Organizing Heterogeneous Data

Arrays allow a programmer to organize lists of values that are all of the same type (homogeneous).

But we are often faced with data values of differing types (heterogeneous) that are logically related, as we have seen earlier with trip data:

Origin	Destination	Miles	Time
Blacksburg, VA	Knoxville, TN	244	3:25
Knoxville, TN	Nashville, TN	178	2:35
Nashville, TN	Memphis, TN	210	3:17
Memphis, TN	Little Rock, AR	137	2:05
Little Rock, AR	Texarkana, TX	141	2:10

While we can organize this data using parallel arrays, that is unsatisfying because we have then distributed the logically related values for a single trip across several different data structures.

A better design would be to have a new data type `Trip` such that a variable of type `Trip` would contain all the related values for a single trip.

The `struct` mechanism allows C++ programmers to do just that…

Structures

structure - a heterogeneous collection of data values called members or fields

- each member has a type and a unique name
- individual members are accessed by name

The definition of a structured type specifies the type name as well as the types and names of each of the members:

```
struct Trip {
   string Origin;       // starting point of trip
   string Destination;  // ending point of trip
   int    Miles;        // distance traveled
   int    Minutes;      // time required, in min
   double MPH;          // average speed
};
```

Again, definitions of data types are almost always global since they are required throughout a program. The statement above does not declare a variable… it defines a type. As long as the type definition is in scope we may declare variables of that type in the usual way:

```
Trip firstLeg;
const int MAXLEGS = 100;
Trip Itinerary[MAXLEGS];  // array of Trips
```

`struct` Variables

A variable of a `struct` type will contain the values for all of the specified members for that type. Of course, the values of those members will just be random garbage until they have been properly initialized. Assuming we've initialized the members of the variable `firstLeg`, we would have a memory layout something like this:

```
Trip firstLeg;
```

In memory:

```
Blacksburg, VA
Knoxville, TN
244
205
71.2
```

To reference a particular member of a `struct` variable, state the variable name followed by a period followed by the member name:

```
firstLeg.Origin      = "Blacksburg, VA";
firstLeg.Destination = "Knoxville, TN";
firstLeg.Miles       = 244;
firstLeg.Minutes     = 205;
firstLeg.MPH         = 71.2;
```

The period is called the member selector operator.

Member Access Example

The members of a `struct` variable may be used just as if they were simple variables of the specified type.

```
enum Color {RED, GREEN, BLUE, NOCOLOR};

struct Rectangle {
   Color Hue;
   int   xNW,
         yNW;
   int   Side[4];
};
. . .
Rectangle R;

cin >> R.xNW >> R.yNW;
cin >> R.Side[0] >> R.Side[1] >> R.Side[2] >> R.Side[3];
R.Hue = NOCOLOR;

int Area = R.Side[0] * R.Side[1];
```

Aggregate Operations

An aggregate operation is an operation that is performed on a data structure, such as an structured variable, as a whole rather than performed on an individual member.

Assume the following declarations:

```
Trip X, Y;
```

Assuming that both `X` and `Y` have been initialized, consider the following statements and expressions involving aggregate operations:

```
X = Y;          // _____ assigning one struct to another

X == Y;         // _____ comparing two structs with a relational operator

cout << X;      // _____ inserting an struct to a stream

X + Y           // _____ performing arithmetic with structs

return X;       // _____ using a struct as the return value from a function

Foo(X);         // _____ passing an entire struct as a parameter
```

Of course, the operations that are not supported by default may still be implemented via user-defined functions.

`struct` Variables as Parameters

Entire struct variables can be passed to functions as parameters. By default is `struct` is passed by value.

For example:

```
void setMPH(Trip& aTrip) {

   aTrip.MPH = MINPERHOUR * double(aTrip.Miles) / aTrip.Minutes;
}
```

Since struct variables tend to be large, it is generally better to pass them by constant reference than by value if possible:

```
void printTrip(ofstream& Out, const Trip& aTrip) {

   Out << left << setw(MAXNAMELENGTH + 1) << aTrip.Origin
       << setw(MAXNAMELENGTH + 1) << aTrip.Destination
       << right << setw(10) << aTrip.Miles
       << setw(10) << (aTrip.Minutes / MINSPERHOUR) << ':'
       << setfill('0') << setw(2) << (aTrip.Minutes % MINSPERHOUR)
       << setfill(' ') << setw(10) << setprecision(1)
       << aTrip.MPH
       << endl;
}
```

Implementing `struct` Operations

A programmer can implement any needed operations that are not supported automatically:

```
bool areSame(const Trip& T1, const Trip& T2) {

   if ( (T1.Origin == T2.Origin) &&
        (T1.Destination == T2.Destination) ) {

      return true;
   }

   return false;
}
```

Note that the meaning of equality for trips must be defined. Here we require the trips to have the same starting and ending points. Other definitions could also make sense; it depends on the context.

```
bool isFaster(const Trip& T1, const Trip& T2) {

   return (T1.MPH < T2.MPH);
}
```

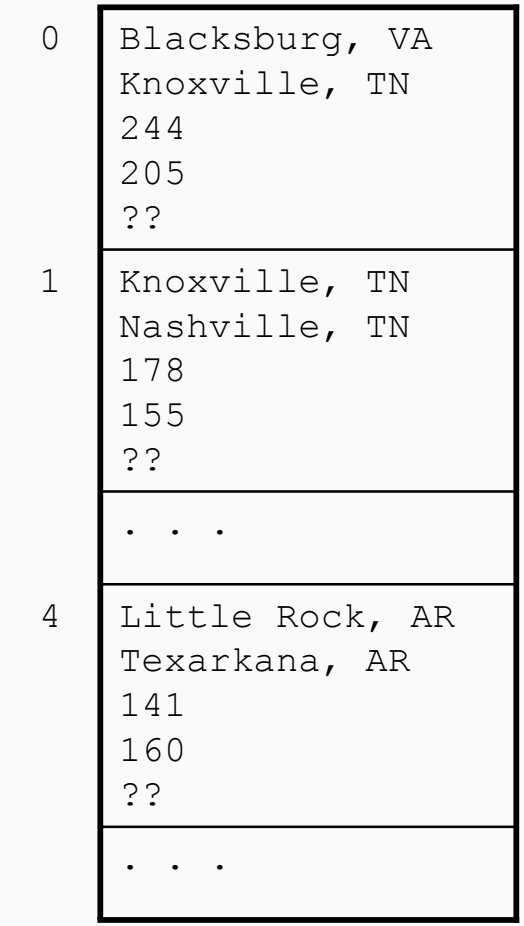
```
Trip reverseTrip(const Trip& T) {
   Trip Reverse = T;
   Reverse.Origin      = T.Destination;
   Reverse.Destination = T.Origin;
   return (Reverse);
}
```

Array of Structures

In most applications of `struct` types, an array (or some other data structure) is used to organize a collection of individual `struct` variables.

An array of structures provides an alternative to using a collection of parallel arrays:

```
const int MAXTRIPS = 500;
Trip Itinerary[MAXTRIPS];
```



Of course, to refer to a member of one of the `struct` variables in the array we must combine array syntax with `struct` syntax.

To set the first array element would require the syntax:

```
Itinerary[0] = firstLeg;
```

To set the `MPG` member of the fifth `struct` variable would require the syntax:

```
Itinerary[4].MPG = 52.88;
```

Designing with Structures

Structured types allow the creation of specialized data types which better model the logical relationships among the data values being stored and manipulated.

This allows the designer to consider the problem from a higher, more natural, level.

For example, we may design the step "print a trip" and defer the details of that until a later refinement of the design. Of course, we may do that without structured types, but the use of structured types encourages designers to think at that level.

Using a structured type may also promote code reuse if the type is suitable for inclusion in independent applications. The `Trip` type presented in these notes could be relevant to a number of different programs.

Properly speaking, a data type is a collection of values and the operations that may be performed on them. For a `struct` type, most of these operations will be implemented in separate user-defined functions, and those may also be recyclable into other applications.

Application: the Trip Program Revisited

Consider implementing the simple trip program using an array of structures to organize the trip data.

Clearly we may use an array of `Trip` variables, as defined earlier, to store the data:

```
Origin               Destination              Miles     Time
-----------------------------------------------------------
Blacksburg, VA       Knoxville, TN            244       3:25
Knoxville, TN        Nashville, TN            178       2:35
Nashville, TN        Memphis, TN              210       3:17
Memphis, TN          Little Rock, AR          137       2:05
Little Rock, AR      Texarkana, TX            141       2:10
. . .
```

By using an array of structures we will be able to implement the same operations as with a collection of parallel arrays, but the data organization will be much simpler. Almost all of the functions will have much simpler parameter lists.

We will consider portions of such an implementation here.

The Overall Organization

Since the data is all encapsulated in a single array of structures we achieve a very simple overall design:

```
int main() {
   Trip Itinerary[MAXTRIPS];  // list of trip data
   int numTrips = 0;          // number of trips reported.

   numTrips = readTripData(Itinerary);        // Read the given trip data.

   // Calculate the average MPH for each of the trips:
   calcAllMPH(Itinerary, numTrips);

   // Calculate the statistics for the summary report:
   int    totalMiles, totalMinutes;
   double overallMPH;
   calcStats(Itinerary, numTrips, totalMiles, totalMinutes, overallMPH);

   // Write output file:
   writeReport(Itinerary, numTrips, totalMiles, totalMinutes, overallMPH);

   return 0;          // Terminate a successful execution.
}
```

Managing Structured Input

Logically, reading and storing the trip data is relatively straightforward, given our earlier discussions. However, the syntax for using an array of `struct` variables bears examination:

```
int readTripData(Trip List[]) {

   int tripsRead = 0;                // counter for trips

   ifstream In(dataFileName.c_str());  // Open the input file.

   // If the input file does not exist, this will detect that.
   // We handle that by printing an error message and stopping the program.
   if ( In.fail() ) {
      cout << "Data file not found: "     // Write an error message...
           << dataFileName                //    including the file name.
           << endl                         // Bang "return"
           << "Exiting now..." << endl;    // Finish the message.
      exit(1);                             // Terminate a failed execution.
   }

// . . . continues on next slide . . .
```

Managing Structured Input

Here is the input management code. Note the use of a local `Trip` variable to "buffer" the input and the use of a helper function:

```
// . . . continued from preceding slide . . .
   In.ignore(INT_MAX, '\n');  // Skip over the two header lines in the
   In.ignore(INT_MAX, '\n');  //    trip data input file.

   Trip nextTrip;
   nextTrip = readOneTrip(In);      // Try to read data for a trip.

   while ( In && (tripsRead < MAXTRIPS) ) {

      List[tripsRead] = nextTrip;   // Store the trip that was just read
      tripsRead++;                  // . . . and count it.

      nextTrip = readOneTrip(In);   // Try to read data for another trip.
   }

   In.close();
   return tripsRead;       // Tell the caller how many trips were read.
}
```

Reading the Structured Record

Here we read and return data for a single trip:

```
Trip readOneTrip(ifstream& In) {

   Trip newTrip;                    // Trip variable to "bundle" the data
   int  tripHours, tripMinutes;

   getline(In, newTrip.Origin, '\t');  // Read: the name of the trip origin.
   getline(In, newTrip.Destination, '\t');  //  and the trip destination.
   In >> newTrip.Miles;                     //  the length of trip in miles
   In >> tripHours;                         //  hours field for trip time
   In.ignore(1, ':');                       //  colon separator
   In >> tripMinutes;                       //  minutes field for trip time
   newTrip.Minutes = convertHHMMtoMin(tripHours, tripMinutes);
   In.ignore(INT_MAX, '\n');          // Skip to beginning of next input line.

   return newTrip;  //  Return a copy of the Trip variable to the caller.
}
```

Managing Updates to the Array

The input code does not update the `Trip` records to include the average speed. This function manages that. Note the use of another helper function.

```
void calcAllMPH(Trip Itinerary[], int numTrips) {

   int Idx;
   for (Idx = 0; Idx < numTrips; Idx++) {

      Itinerary[Idx].MPH = calcMPH(Itinerary[Idx].Miles,
                                   Itinerary[Idx].Minutes);
   }
}
```

As usual, we have a for loop to traverse the data array so we can process its cells one-by-one.

The caller "extracts" the appropriate members of the current `Trip` variable and passes them to the helper function.

```
double calcMPH(int Miles, int Minutes) {

   return (MINPERHOUR * double(Miles) / double(Minutes));
}
```

Alternative Implementation

The preceding implementation is correct but it requires both functions to incorporate information about the internal structure of a `Trip` variable. Here is a revision that makes the top-level function relatively unaware of those internals.

```
void calcAllMPH(Trip Itinerary[], int numTrips) {

   int Idx;
   for (Idx = 0; Idx < numTrips; Idx++) {

      setMPH(Itinerary[Idx]);
   }
}
```

Now the caller simply passes an entire data element of the array to its helper function.

The caller has no need to "know" anything about the internal organization of a `Trip` variable.

That's all encapsulated within the helper function now.

```
void setMPH(Trip& T) {

   T.MPH = MINPERHOUR * double(T.Miles) / double(T.Minutes);
}
```

Writing the List to File

Compare the top-level function here to `calcAllMPH()`. See a "pattern"?

```
void writeTripData(ofstream& Out, const Trip Itinerary[], int numTrips) {

   int Idx;
   for (Idx = 0; Idx < numTrips; Idx++) {

      writeOneTrip(Out, Itinerary[Idx]);
   }
}
```

Note the two uses of pass by constant reference to prevent unnecessary modification of data.

```
void writeOneTrip(ofstream& Out, const Trip& toPrint) {

   Out << left << setw(MAXNAMELENGTH + 1) << toPrint.Origin;
   Out << setw(MAXNAMELENGTH + 1) << toPrint.Destination;
   Out << right << setw( 7) << toPrint.Miles
       << setw(10) << toPrint.Minutes
       << setw( 8) << setprecision(1) << toPrint.MPH
       << endl;
}
```

Hierarchical Organization

In some cases a designer will plan a structured type with members that are also reasonably considered to be structured themselves.

For example, we might reconsider the design of the `Trip` type to allow a more useful description of the origin and destination. Logically each of these is just a "place" which we might consider to be represented by a city name and a state abbreviation:

```
struct Place{
   string City;
   string State;
};
```

```
struct Trip {
   Place  Origin;
   Place  Destination;
   int    Miles;
   int    Minutes;
   double MPH;
};
```

This approach provides two custom data types, instead of one. Variables of type `Place` might well be useful in other applications.

Hierarchical organization is often designed as a natural way to take advantage of already-existing custom types.

Of course a hierarchical organization also requires slightly more complex syntax when accessing the members of a structured member.

Member Access in a Hierarchy

The usual syntax rules apply. It's just a matter of keeping straight exactly what the syntax means. Given the type definitions from the previous slide:

```
Trip toSmithsonian;
toSmithsonian.Origin.City  = "Blacksburg";
toSmithsonian.Origin.State = "VA";
. . .
toSmithsonian.Miles   = xxx;
toSmithsonian.Minutes = xxx;
. . .
```

Alternatively we could use an aggregate assignment to set the `Place` members of our `Trip` variable:

```
Place WashDC;
WashDC.City  = "Washington";
WashDC.State = "DC";
Trip toSmithsonian;
toSmithsonian.Destination = WashDC;
. . .
```