SimCenter NHERI
Center for Computational Modeling and Simulation

Programming Bootcamp

C: Day 2

Pointers, Arrays, User Defined Types & Abstraction

Frank McKenna
University of California at Berkeley

NSF award: CMMI 1612843

Todays Outline

- Memory, Pointers & Arrays (15min)
- Exercise: dgemm operation: C = C + A*B (45min)
- Abstraction (15 min)
- Exercise: stressTransform with structures (45min)
- File I/O (10min)
- Exercise: stressTransform – read and write (50min)

- Exercises: advanced options available.

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C: Memory, Pointers & Arrays

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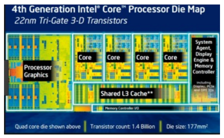
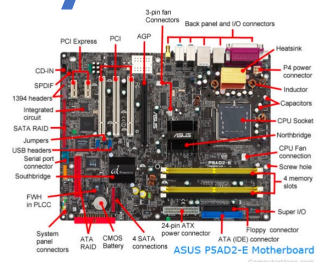
Computer Memory Hierarchy

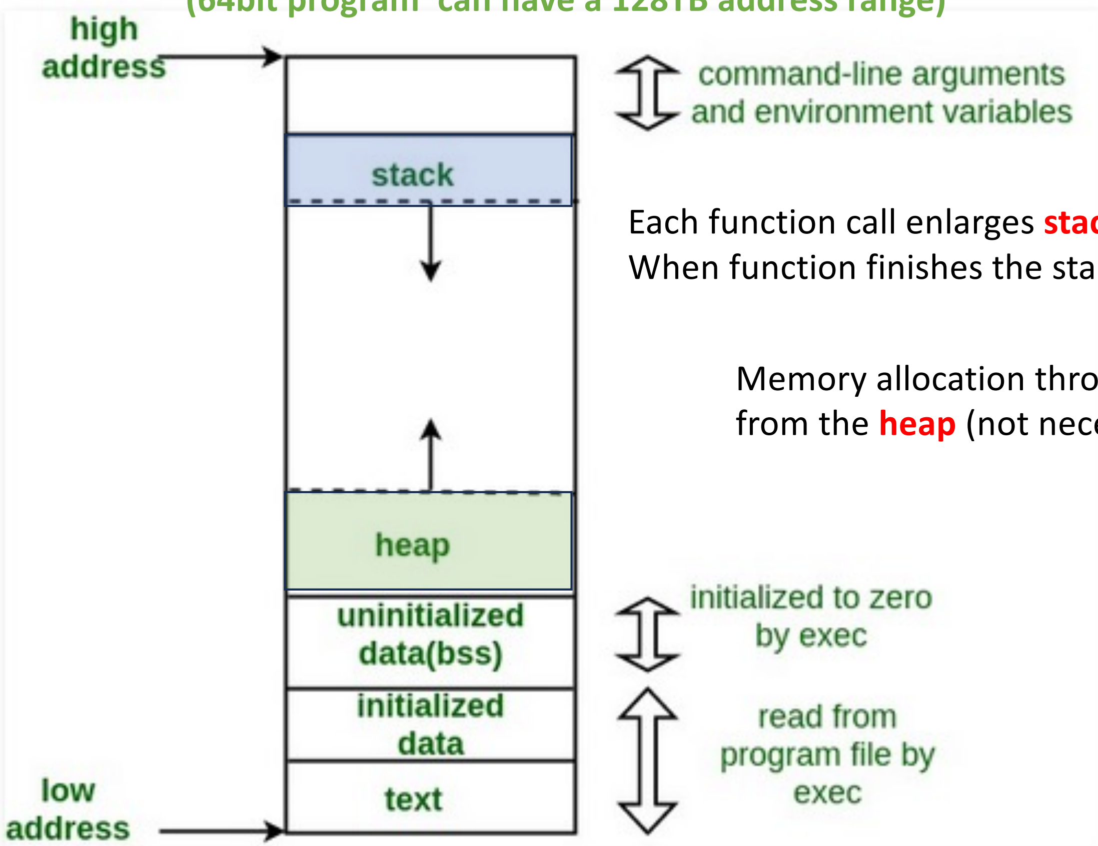




	Core Processor	L1 Cache	L2 Cache	L3 Cache	*Memory(RAM)*	Disk: **Hard Drive**	Disk: **SSD**
	Control Arithmetic Registers						
Size	1000 Bytes	64 KB	256 KB	2-4 MB	4-32 GB	4-16 TB	*.25-1TB*
Latency	0.3 ns	1 ns	3-10 ns	20-30 ns	50-100 ns	5-10e6 ns	25-50e3 ns
	Compiler	HW	HW	HW	Operating System	Operating System	

Memory Layout of a RUNNING Program

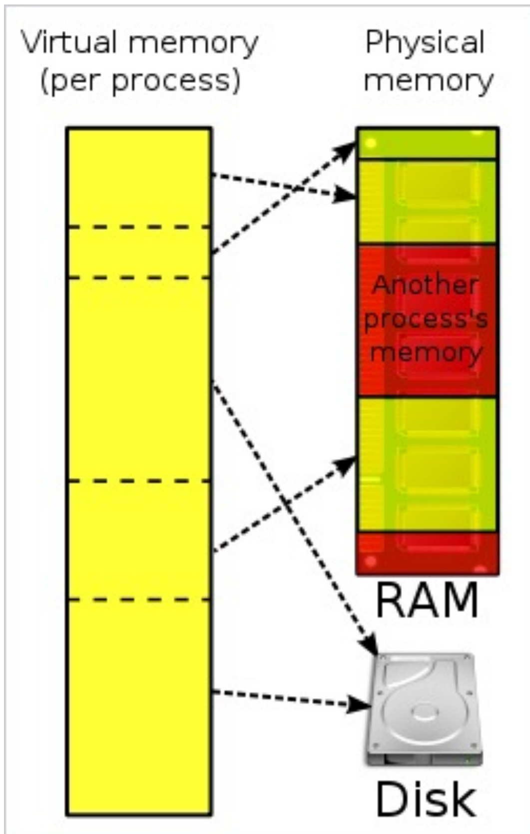
(64bit program can have a 128TB address range)



Each function call enlarges **stack** with the function variables
When function finishes the stack is popped

Memory allocation through malloc() and new[] is allocated memory from the **heap** (not necessarily one chunk after another)

Operating System & Virtual Memory



- Virtual Memory is a memory management technique that provides an "idealized abstraction of the storage resources that are actually available on a given machine” wikipedia.
- Program Memory is broken into a number of pages. Some of these are in memory, some on disk, some may not exist at all (segmentation fault)
- CPU issues virtual addresses (load b into R1) which are translated to physical addresses. If page in memory, HW determines the physical memory address. If not, page fault, OS must get page from Disk.
- Page Table: table of pages in memory.
- Page Table Lookup – relatively expensive.
- Page Fault (page not in memory) very expensive as page must be brought from disk by OS
- Page Size: size of pages
- TLB Translation Look-Aside Buffer HW cache of virtual to physical mappings.
- Allows multiple programs to be running at once in memory.

WARNING

- Arrays and Pointers are the **source of most bugs in C Code**
  - You will have to use them if you program in C
  - Always initialize a pointer to 0
  - Be careful you do not go beyond the end of an array
    - Be thankful for segmentation faults
    - If you have a race condition (get different answers every time you run, probably a pointer issue)

Pointer Variables

A **Pointer Variable** is a named memory location that can holds an address**.**

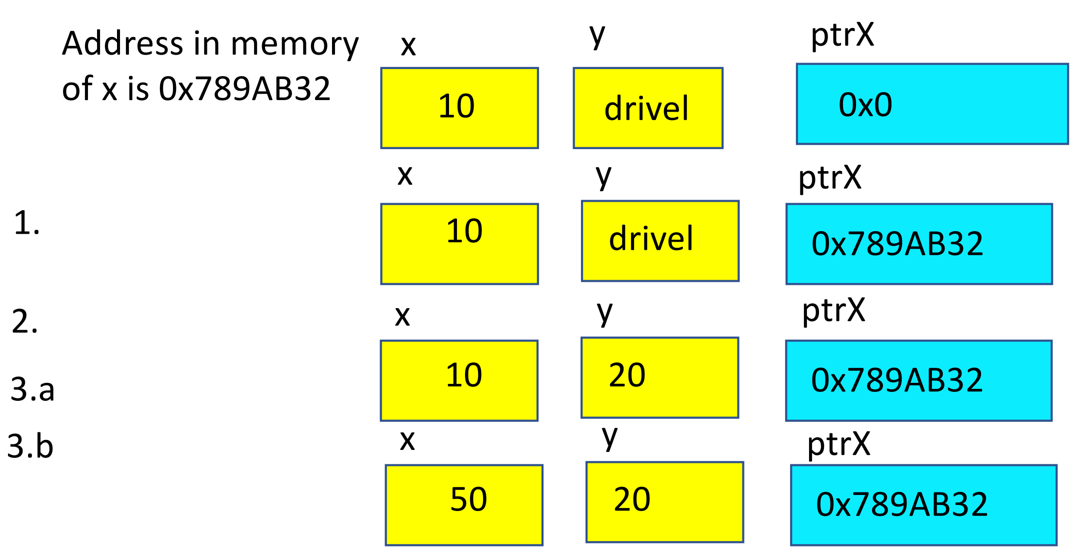
1. The unary ***** in a declaration indicates that the object is a pointer to an object of a specific type
2. The unary **&** gives the "**address**" of an object in memory, e.g. &x is location of variable x
3. The unary ***** elsewhere treats the operand as an address and dereferences it, which depending on which side of operand is does one of two things:

   a. fetches the contents for use in an expression

   b. Sets the memory location to which it points to some value.

```
#include <stdio.h>
int main() {
    int x =10, y;
    int *ptrX =0;
    ptrX = &x;
    y = *ptrX + x;
    *ptrX = 50;
}
```

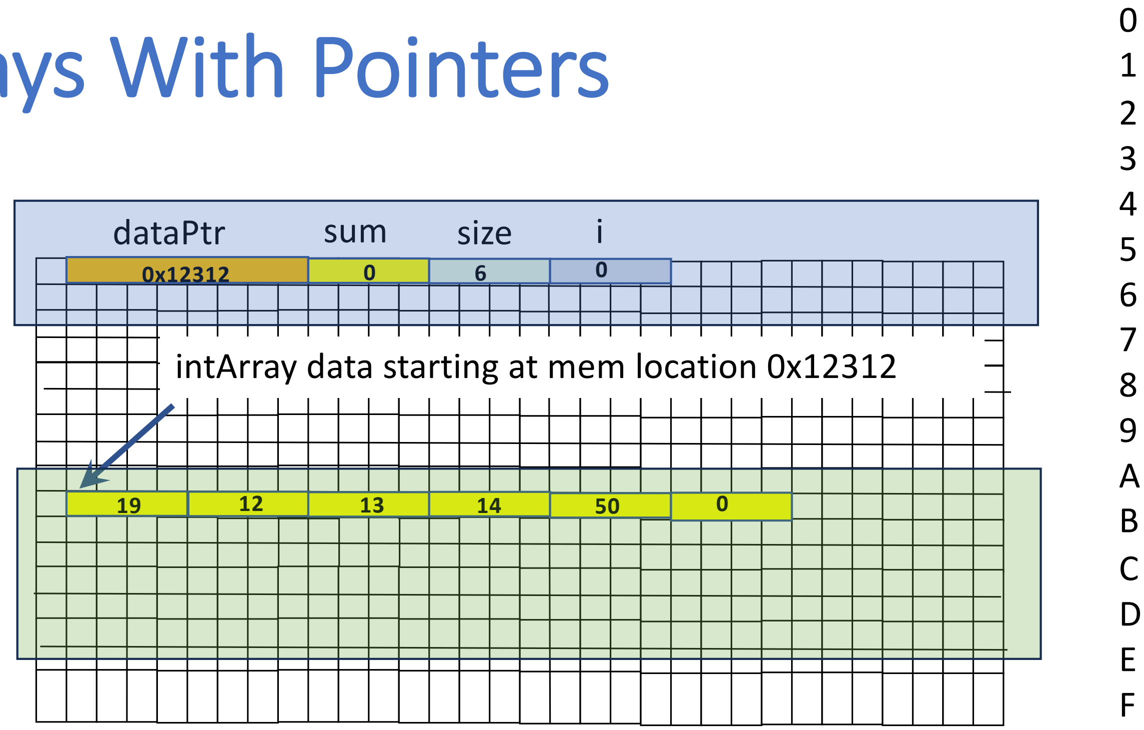
pointer1.c




```
int x=10;
int y;
int *ptrX = 0;

ptrX = &x;

y = *ptrX + x;

*ptrX = 50;
```

Iterating Through Arrays With Pointers

```
#include <stdio.h>
int sumArray(int *arrayData, int size);
int main(int argc, char **argv) {
  int intArray[6] = {19, 12, 13, 14, 50, 0};
  int sum1 = sumArray(intArray, 6);
  printf("sum: %d\n", sum1);
  return(0);
 }

// function to evaluate vector sum
int sumArray(int *dataPtr, int size) {
  int sum = 0;
  for (int i = 0; i < size; i++) {
    sum += *dataPtr;
    dataPtr++;
  }
  return sum;
}
```

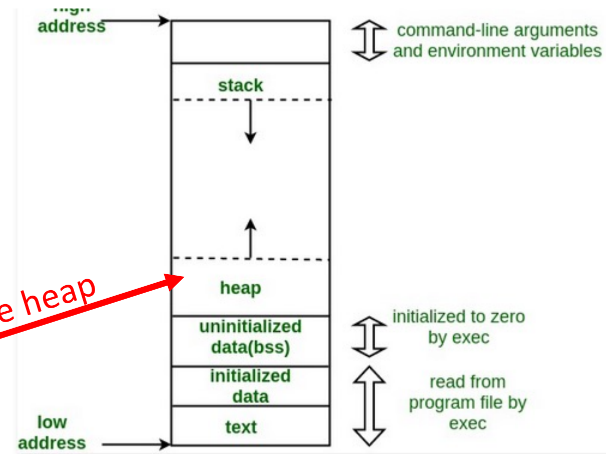


I	dataPtr	*dataPtr	sum
0	0x12312	19	19
1	0X12316	12	31
2	Ox1231A	13	44
3	Ox1231E	14	58
4	Ox12322	50	108
5	Ox12326	0	108

pointer, malloc() and free()

```
#include <stdio.h>
#include <stdlib.h>
int main(int argc, char **argv) {
  if (argc != 2) {
     fprintf(stderr,"Need 3 args: appName n\n");
     return -1;
  }
  double *array1=0, *array2=0, *array3=0;
  int n = atoi(argv[1]);

  // allocate memory & set the data
  array1 = (double *)malloc(n*sizeof(double));
  for (int i=0; i<n; i++) {
    array1[i] = i;
  }
  array2 = array1;
  array3 = &array1[0];

  for (int i=0; i<n; i++, array2++, array3++) {
    double value1 = array1[i];
    double value2 = *array2;
    double value3 = *array3;
   printf("%.4f %.4f %.4f %p %p %p\n",
     value1, value2, value3, &array1[i], array2, array3);
  }
  // free the array
  free(array1);
  return(0);
}
```

Memory from the heap




```
c >gcc memory2.c; ./a.out 4
0.0000 0.0000 0.0000 0x7f8dd84059a0 0x7f8dd84059a0 0x7f8dd84059a0
1.0000 1.0000 1.0000 0x7f8dd84059a8 0x7f8dd84059a8 0x7f8dd84059a8
2.0000 2.0000 2.0000 0x7f8dd84059b0 0x7f8dd84059b0 0x7f8dd84059b0
3.0000 3.0000 3.0000 0x7f8dd84059b8 0x7f8dd84059b8 0x7f8dd84059b8
```

These 2 statements are equivalent

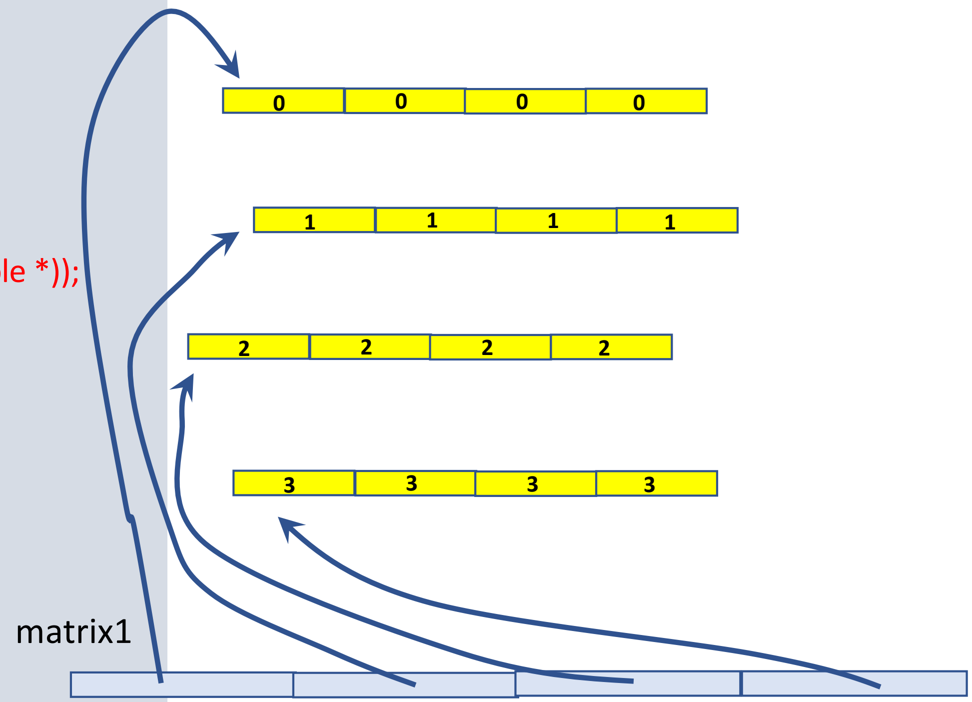
What would happen if I invoked free with array2 and array3??

Pointers to pointal & multi-dimensional arrays

memory3.c

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

int main(int argc, char **argv) {
   if (argc != 2) {
     fprintf(stderr,"Need 3 args: appName n\n");
     return -1;
  }
 int n = atoi(argv[1]);

 // allocate memory & set the data
 double **matrix1 = (double **)malloc(n*sizeof(double *));
 for (int i=0; i<n; i++) {
    matrix1[i] = (double *)malloc(n*sizeof(double));
    for (int j=0; j<n; j++)
       matrix1[i][j] = i;
 }
 for (int i=0; i<n; i++) {
    for (int j=0; j<n; j++)
       printf("(%d,%d) %.4f\n", i,j, matrix1[i][j]);
 }
 // free data
 for (int i=0; i<n; i++)
     free(matrix1[i]);
 free(matrix1);
}
```

Case for n = 4



matrix 1 is an array of pointers to double *, i.e. each component of the matrix1 points to a

THIS iS BAD BAD BAD CODE

1. Spatial Locality

remember Why Do Caches Work?

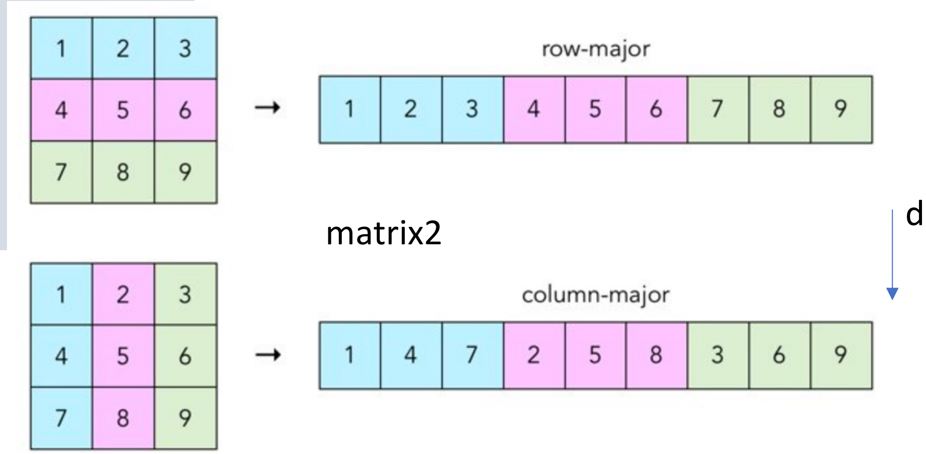
- **Temporal Locality** – probability is high that if program is accessing some memory location it will access same location again soon.
- **Spatial Locality** – probability is high that if program is accessing some memory on 1 instruction, it is going to access a nearby one soon

```
int main() {
    …
   double dotProduct = 0
    for (int i=0, i<vectorSize; i++)
        dotProduct += x[i] * y[i];
    …
}
```

2. Compatibility with many matrix libraries:

```
double **matrix2 =0;
matrix2 = (double  **)malloc(numRows*si                              ));
  for (int i=0;  i<numRows;  i++)  {
      matrix2[i]  =  (double                   Cols*sizeof(double));
        for (int j=0;
            m                          j;
  }
```

Because many prebuilt libraries work assuming continuous layout and Fortran column-major order:




```
double  *matrix2 =0;
matrix2 = (double
  for  (int  i=0;  i<nu
       for  (int  j=0;
            matrix2[I +
  }
```

```
double  *matrix2 =0;
matrix2 = (double  *)malloc(numRows*num
  for  (int  j=0;  j<numCols;  j++)
     for  (int  i=0;  i<numRows;  i++)  {
            matrix2[i + j*numCol]  =  i(j;
  }
```

memory3.c

```
double *matrix2 =0;
matrix2 = (double  *)malloc(numRows*numCols*sizeof(double));
double *dataPtr = matrix2;
  for  (int  j=0;  j<numCols;  j++)
     for  (int  i=0;  i<numRows;  i++)  {
          *dataPtr++  =  (i+1)*(j+1);
  }
```

How do you know if the pointer type is pointing to an array or a single value?

```
int x =10, y;

int *ptrX = &x;
```

```
int *arrayX = (int *)malloc(10*sizeof(int));
ont *ptrX = arrayX;
for (int i=0; i<n; i++) {
   *dataPtr++ = i;
 }
```

Would compiler give warning if the following next appeared after either?

```
for (int i=0; i<10; i++) {
  *ptrX++ = i;
}
```

What would happen if code is run?

Special Problems with char * and Strings

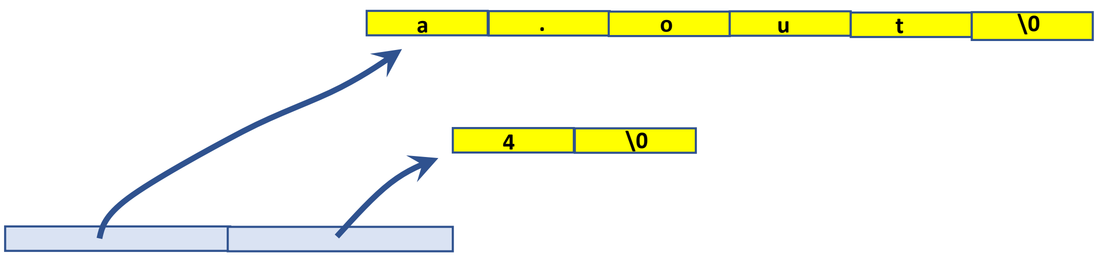
- No string datatype in C,
- string in C is represented by type char *
- There are special functions for strings in <string.h>
  - strlen()
  - strcpy()
  - ….
- To use them requires a special character at end of string, namely **'\0'**
- This can cause no end of grief, e.g. if you use malloc, you need **size+1** and need to append '\0'

```
#include <string.h>
....
char greeting[] = "Hello";
int length = strlen(greeting);
printf("%s a string of length %d\n",greeting, length);

char *greetingCopy = (char *)malloc((length+1)*sizeof(char));
strcpy(greetingCopy, greeting);
```

So Now you can understand char **argv in main!

argv is an array of pointers to char *, i.e. each component of the argv points to a string.

say program started with "./a.out 4"



argv1.c

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
int main(int argc, char **argv) {

  printf("Number of arguments: %d\n", argc);

  /* print out location, size and v
      alue of each argument */
  for (int i=0; i<argc; i++) {
    int length = strlen(argv[i]);
    printf("%d %d %s\n", i, length, argv[i]);
  }
  return 0;
}
```

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CMake

Frank McKenna
University of California at Berkeley

NSF award: CMMI 1612843

CMake

- A widely used application for building cross platform applications and libraries which typically consist of many many different source files.
- Simple few commands to type from a shell window

```
> mkdir build
> cd build
> cmake ..
> cmake --build . --config Release
> cmake --install .
```

- If you install software, there will be a CMakeLists.txt file in source directory
- Still requires you to install dependencies
    - Conan is something that integrates with CMake

PROGRAMMING

DGEMM

$$c_{ij} = c_{ij} + a_{i1}b_{1j} + a_{i2}b_{2j} + \cdots + a_{in}b_{nj} = c_{ij} + \sum_{k=1}^{n} a_{ik}b_{kj}$$

Hands On – matMul

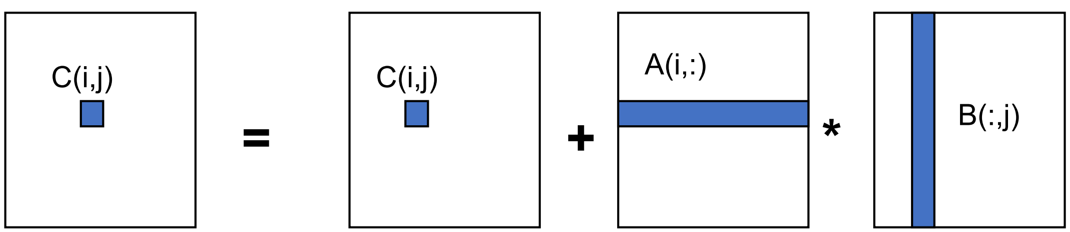
In assignments/C-Day2/matmul there are some files.
CMakeLists.txt will build 2 executables matMul & benchmark

You need to:
1. edit matMul.c (malloc & free functions)
2. edit myDGEMM.c (function needs filling in)
3. when done submit matMul.c

ADVANCED:
1. Run the benchmark exe. It shows GFLOP/s performance of your myDGEMM versus the BLAS dgemm.
2. Can you get at least 30% of the BLAS performance?? (see following 2 slides)

Naïve Matrix Multiply

```
{implements C = C + A*B}
for i = 1 to n
  {read row i of A into fast memory}
   for j = 1 to n
      {read C(i,j) into fast memory}
      {read column j of B into fast memory}
      for k = 1 to n
         C(i,j) = C(i,j) + A(i,k) * B(k,j)
      {write C(i,j) back to slow memory}
```



Source: UC Berkeley, Jim Demmell, CS267

Blocked (Tiled) Matrix Multiply

Consider A,B,C to be N-by-N matrices of b-by-b subblocks where b=n / N is block size

for i = 1 to N

for j = 1 to N

cache does this automatically

3 nested loops inside

{read block C(i,j) into fast memory}

for k = 1 to N

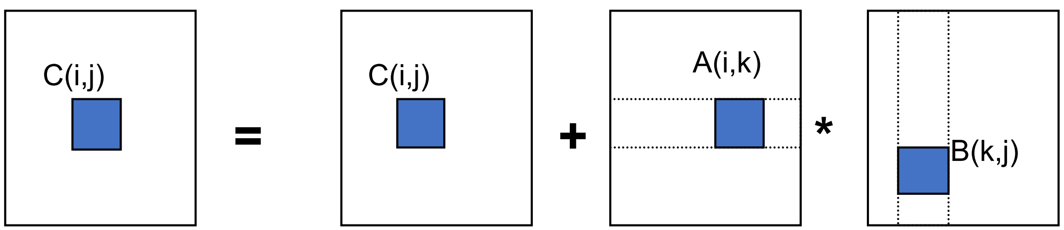
block size = loop bounds

{read block A(i,k) into fast memory}

{read block B(k,j) into fast memory}

C(i,j) = C(i,j) + A(i,k) * B(k,j) {do a matrix multiply on blocks}

{write block C(i,j) back to slow memory}



Tiling for registers (managed by you/compiler) or caches (hardware)

Source: UC Berkeley, Jim Demmell, CS267

Programming Bootcamp

Abstraction & User Defined Types

Frank McKenna
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Abstraction

The goal of "**abstracting**" data is to reduce complexity by removing unnecessary information. Think bigger, ignore the minutia.

float
integer
double
string

C Structures

```
struct structName {
    type name;
    ….
};
```

- A Powerful feature that allows us to put together **our own abstractions.**
- **A struct is a composite data type that we define that defines a physically grouped list of variables under one name in a block of memory.**
- We can compound as many different types as we want to form a new type

struct1.c

```
#include <stdio.h>
struct point {
   float x;
   float y;
};
```

Note the semi-colon after the struct definition

```
int main(int argc, char **argv) {
  struct point p1 = {1.0, 50};
  struct point p2;
  p2.x = 100 + p1.x;
  p2.y = 50;

  printf(" Point1: x %10f y%10f\n", p1.x, p1.y);
  printf(" Point2: x %10f y%10f\n", p2.x, p2.y);
  return 0;
}
```

typedef

`typedef varType alias;`

A way to create new type name. New names are an alias the compiler uses to make programmers life easier.

Something to utilize for making working with structs easier

struct2.c

```
#include <stdio.h>

;

typedef struct point {
  float x;
  float y;
} Point;

int main(int argc, char **argv) {
  numType value = 20.;

  Point p1 = {1.0, 50};
  Point p2;
  p2.x = 100 + p1.x;
  p2.y = value;


  printf(" Point1: x %10f y%10f\n", p1.x, p1.y);
  printf(" Point2: x %10f y%10f\n", p2.x, p2.y);
  return;
}
```

Data Structures

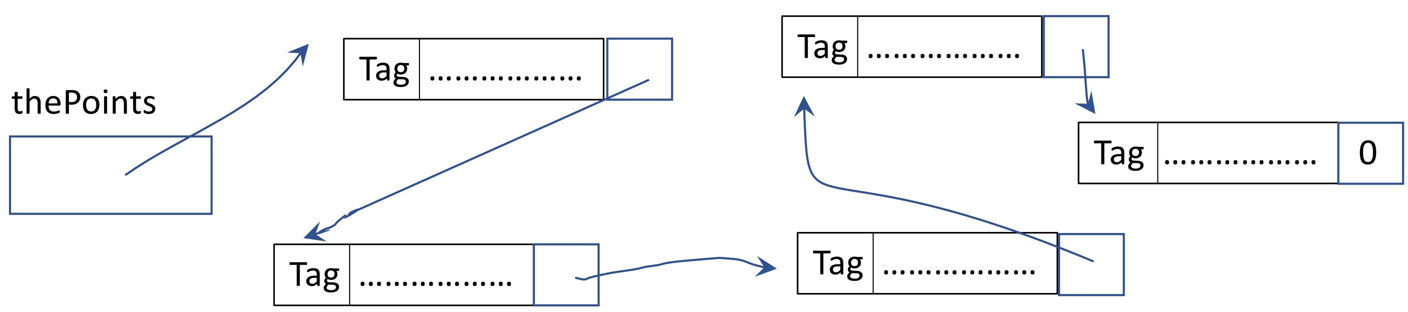
"In computer science, a **data structure** is a **data** organization, management, and storage format that enables efficient access and modification to data" (Wikipedia).

Examples of Data Structures: Arrays, Stack, Queue, Linked List, Tree.

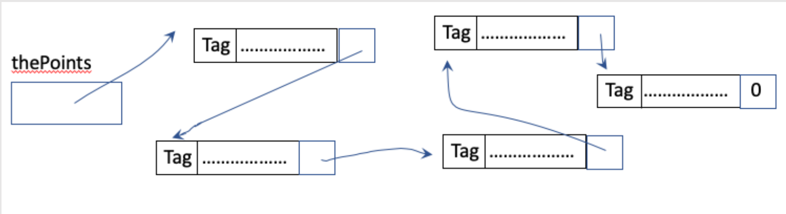
The C Programming language provides the ability to program many common data structures like *arrays, stacks, queues, linked list, tree, etc*. It is of course flexible. enough to allow you to come up with your own data structures.

Which data structures to use to store the objects depends on how the user intends to access the data

Example Linked List of Points



thePoints – pointer to a Point *, each Point has a pointer to another node linkedList.c

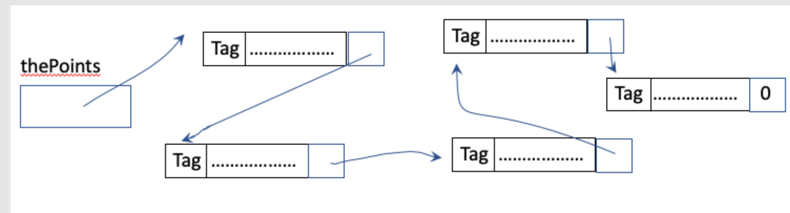



```c
#include <stdio.h>
#include <stdlib.h>
#include <stdbool.h>
typedef struct point {
  int     tag;
  float   x;
  float   y;
  struct point *next;
} Point;

int main(int argc, char **argv) {
  // pointer to hold the link to all points
  Point *thePoints = 0;
  // read in points
  int tag;
  float x,y;
  FILE *inputFile = fopen(argv[1],"r");
  while (fscanf(inputFile, "%d, %f, %f\n", &tag, &x, &y) != EOF) {
    Point *nextPoint = (Point *)malloc(sizeof(Point));
    nextPoint->tag = tag; nextPoint->x = x; nextPoint->y = y;
    nextPoint->next = thePoints;
    thePoints = nextPoint;
  }
 // do something with linked list
```

```
 // doing something with linked list
 bool done = false;
  while (done == false) {
    int tagToFind;
    printf("Enter tag to find: ");
    scanf("%d",&tagToFind);
    int tagToFind;
    Point *currentPoint = thePoints;
    while (currentPoint != 0 && currentPoint->tag != tagToFind) {
      currentPoint = currentPoint->next;
    }

    if (currentPoint != 0) {
      printf("FOUND Point with tag %d at locaction: %f %f\n", tag, currentPoint->x, currentPoint->y);
     } else {
      printf("Could not find point with tag %d\nExiting\n", tagToFind);
      done = true;
    }
  }
  fclose(inputFile);
  return 0;
}
```



Structs, Pointers and Data Structures

allowed us to think of searching in terms of looking for a points in a file

Why not of course think in terms of other abstractions!

What about Abstractions for a Finite Element Application?

Node

Load

Element

Domain

Matrix

Constraint

Analysis

Vector

What Does A Node Have?

- Node number or tag
- Coordinates
- Displacements?
- Velocities and Accelerations??

2d or 3d?
How many dof?
Do We Store Velocities and Accel.

Depends on what the program needs of it

Say Requirement is 2dimensional, need to store the displacements (3dof)?

```
struct node {
   int tag;
   double xCrd;
   double yCrd;
   double displX;
   double dispY;
   double rotZ;
};
```

```
struct node {
   int tag;
   double coord[2];
   double displ[3];
};
```

I would lean towards the latter; easier to extend to 3d w/o changing 2d code, easy to write for loops .. But is there a cost associated with accesing arrays instead of variable directly .. Maybe compile some code and time it for intended system

```
#includede <stdio.h>
struct node {
    int tag;
    double coord[2];
    double disp[3];
};
void nodePrint(struct node *);

int main(int argc, const char **argv) {
    struct node n1;  // create variable named n1 of type node
    struct node n2;
    n1.tag = 1;          // to set n1's tag to 1 .. Notice the DOT notation
    n1.coord[0] = 0.0;
    n1.coord[0] = 1.0;
    n2.tag = 2;
    n2.coord[0] = n1.coord[0];
    n2.coord[0] = 2.0;
    nodePrint(&n1);
    nodePrint(&n2);
}
void nodePrint(struct node *theNode){
    printf("Node : %d ", theNode->tag);    // because the object is a pointer use -> ARROW to access
    printf("Crds: %f %f ", theNode->coord[0], theNode->coord[1]);
    printf("Disp: %f %f %f \n", theNode->disp[0], theNode->disp[1], theNode->disp[2]);
}
```

```
C >gcc node2.c; ./a.out
Node : 1 Crds: 0.000000 1.000000 Disp: 0.000000 0.000000 0.000000
Node : 2 Crds: 0.000000 2.000000 Disp: 0.000000 0.000000 0.000000
C >
```

```
#includede <stdio.h>
typedef struct node {.
  int tag;
  double coord[2];
  double disp[3];
} Node;
void nodePrint(Node *);
void nodeSetup(Node *, int tag, double crd1, double crd2);
int main(int argc, const char **argv) {
    Node n1;
    Node n2;
    nodeSetup(&n1, 1, 0., 1.);
    nodeSetup(&n2, 2, 0., 2.);
    nodePrint(&n1);
    nodePrint(&n2);
}
void nodePrint(Node *theNode){
    printf("Node : %d ", theNode->tag);
    printf("Crds: %f %f ", theNode->coord[0], theNode->coord[1]);
    printf("Disp: %f %f %f \n", theNode->disp[0], theNode->disp[1], theNode->disp[2]);
}
void nodeSetup(Node *theNode, int tag, double crd1, double crd2) {
    theNode->tag = tag;
    theNode->coord[0] = crd1;
    theNode->coord[1] = crd2;
```

Using typedef to give you to give the new struct a name;
Instead of struct node now use Node

Also created a function to quickly initialize a node

```
C >gcc node2.c; ./a.out
Node : 1 Crds: 0.000000 1.000000 Disp: 0.000000 0.000000 0.000000
Node : 2 Crds: 0.000000 2.000000 Disp: 0.000000 0.000000 0.000000
C >
```

Clean This up for a large FEM Project

Files for each date type and their functions:
node.h, node.c, domain.h, domain.c, …

fem/main1.c

```
#include "node.h"
#include "domain1.h"
int main(int argc, const char **argv) {
  Domain theDomain;
  theDomain.theNodes=0; theDomain.NumNodes=0; theDomain.maxNumNodes=0;
  domainAddNode(&theDomain, 1, 0.0, 0.0);
  domainAddNode(&theDomain, 2, 0.0, 2.0);
  domainAddNode(&theDomain, 3, 1.0, 1.0);
  domainPrint(&theDomain);
  // get and print singular node
  printf("\nsingular node:\n");
  Node *theNode = domainGetNode(&theDomain, 2);
  nodePrint(theNode);
}
```

Domain is some CONTAINER that holds the nodes and gives access to them to say the elements and analysis

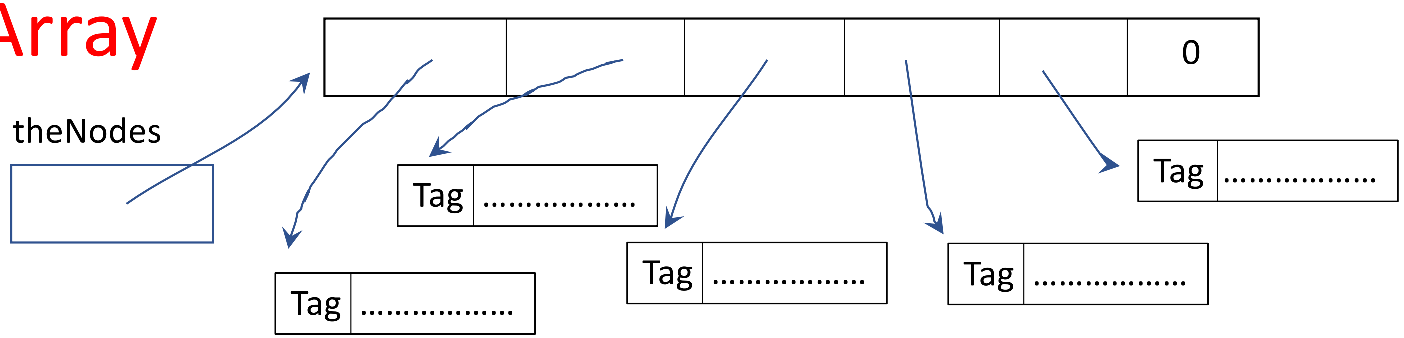
Domain

- Container to store nodes, elements, loads, constraints
- How do we store them
- In CS a number of common storage schemes:
  1. Array
  2. Linked List
  3. Double Linked List
  4. Tree
  5. Hybrid

Which to Use – Depends on Access Patterns, Memory, …

but all involve Pointers (2 examples)

Array



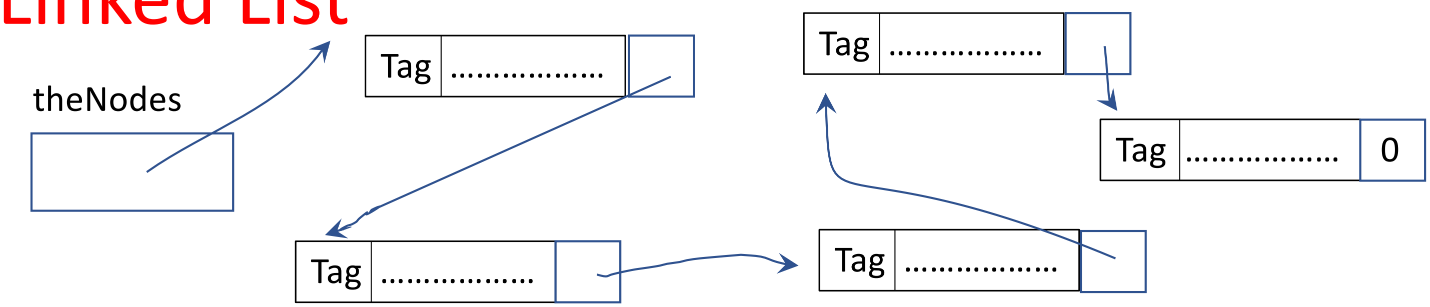
theNodes – pointer to an array of Node *, i.e. each component of array points to a Node.
Want a variable sized array (small and large problems), what happens if too many nodes
Added – malloc an even bigger array, copy existing pointers (just address not objects)
=> need Node**, variable to hold current size, variable to hold max size

c/fem/domain1.h

```
#include "node.h"
typedef struct struct_domain {
  Node **theNodes;
  int numNodes;
  int maxNumNodes;
} Domain;

void domainPrint(Domain *theDomain);
void domainAddNode(Domain *theDomain, int tag, double crd1, double crd2);
void domainPrintNodes(Domain *theDomain);
Node *domainGetNode(Domain *, int nodeTag);
```

Linked List



theNodes – pointer to a Node *, each Node has a pointer to another node

c/fem/domain2.h

```
#include "node.h"
typedef struct struct_domain {
  Node *theNodes;
} Domain;

void domainPrint(Domain *theDomain);
void domainAddNode(Domain *theDomain, int tag, double crd1, double crd2);
void domainPrintNodes(Domain *theDomain);
Node *domainGetNode(Domain *, int nodeTag);
```

fem/domain1.c

```
Node *domainGetNode(Domain *theDomain, int nodeTag) {
  int numNodes = theDomain->numNodes;
  for (int i=0; i<numNodes; i++) {
    Node *theCurrentNode = theDomain->theNodes[i];
    if (theCurrentNode->tag == nodeTag) {
      return theCurrentNode;
    }
  }
  return NULL;
}
```

Array Search

fem/domain2.c

```
Node *domainGetNode(Domain *theDomain, int nodeTag) {
  Node *theCurrentNode = theDomain->theNodes;
  while (theCurrentNode != NULL) {
    if (theCurrentNode->tag == nodeTag) {
      return theCurrentNode;
    } else {
      theCurrentNode = theCurrentNode->next;
    }
  }
  return NULL;
}
```

List Search

c/fem/node.h

```c
#ifndef _NODE
#define _NODE

#include <stdio.h>

typedef struct node {
  int tag;
  double coord[2];
  double disp[3];
  struct node *next;
} Node;

void nodePrint(Node *);
void nodeSetup(Node *, int tag, double crd1, double crd2);

#endif
```

What About Elements
Data & Function (tangent, resisting force)

We want a model that can handle many different element types and user defined types

Abacus element interface:

```
      SUBROUTINE UEL(RHS,AMATRX,SVARS,ENERGY,NDOFEL,NRHS,NSVARS,
     1 PROPS,NPROPS,COORDS,MCRD,NNODE,U,DU,V,A,JTYPE,TIME,DTIME,
     2 KSTEP,KINC,JELEM,PARAMS,NDLOAD,JDLTYP,ADLMAG,PREDEF,NPREDF,
     3 LFLAGS,MLVARX,DDLMAG,MDLOAD,PNEWDT,JPROPS,NJPROP,PERIOD)
```

For each element we have a function, for args to be same we need to pass element parameters and element state information (assuming nonlinear problem) in function call. We also need to manage for the element the state information (trial steps to converged step) in Newton iteration

Element?

```
#ifndef _ELEMENT
#define _ELEMENT

#include ”node.h”
#include <stdio.h>
typedef (int)(*elementStateFunc)(Domain *theDomain, double *k, double *P);

typedef struct element {
  int tag;
  int nProps, nHistory;
  int *nodeTags;
  double *paramaters;
  double *history;
  elementStateFunc eleState;
  struct element *next;
} Element;

void elementPrint(Element *);
void elementComputeState(Element *theEle, double *k, double *R);

#endif
```

Creating Types is easy

- Creating smart types where we need to keep data and functions that operate on the data for different possible types becomes tricky.

PROGRAMMING

Problem 2: Using structures

The implementation of `StressTransform()` was intentionally done a bit clumsy, just the way a beginner might write it. Your task in this exercise is to create a structure

```
typedef struct {
        double sigx;
        double sigy;
        double tau;
} STRESS ;
```

SimCenter NHERI

Center for Computational Modeling and Simulation

Programming Bootcamp

C: File I/O

Frank McKenna
University of California at Berkeley

NSF award: CMMI 1612843

File * - another pointer type, a pointer to a file

File I/O in C is done with the following built in functions:

- **fopen** and **fclose:** to open and close files
- **fwrite** and **fread:** to read and write chunks of data
- **fprintf** and **fscanf:** to read and write formatted blocks of data
- ~~**fgetc** and **fputc:** to read and write individual bytes(char~~)

Formatted output

file2.c

```
#include <stdlib.h>
#include <time.h>
int main(int argc, char **argv) {
  if (argc != 4) {
    fprintf(stdout, "ERRORusage appName n max filename \n");
    return -1;
  }
  int n = atoi(argv[1]);
  float maxVal = atof(argv[2]);
  FILE *filePtr = fopen(argv[3],"w");

  for (int i=0; i<n; i++) {
    float float1 = ((float)rand()/(float)RAND_MAX) * maxVal;
    float float2 = ((float)rand()/(float)RAND_MAX) * maxVal;
    fprintf(filePtr,"%d, %f, %f\n", i, float1, float2);
  }
  fclose(filePtr);
}
```

int fprintf(FILE *fp, const char *format, ...)

format is the C string that contains the text to be written to the file. It can optionally contain embedded format tags that are replaced by the values specified in subsequent additional arguments and formatted as requested. Format tags prototype is **%**

```
c >gcc file2.c -o file2
c >./file2 5 1 file2.out
c >cat file2.out
0, 0.153779, 0.560532
1, 0.865013, 0.276724
2, 0.895919, 0.704462
3, 0.886472, 0.929641
4, 0.469290, 0.350208
c >
```

Formatted Input

int fscanf(FILE *fp, const char *format, ...)

file3.c

```
#include <stdio.h>
#include <stdlib.h>
int main(int argc, char **argv) {
  FILE *filePtr = fopen(argv[1],"r");
  int i = 0;     float float1, float2;
  int maxVectorSize = 100;
  double *vector1 = (double *)malloc(maxVectorSize*sizeof(double));
  double *vector2 = (double *)malloc(maxVectorSize*sizeof(double));
  int vectorSize = 0;
  while (fscanf(filePtr,"%d, %f, %f\n", &i, &float1, &float2) != EOF) {
    vector1[vectorSize] = float1;
    vector2[vectorSize] = float2;
    printf("%d, %f, %f\n",i, vector2[i], vector1[i]);
    vectorSize++;
    if (vectorSize == maxVectorSize) {
      // some code needed here .. programming exercise
    }
  }
  fclose(filePtr);
}
```

```
c >gcc file2.c -o file2
c >./file2 4 1 file2.out
c >cat file2.out
0, 0.153779, 0.560532
1, 0.865013, 0.276724
2, 0.895919, 0.704462
3, 0.886472, 0.929641
c >
c >gcc file3.c -o file3
c >./file3 file2.out
0, 0.560532, 0.153779
1, 0.276724, 0.865013
2, 0.704462, 0.895919
3, 0.929641, 0.886472
c >
```

BUT

`int fscanf(FILE *fp, const char *format, ...)`

file3.c

```
#include <stdio.h>
#include <stdlib.h>
int main(int argc, char **argv) {
  FILE *filePtr = fopen(argv[1],"r");
  int i = 0;      float float1, float2;
  int maxVectorSize = 100;
  double *vector1 = (double *)malloc(maxVectorSize*sizeof(double));
  double *vector2 = (double *)malloc(maxVectorSize*sizeof(double));
  int vectorSize = 0;
  while (fscanf(filePtr,"%d, %f, %f\n", &i, &float1, &float2) != EOF) {
    vector1[vectorSize] = float1;
    vector2[vectorSize] = float2;
    printf("%d, %f, %f\n",i, vector2[i], vector1[i]);
    vectorSize++;
    if (vectorSize == maxVectorSize) {
      // some code needed here .. programming exercise
    }
  }
  fclose(filePtr);
}
```

```
c >./file2 1000 1 fileBIG.out
c >./file3 fileBIG.out
0, 0.560532, 0.153779
1, 0.276724, 0.865013
2, 0.704462, 0.895919
3, 0.929641, 0.886472
4, 0.350208, 0.469290
5, 0.096535, 0.941637
6, 0.346164, 0.457211

161, 0.533222, 0.600734
162, 0.073887, 0.854827
163, 0.808359, 0.811912
164, 0.884276, 0.084779
165, 0.301760, 0.022628
Segmentation fault: 11
```

Writing to Binary or ASCII file

size_t fwrite(const void * ptr, size_t size, size_t count, FILE * stream);

file4.c

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
int main(int argc, char **argv) {
  int n =  atoi(argv[1]);
  float maxVal = atof(argv[2]);
  float *theVector = (float *)malloc(n * sizeof(float));
  FILE *fileBinaryPtr = fopen("file3.out","wb");
  FILE *fileAsciiPtr = fopen("file3Ascii.out","w");
  for (int i=0; i<n; i++)
    theVector[i]= ((float)rand()/(float)RAND_MAX) * maxVal;

  for (int i=0; i<n; i++) {
    fprintf(fileAsciiPtr,"%f ",theVector[i]);
  }
  fprintf(fileAsciiPtr,"\n");
  fwrite(theVector, sizeof(float), n, fileBinaryPtr);
  fclose(fileBinaryPtr);
  fclose(fileAsciiPtr);
}
```

modes: "w" and "wb"

w = ascii text
wb = binary

Binary File:
- No data loss
- Smaller (half the size)
- BUT cannot read as not an ASCII file

```
c >gcc file4.c -o file4
c >./file4 5 5
c >cat file4Ascii.out
0.768894 2.802661 4.325066 1.383619 4.479593
c >
c >cat file4.out
>?D??^3@?f?@k???X?@c >
c >
c >ls -sal *4*.out
8 -rw-r--r--  1 fmckenna  staff  20 Jan  4 21:01 file4.out
8 -rw-r--r--  1 fmckenna  staff  46 Jan  4 21:01 file4Ascii.out
```

READING from Binary

```
size_t fread ( void * ptr, size_t size, size_t count, FILE * stream );
int main(int argc, char **argv) {
```

file5.c

```
#include <stdlib.h>
#include <time.h>
#include <stdbool.h>.
int main(int argc, char **argv) {
  FILE *fileBinaryPtr = fopen(argv[1],"rb");
  int vectorSize = 0;
  int maxVectorSize = 100;
  float *theVector = (float *)malloc(maxVectorSize*sizeof(float));
  // read multiple times until no more data, enlarging vector each time in maxVectorSize chunk
  int numValues = 0;
  long numRead = 0;
  bool allDone = false;
  while (allDone == false) {
    long numRead = fread(&theVector[vectorSize], sizeof(float), maxVectorSize, fileBinaryPt
    numValues += numRead;
    vectorSize += numRead;
    if (numRead == maxVectorSize) {
      // not done, enlarge for next time
      float *newVector = (float *)malloc((vectorSize + maxVectorSize)*sizeof(double));
      for (int i=0; i< vectorSize; i++)
          newVector[i] = theVector[i];
      free(theVector);
      theVector = newVector;
    } else
      allDone = true;
```

PROGRAMMING

EXERCISE – Day 2

- stressTensorFile/ex2-3
- stressTensorFile/ex2-4

-binaryFile