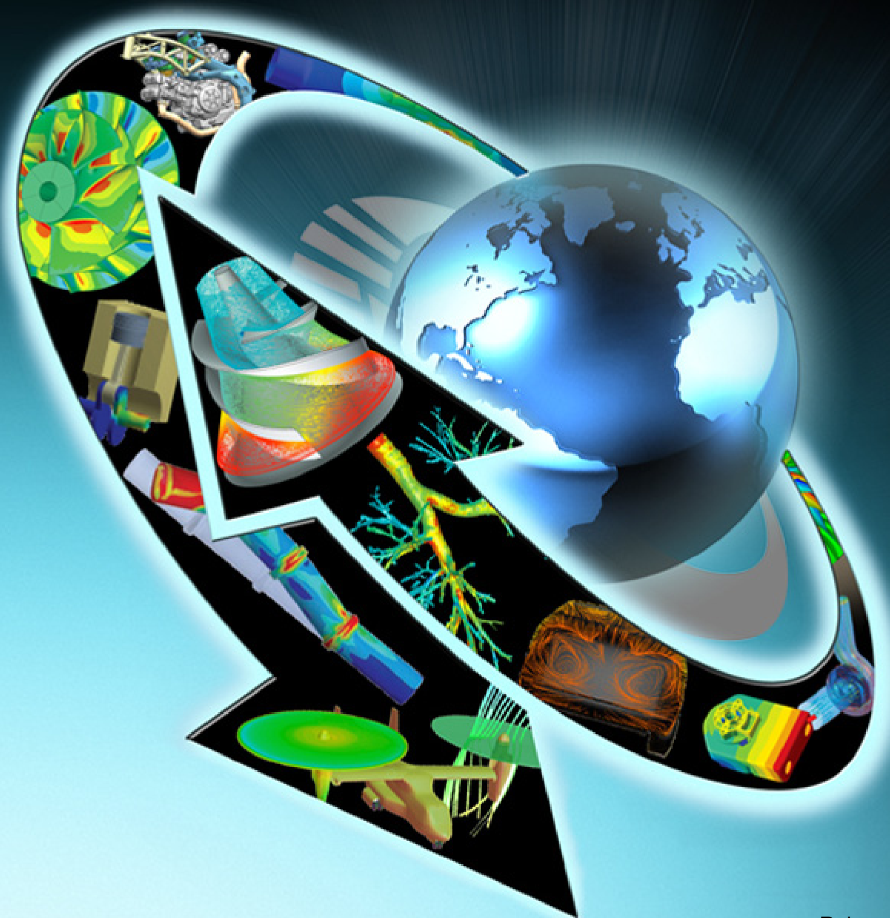
Chapter 1

Introduction and FLUENT Data Structure



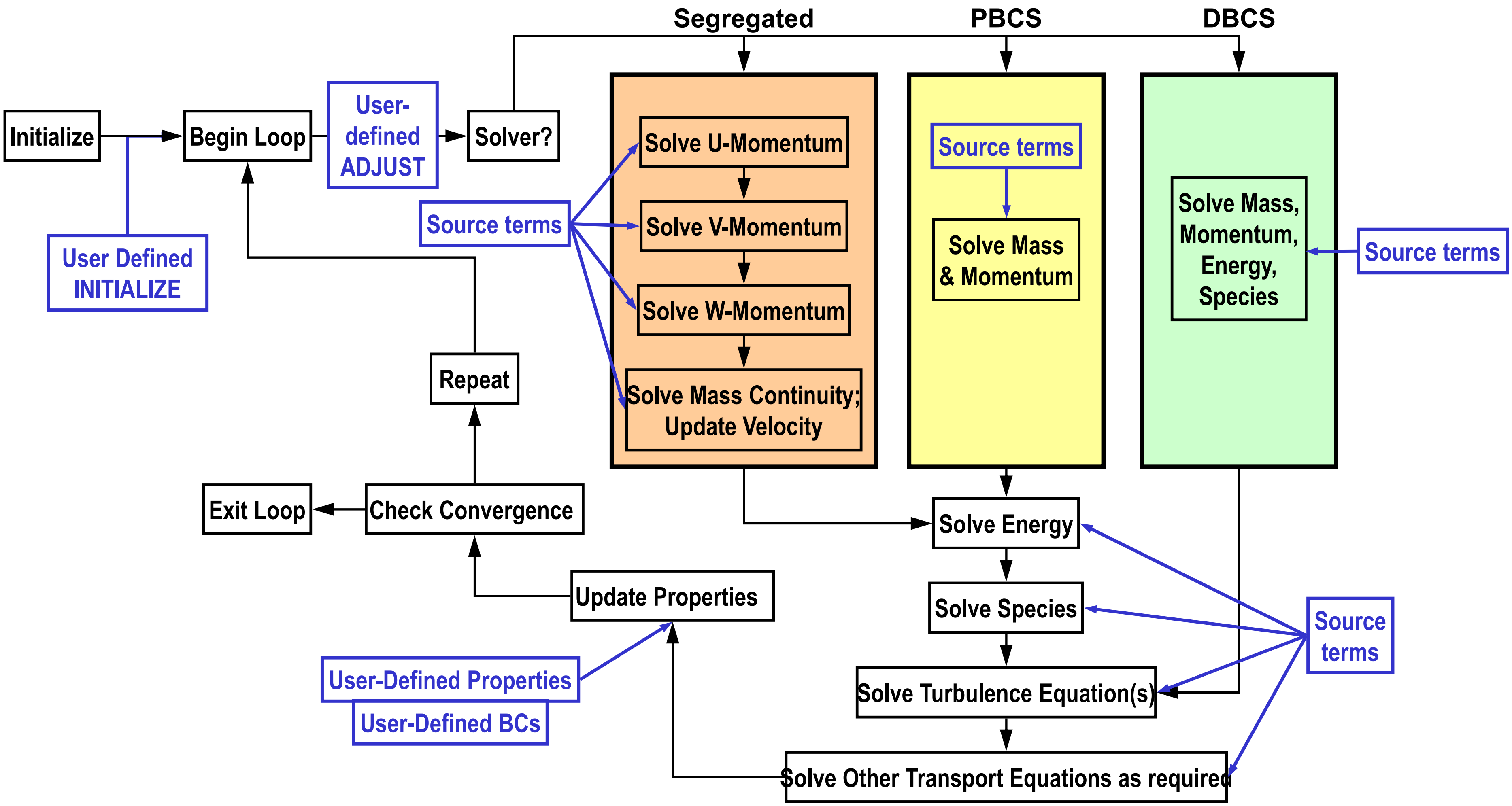
Advanced FLUENT User-Defined Functions

Release 13.0
December 2010

Introduction

- **The FLUENT solver is a general-purpose code. In order to customize the FLUENT solver, users can use their own C-codes called user-defined functions (UDFs) to accomplish:**
  - **Special boundary conditions**
  - **Customized or solution dependent material properties**
  - **New physical models**
  - **Reaction rates**
  - **Source terms**
  - **Customized post-processing**
  - **Solving user-supplied partial differential equations**
  - **More ….**

User Access to the FLUENT Solver



C Programming (1)

- Basic syntax rules:
  - each statement must be terminated with a semicolon ;
  - comments can be inserted anywhere between /* and */
  - variables must be explicitly declared (unlike in FORTRAN)
  - compound statements must be enclosed by braces { }
  - functions have the following format:

```
return-value-type function-name (parameter-list)
        { function body }
```

  - Macros are defined in the header files, they can be used just like functions
- Built-in data types: int, float, double, enum, boolean:

```
int  niter, a;  /* declaring 'niter' and 'a' as integers */
float  dx[10];   /* 'dx' is a real array with 10 members, the
                                   array index always starts from dx[0]  */

enum {X, Y, Z};  /* X, Y, Z are enumeration constants 0, 1, 2 */
```

C Programming (2)

- pointer is a special kind of variable that contains the memory address, not content, of another variable
- Pointers are declared using the * notation:

```
int *ip; /* ip is declared as a pointer to integer */
```

- We can make a pointer point to the address of predefined variable as follows:

```
int a=1;
int *ip;
ip = &a; /* &a returns the address of variable a */
printf("content of address pointed to by ip = %d\n", *ip);
```

- Pointers are also used to point to the beginning of an array
  – Thus pointers are used to address arrays in C
- Array variables can be defined using the notation name[size] where name is the variable name and size is an integer which defines the number of elements in the array (from 0 to size-1)

C Programming (3)

– **Operators**

`=` (assignment)

`+, -, *, /, %` (modulus)

`<, >, >=, <= , ==, !=`

`++` increment; `i++` is “post-increment”: use the *current* value of `i` in the expression, then increment i by 1 (`i=i+1`)

`--` decrement: `j--` post-decrement, use the current value of `j`, then decrement j by 1 `(j=j-1)`

`+=` addition assignment:

```
agg += single; /* it means agg=agg+single;  */
```

`*=` multiplication assignment, `-=` subtraction assignment,

`/=` division assignment

C Programming (4)

– **Basic control structures**

```
if ( … )
 <statement>;

if ( …)
 <statement>;
else
 <statement>;

if ( …)
  <statement>;
else if ( … )
 <statement>;
```

For Loops:

```
for ( k=0; k < NUM; k++ )
        <statement>;
```

While Loops:

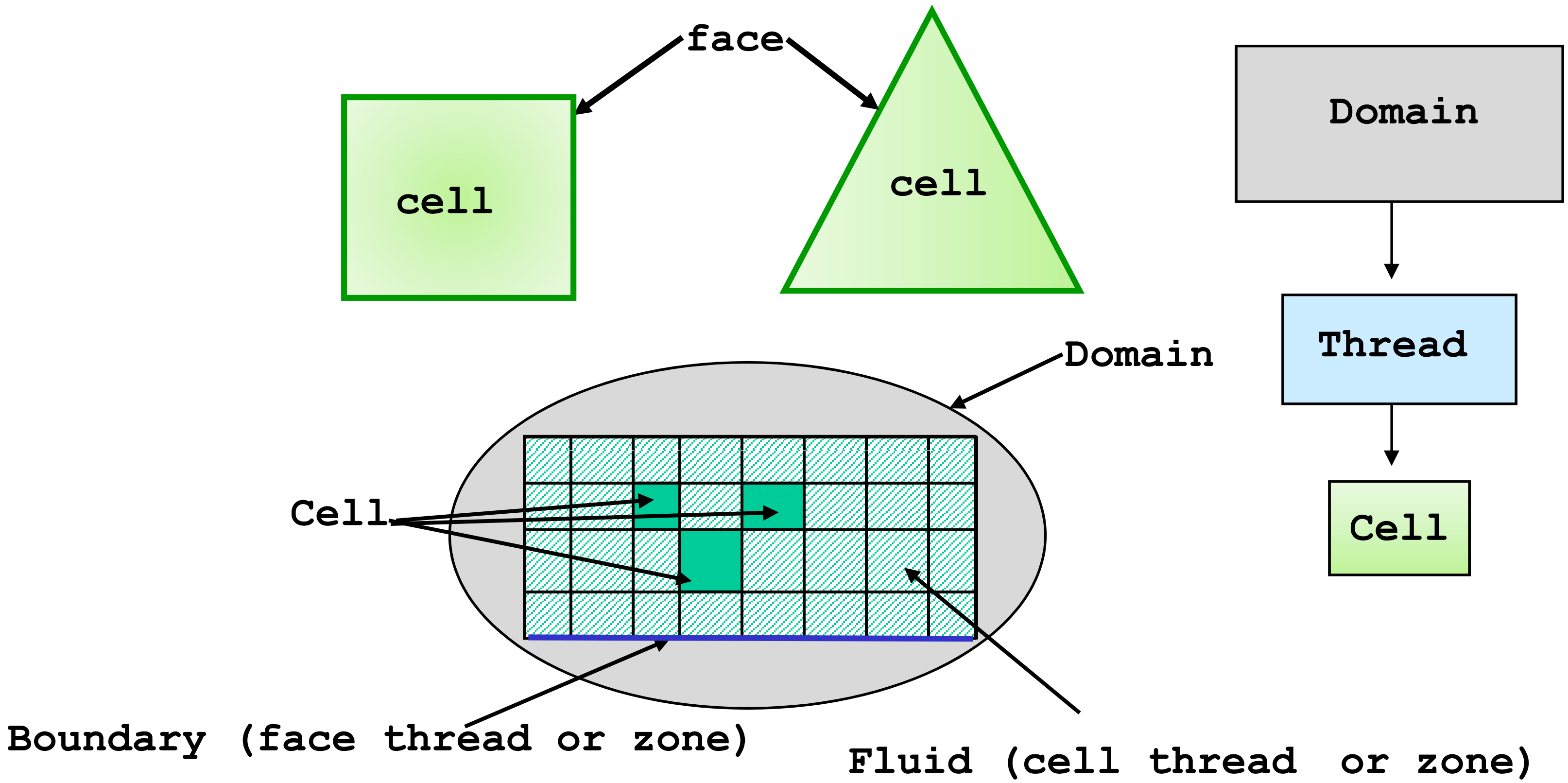
```
while ( … )
<statement>;
```

Conditional Operator (? :)
(condition ? operand a : operand b)
example:
real At = (rp_axi ? At*2*M_PI : At);

CFD Programming in FLUENT

- **We (as CFD programmers in FLUENT) want to know how FLUENT organizes data so that we know:**
  - **How to access mesh information for a particular cell zone or a face zone**
    - **Cell centroids, cell volumes, the neighbors, etc.**
    - **Face centroids, face areas, face normal directions (vectors), etc.**
  - **How to access field data for cells (and faces): pressure, velocity, density, etc.**
  - **How to efficiently loop through these cells or faces in the codes**
- **How to supply customized source terms, boundary conditions, and fluid properties, etc., to the solver**
- **How to modify the behaviors or specific model parameters for various physical models as in turbulence, reactions kinetics, multiphase, and dynamic mesh, etc.**
- **How to implement user's own governing equations in the finite-volume framework of FLUENT solver**

Data Structure Overview



The Domain

- **Domain is the set of connectivity and hierarchy info for the entire data structure in a given problem for single phase flows. It includes:**
  - **all fluid zones ('fluid threads')**
  - **all solid zones ('solid threads')**
  - **all boundary zones ('boundary threads')**
- **Cell: Cell is the computational unit, conservation equations are solved over each cell**
- **Face: direction is in the outward normal**
- **Threads: represent the zones of cells or faces; a Thread represents a fluid zone or solid zone, or a boundary zone**
- **multiphase simulations (single-phase simulations has one domain only)**
  - **Each phase has its own "Domain-structure"**
  - **Geometric and common property information are shared among 'sub-domains'**
  - **Multiphase UDF will be discussed later**

The Threads

- A `Thread` is a sub-set of the `Domain` structure
- Individual '`fluid`', '`solid`' and each '`boundary`' zones are identified as '`zones`' and their datatype is `Thread`
- '`Zone`' and '`Thread`' terms are often used interchangeably
- Some further details about `Zone/Thread ID` and `Thread-datatype`:
  - Zones are identified at mesh level with an integer `ID` in the `Define/Boundary Condition` panel
  - `Threads`, a Fluent-specific datatype, store structured information about the mesh, connectivity, models, property, etc. all in one place
  - Users identify zones through the `ID`'s
  - `Zone/Thread-ID` and `Threads` are correlated through UDF macro's

Cell and Face Datatypes

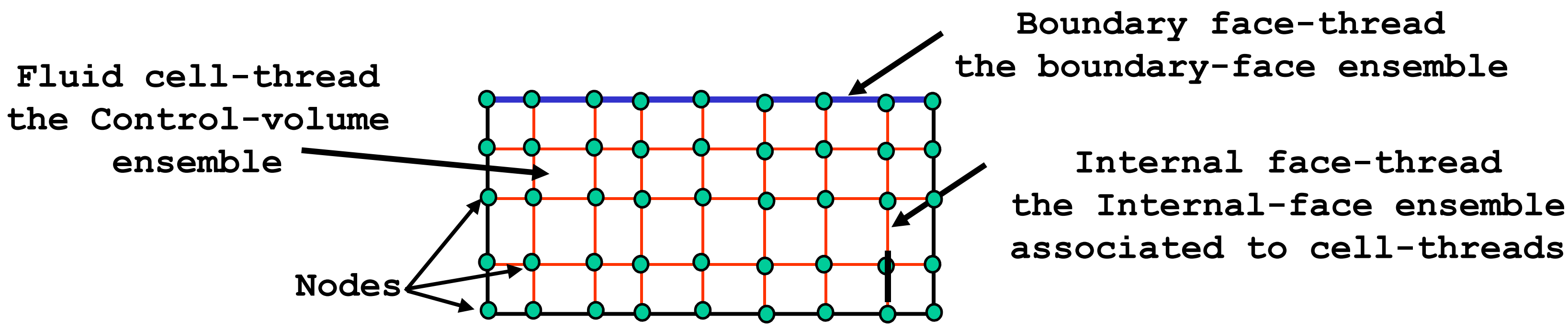
- **Control volumes of fluid and solid zones are also called '`cells`' in FLUENT**
  - **The member of a cell zone is typed as '`cell_t`' (the cell index)**
  - **The member the cell faces is typed as '`face_t`' (the face index)**
- **Each individual cell can be accessed by using cell index and the cell thread pointer (the zone which contains the cell)**
- **Each individual (boundary or internal) face can be accessed by using the face index and the face thread pointer (the zone which contains the face)**

Some additional info on Faces

- **Each Control volume has a finite number of faces**
  - **Face zones are listed as boundary `face-threads` with the fluid & solid cell-threads under `Define-Boundary_Condition` panel**
  - **Those faces which are inside the flow-domain and do not share any external boundary are not accessible from GUI (because you do not need them in general)**
  - **They can still be accessed from User-Defined-Functions**

Fluent UDF Data Structure Summary

- **The data structure for accessing a cell zone is typed as '`cell_t`' (the cell index); the data structure for faces is typed as '`face_t`' (the face index)**



Type	Example	Declaration
`Domain`	`*d`	`d` is a pointer to domain thread
`Thread`	`*t`	`t` is a pointer to thread
`cell_t`	`c`	`c` is cell thread index
`face_t`	`f`	`f` is a face thread index
`Node`	`*node`	`node` is pointer to a node

Fluent UDF Data Structure Summary (2)

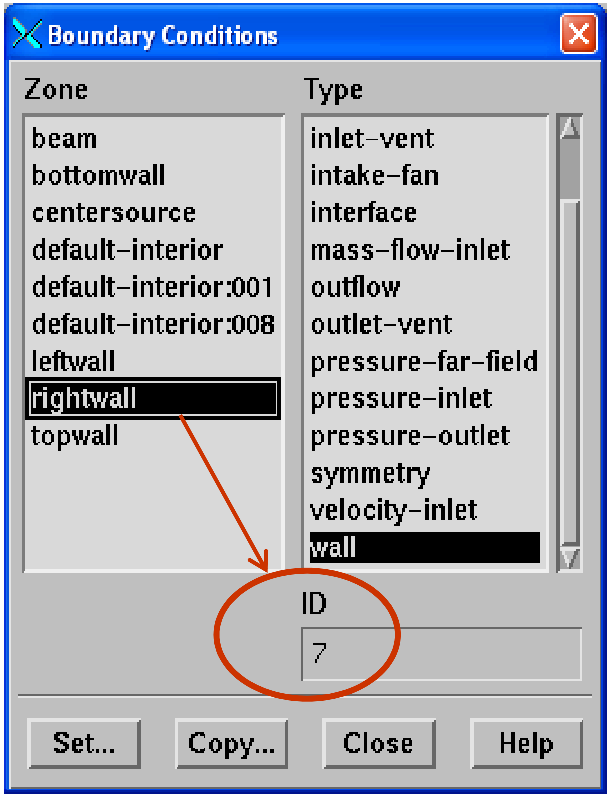
- **Each thread (zone) has a unique integer ID available in the boundary condition panel (or can be listed by the list-zone TUI command: `/grid/modify-zones/list-zones`)**
- **Given a correct ID, the `Lookup_Thread` macro can retrieve the *thread pointer***

```
int ID=7;
Thread *tf=Lookup_Thread(domain, ID);
```

- **Conversely, given a thread pointer tf, the zone ID can be retrieved**

```
ID=THREAD_ID(tf);
```

- **Once we have the correct pointer (for a specific zone), we can access the members belonging to the zone without any problem. Thread pointer provides the leading address of the thread (zone)**

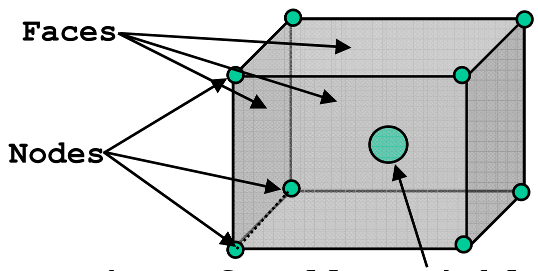


Geometry Macros

- `C_NNODES(c, t)` **Number of nodes in a cell**
- `C_NFACES(c, t)` **No. of faces in a cell**
- `F_NNODES(f, t)` **No. of nodes in a face**
- `C_CENTROID(x, c, t)` **x, y, z-coords of cell centroid**
- `F_CENTROID(x, f, t)` **x, y, z-coords of face centroid**
- `F_AREA(A, f, t)` **Area vector of a face;**
- `NV_MAG(A)` **Area-magnitude**
- `C_VOLUME(c, t)` **Volume of a cell**
- `C_VOLUME_2D(c, t)` **Volume of a 2D cell**

  (Depth is 1 m in 2D; 2*π rad in axi-symmetric)

A Hex cell



Location of cell variables

```
C_NNODES(c,t) = 8
C_NFACES(c,t) = 6
F_NNODES(f,t) = 4 each
```

- `NODE_X(nn)` **Node x-coord; (nn is a node pointer)**
- `NODE_Y(nn)` **Node x-coord;**
- `NODE_Z(nn)` **Node x-coord;**

Many more are available. See the FLUENT UDF Manual

Macros for Cell Variables

`C_R(c,t)`	Density
`C_P(c,t)`	Pressure
`C_U(c,t)`	Velocity components
`C_V(c,t)`	Velocity components
`C_W(c,t)`	Velocity components
`C_T(c,t)`	Temperature
`C_H(c,t)`	Enthalpy
`C_K(c,t)`	Turbulent kinetic energy
`C_D(c,t)`	Turbulent energy dissipation
`C_YI(c,t,i)`	`the i-th` Species' mass fraction
`C_UDSI(c,t,i)`	`the i-th` User defined scalar

`t` is a cell-thread pointer, `c` is a cell index, and `i` is an integer for indexing

More Cell Macros

- `C_DUDX(c,t)`
- `C_DUDY(c,t)`
- `C_DUDZ(c,t)`
- `C_DVDX(c,t)`
- `C_DVDY(c,t)`
- `C_DVDZ(c,t)`
- `C_DWDX(c,t)`
- `C_DWDY(c,t)`
- `C_DWDZ(c,t)`

Velocity derivatives

- `C_MU_L(c,t)` **Laminar viscosity**
- `C_MU_T(c,t)` **Turbulent viscosity**
- `C_MU_EFF(c,t)`
- `C_DP(c,t)[i]` **Pressure gradient (derivative)**
- `C_D_DENSITY(c,t)[i]` **Density gradient (derivative)**

Loop Macros in UDF

- `thread_loop_c(ct,d) { }` for loop over cell threads in domain d
- `thread_loop_f(ft,d) { }` for loop over face threads in domain d

  (Note: ct, ft and d are pointers to Thread)

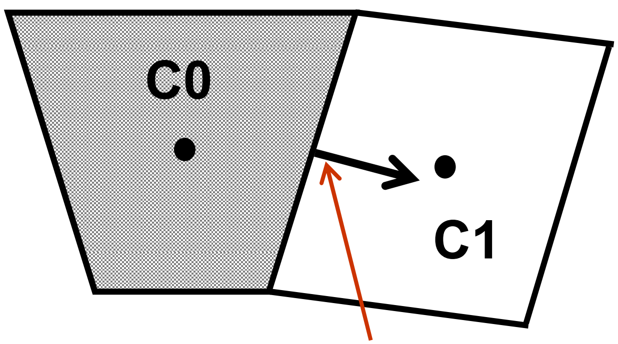
- ```
  begin_c_loop(c, t)
  {...}
  end_c_loop (c,t)
  ```
  for loop over cells in a given cell thread t

- ```
  begin_f_loop(f, f_thread)
    { ... }
   end_f_loop(f, f_thread)
  ```
  for loop over all faces in a given face thread f_thread

Macros for Accessing Cells/Faces

- **For any given face, the cell from which the face normal vector points *away* is called the C0 cell; and the cell which the face normal vector points at is called the C1 cell. The following program fragment calculate the total cell volume next to a given face zone with zone ID on the C0 side:**

```
Thread *tf, *t0;
face_t f;
cell_t c0;
real totalV=0.;
tf = Lookup_Thread(domain, ID);
t0 = THREAD_T0(tf);     /*get the c0 thread */
begin_f_loop(f, tf)
  { c0=F_C0(f, tf);
    totalV += C_VOLUME(c0, t0);
  }
end_f_loop(f, tf)
```



a face normal vector for the C0 cell

Top-Level UDF Macros

- **User's own codes must use the *top-level* UDF macros in order to communicate with the FLUENT solver**
  - **Profiles** : `DEFINE_PROFILE`
  - **Source terms** : `DEFINE_SOURCE`
  - **Properties** : `DEFINE_PROPERTY`
  - **User-defined Scalars** : `DEFINE_UNSTEADY`, `DEFINE_FLUX`, `DEFINE_DIFFUSIVITY`
  - **Initialization** : `DEFINE_INIT`
  - **Global Functions** : `DEFINE_ADJUST`, `DEFINE_ON_DEMAND`, `DEFINE_RW_FILE`
  - **Wall-heat-flux** : `DEFINE_HEAT_FLUX`
  - **Model-Specific Functions** : `DEFINE_DPM_`…, `DEFINE_SR_RATE`, `DEFINE_VR_RATE`, …

Refer to the UDF Manual for a complete list

The Header Files

- **The udf-macros are defined in the `'udf.h'` file**
- **`udf.h` is a fluent header file in the `{Fluent installed directory}/Fluent12.y/src/` directory**
- **`udf.h` must be included at the top in each and every udf file**
  - **A file may contain more than one UDF**
  - **User can use multiple files for UDF**
- **Any UDF you might write <u>`must`</u> use one of the `'DEFINE_…'` macros from this `udf.h` file**
- **There are many more header files stored in the same directory can be browsed by users**

```
#define DEFINE_PROFILE(name, t, i) void name(Thread *t, int i)
#define DEFINE_PROPERTY(name,c,t) real name(cell_t c, Thread *t)
#define DEFINE_SOURCE(name, c, t, dS, i) \
        real name(cell_t c, Thread *t, real dS[], int i)
#define DEFINE_INIT(name, domain) void name(Domain *domain)
#define DEFINE_ADJUST(name, domain) void name(Domain *domain)
#define DEFINE_DIFFUSIVITY(name, c, t, i) \
        real name(cell_t c, Thread *t, int i)
```