, nbdy_xe,      &  ! CG FG X end
    cbdy_ys, nbdy_ys,      &  ! CG FG Y start
    cbdy_ye, nbdy_ye,      &  ! CG FG Y end
    cbdy_txs, nbdy_txs,    &  ! TEND X start
    cbdy_txe, nbdy_txe,    &  ! TEND X end
    cbdy_tys, nbdy_tys,    &  ! TEND Y start
    cbdy_tye, nbdy_tye,    &  ! TEND Y end
    cdt, ndt               )  ! CG FG dt
```

Building Automatically Accessed Routines

- Any extra variables are ALWAYS tagged on to the end of the subroutine, and always in pairs: parent and child (for example: time step, land mask, etc).

Building Automatically Accessed Routines

`Registry.EM_COMMON` example:

state real TGR_URB2D ij misc 1 - \
rd=(**`interp_mask_land_field:lu_index`**)u=(copy_fcnm) \
"TGR_URB" "URBAN GREEN ROOF SKIN TEMPERATURE"
"K”

Building Automatically Accessed Routines

Manufactured call to this routine:

```
SUBROUTINE interp_mask_land_field ( &
  enable,          &
  cfld,            &
  cids, cide, ckds, ckde, cjds, cjde,   &
  cims, cime, ckms, ckme, cjms, cjme,   &
  cits, cite, ckts, ckte, cjts, cjte,   &
  nfld,            &
  nids, nide, nkds, nkde, njds, njde,   &
  nims, nime, nkms, nkme, njms, njme,   &
  nits, nite, nkts, nkte, njts, njte,   &
  shw, imask, xstag, ystag, ipos, jpos, nri, nrj, &
  clu, nlu         )
```

Building Automatically Accessed Routines

- The user may place the new routine (called by the name given in the Registry file) in the **`share/interp_fcn.F`** file

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Nesting PART 2

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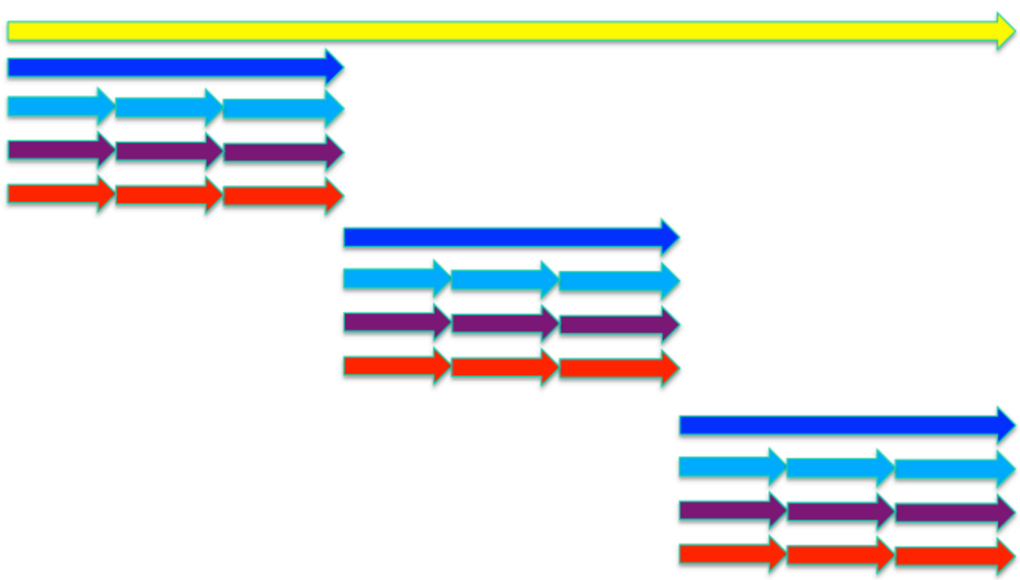
Always, the parent domain completes a time step, before starting a child time step



Always, a test is made for a valid child domain before taking a parent domain step

Nesting PART 2

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U: up

Feed back FG to CG at the end of each FG sequence

D: down

Horizontally interpolate CG to FG at the instantiation of each FG domain

Nesting PART 2

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F: forcing

1) Primarily for lateral boundary forcing
2) Also used for SST (CG to FG), as these routines are called at the beginning of each FG sequence

Nesting PART 2

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Users may choose different horizontal interpolators, though mostly required to be the same for all variables during a single run

Nesting PART 2

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Several types of routines are automatically manufactured by the registry program, including most nesting operations

Users may develop their own nesting features by following the assumed calling structure