The DataDraw Manual

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1 Introduction

DataDraw is an ultra-fast persistent database for high performance programs written in C. It's so fast that many programs keep all their data in a DataDraw database even while being manipulated in inner loops of compute intensive applications. Unlike slow SQL databases, DataDraw databases are compiled and directly link into your C programs. DataDraw databases are resident in memory, making data manipulation even faster than if they were stored in native C data structures (really). Further, they can automatically support infinite undo/redo, greatly simplifying many applications.

DataDraw databases can be persistent. Modifications to persistent data are written to disk as they are made, which of course dramatically slows write times. However, DataDraw databases can also be volatile. Volatile databases exist only in memory, and only for the duration that your program needs it. Volatile databases can be directly manipulated faster than C structures, since data is better organized in memory to optimize cache performance. DataDraw supports modular design. An application can have one or more common persistent databases and multiple volatile databases to support various tools' data structures. Classes in a tool's database can extend classes in the common database. DataDraw is also 64-bit optimized, allowing programs to run much faster and in less memory than standard C programs using 64-bit pointers. This is because DataDraw databases support over 4 billion objects of a given class with 32-bit object references.

DataDraw is released under the GNU Library General Public License, Version 2. It costs you nothing to use and does not restrict your application in any way. Only the DataDraw program itself is covered by the license.

2 Use Cases

If your application is 99% GUI and 1% data manipulation, don't use DataDraw, because that 1% isn't worth automating. If you need to write a CGI application for the Apache web server with a MySQL back-end, don't use DataDraw, because the speed DataDraw gives your application will be wasted. If you don't use data structures more complex than a tree, don't use DataDraw, because there will be little for DataDraw to automate. Use DataDraw when you need speed, efficiency, and/or rich data structures. Use it for the simplicity it brings to your project, it's automated debugging, persistence and undo/redo capabilities.

DataDraw is extensively used in EDA tool development, where speed is critical and data structures are complex. It has, for example, been used in technology mappers, circuit simulators (both analog and digital), placers and routers. DataDraw has been in use in EDA since 1992 and has matured greatly over that time. DataDraw has also been used in compiler development.

Internet servers also may benefit from DataDraw. A DataDraw backed application can process 100X to 1000X more transactions per second than a LAMP based application. This makes DataDraw a good choice for SIP servers, BitTorrent and other applications supporting thousands of simultaneous connections. Embedded web servers could also benefit from DataDraw's small memory footprint, power efficient data manipulation and ultra-high speed. Telephony applications and other CPU intensive tasks are potentially a good fit. Editors of all kinds are a good fit with DataDraw, because of its infinite undo/redo automation.

3 When to use DataDraw vs. MySQL and PHP

LAMP is a very powerful combination for creating web applications: Linux, Apache, MySQL and

PHP. Apache provides an incredibly powerful framework built around a world-class web server. PHP provides a powerful language for developing web applications rapidly. MySQL provides a way for these web applications to manage data. DataDraw is not meant to replace any of this. However, Apache is bloated, PHP is a slow interpreted language and MySQL interprets ASCII commands that it reads through sockets that communicate with PHP. All this slows the system down 100-1000X relative to plain old C code. Most applications don't care: if I'm just trying to sell stuff over the Internet, being able to process even one transaction per second is probably fine.

DataDraw is for demanding applications for which LAMP is too slow and/or bloated. While running, a DataDraw application owns the database and does not share it with others. That makes it well suited for implementing some tasks, and not others. For example, it is well suited for building SQL servers, BitTorrent trackers and embedded servers, but not well suited for Apache modules. In these cases, consider embedding both DataDraw and a free, fast, tiny HTML server, such as the MiniWeb HTTP server, directly in your application. This will allow you to serve many times more requests per second in far less memory.

4 Benchmarks vs. C++ STL code

DataDraw has been extensively benchmarked against the #1 rival for EDA software development: C++ using the Standard Template Library. In short DataDraw smokes C++/STL. In simple depth-first graph traversal, the graph_benchmark example shows DataDraw runs over 15X faster than the C++/STL version. It also uses less than half the memory when compiled in 64-bit mode. Check out the examples directory for current benchmarks. The speed difference is due to L2 data cache-hit rates:

	L1 Miss Rate	*L2 Miss Rate*	*Run Time*	*Memory*
DataDraw	3.8%	1.3%	7.83s	432MB
C++/STL	32.9%	21.7%	124.6s	1.1GB

5 The DataDraw Language

Think of DataDraw database definition files as being similar to SQL files but heavily focused on C-style data instead of the cryptic data formats supported by SQL. Like SQL, DataDraw is a language for describing data, not algorithms. You write your algorithms in C but describe your database in DataDraw.

Here are the basic elements that make up DataDraw code, and how they correspond to SQL terms:

- Module – similar to SQL databases
- Class – similar to SQL tables
- Relationship – similar to SQL foreign keys and C++ collections
- Typedef – similar to SQL blobs, which allow user-defined binary data to be stored
- Schema – just a logical grouping of classes that would look good together in an entity-relationship diagram
- Class fields – like fields (or “columns”) in SQL tables
- Objects – like SQL table rows
- Object reference – similar to an SQL “primary key”, or a C pointer

There are also some elements taken from C which have no equivalent in SQL:

- Enum

- Relationship types: linked lists, hash tables, etc

Like SQL tables, DataDraw classes are made up of fields. Currently supported field types include:

- bool – Boolean type similar to C++ 'bool'
- bit – Exactly like bool, but uses only 1 bit in memory
- int – C integers
- uint – C unsigned integers
- char – C chars
- float – C float
- double – C double
- pointer – Reference to an object
- typedef – User defined data types, typically C structures in their programs
- enum – C enum
- sym – A symbol in a symbol table, with a C string for its name

Pointer is similar to a C pointer, but in reality is an "object reference" which is a value used to access an object's fields. Pointers can be declared "cascade", which means that when an object is destroyed, the object pointed at should also be destroyed. The "sym" is a handy symbol type. There is a global symbol table provided by DataDraw which keeps track of symbols. A typical use for symbols is naming objects. The "bit" type is different from "bool" only in that it tells DataDraw to encode the field as a bit in memory rather than allocating a whole byte. This saves memory but slows down reading and writing the value slightly.

You can also have unions of fields, just like in C, to save space in the database. Integers are 32-bit by default, but you can be more specific with any of the following:

    int8, int16, int32, int64, uint8, uint16, uint32, uint64

"uint" means unsigned integers. Any field can also be declared as an array, which can be dynamically sized. See the section "Arrays" below for more detail.

Perhaps the most important feature of DataDraw is "relationships". These are similar to "container classes" in C++. A big difference is that relationships are symmetric between a "parent" class and a "child" class. So, for example, if a car has a linked-list of tires, the tires will also have an owning car. Supported relationship types are:

- pointer – the parent and child simply cross point to each other
- linked_list – the parent has a singly linked list of children
- tail_linked – the parent has a linked list of children, and also a pointer to the last child
- doubly_linked – the parent has a doubly linked list of children
- array – The parent has dynamically sized array of the children
- hashed – The parent has a hash table of children, queried by any combination of fields

In addition to fields, any object can have attributes assigned to it dynamically at runtime. See the Attributes section in the C API for more information.

6 A Simple Example

A DataDraw file starts with the module declaration:

    module database db

This declares the "database" module and says that all generated C functions and macros will be prefixed with "db", to keep them from conflicting with other functions in your application. If you

leave out the prefix, all functions will be prefixed with the full module name.

After the module declaration, you can declare enumerated types:

```
enum Day DAY_
    SUNDAY
    MONDAY
    TUESDAY
    WEDNESDAY
    THURSDAY
    FRIDAY
    SATURDAY
```

In the generated code, the prefix “DAY_” will be prefixed to your enum values. These constants can be used directly in your program. For example, you could write code to thank God on Friday like this:

```
if(day == DAY_FRIDAY) {
    thankGod(); /* You have to provide this function yourself */
}
```

You can also declare external types defined in your C program. This is similar to the concept of a binary “blob” in a database. DataDraw will generate code that allows you to store these types in the DataDraw database. Just tell DataDraw that they exist with a “typedef” statement. So, for example, if you have a custom C structure you wrote by hand that keeps track of what's in a funky chicken's gizzard, you can tell DataDraw like this:

```
typedef Gizzard = “NULL”
```

And then you can declare classes that use these types. Default initial values can be declared, as in this example. Let’s suppose you wanted a database of funky chickens. Instead of creating a funky chicken table in SQL, you declare a class in DataDraw:

```
class FunkyChicken
    Gizzard gizzard // Who knows what the heck you defined in there...
    Day birthday // Just in case birthdays are very important to funky chickens
    FunkyChicken bestFriend
    array FunkyChicken chicks // Every funky chicken has lots of chicks
```

If you haven't noticed yet, there are no semicolons at the end of lines. In DataDraw code, elements are grouped by indentation, as in Python. Here's a simple DataDraw file describing a basic poker game database.

```
module Poker pk persistent // “Poker” is the module name, “pk” is it's prefix

enum CardValue // Enumerated type of card values.
    CARD_2 = 2
    CARD_3 = 3
    CARD_4 = 4
    CARD_5 = 5
    CARD_6 = 6
    CARD_7 = 7
    CARD_8 = 8
    CARD_9 = 9
    CARD_10 = 10
```

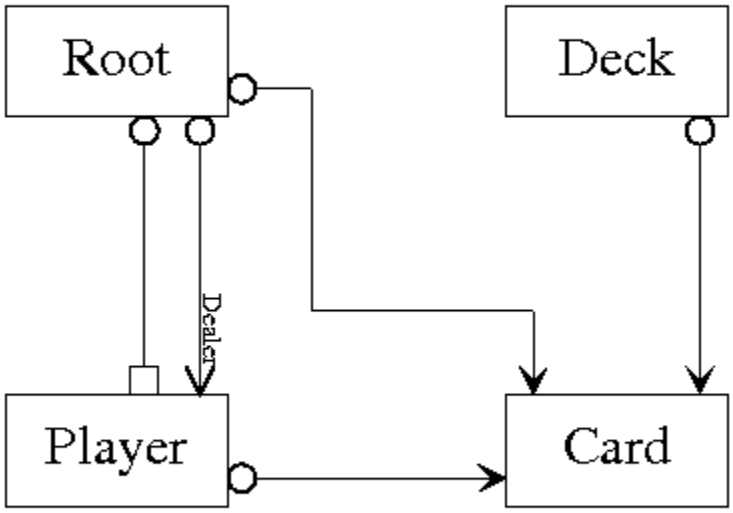
```
        CARD_J = 11
        CARD_Q = 12
        CARD_K = 13
        CARD_A = 14

    class Root // The root of the database – a good place for global data
        uint pot // Money in the middle – not the kind you smoke
        uint anteUp

    class Deck //A deck of cards

    class Card // One card in a deck
        CardValue value
        bool shown

    class Player // A player in the card game
        uint cash = "1000000" // Players are millionaires by default

    relationship Root Player hashed // This also gives the player a 'Sym' field containing his name
    relationship Root Player:dealer // By default relationships are 'pointer', or one-to-one
    relationship Root Card linked_list
    relationship Deck Card doubly_linked
    relationship Player Card doubly_linked
```

Hopefully, two things about this format grabbed your attention. First, the classes don't seem to have many fields. Deck doesn't have any! Second, there are a lot of relationships. This is fairly typical of DataDraw applications: heavy into relationships. Also, the "persistent" keyword causes DataDraw to generate a persistent database that keeps data mirrored in real-time on disk, and which loads at start-up. By default, all fields are initialized to their default NULL value, or 0 for typedefs. Initializers can be specified, as in the Player's cash example above.

To help you view your schema, DataDraw comes with an additional utility, DataView. If DataView is installed, try entering the above schema into a file called Poker.dd, and type:

```
dataview Poker.dd
```

It should create a postscript file with the following image:



This view of your database is called a schema. each box represents one class, and the connections between them represent relationships. This can be very useful for visualizing your database. This is discussed in more detail later.

Now let's suppose that you want to write an AI for playing poker. The AI will of course have all kinds of additional data, classes and relationships. Further, it will want to attach additional data to the cards and players. DataDraw makes this easy to do. You just create an additional DataDraw file that might look a bit like:

```
module ai volatile // the prefix is the same as the module name in this case

import Poker // This module runs off the 'Poker' module

class Card:Poker
        int scoreIfPlayed

class Player:Poker
        double score
```

The “volatile” keyword is optional, since databases are volatile by default. What we've introduced here is dynamic extension, similar to what you can do in Python but without any execution time penalty. The line “class Card:Poker” indicates that the local class card is a dynamic extension of the class of the same name in the poker module. Normally, C/C++ programmers have to put void pointers in their database classes as hooks to dangle additional tool specific data. DataDraw not only automates the extension, it does so without adding any void pointers to anything. This is one of the coolest features of DataDraw. See the Dynamic Extension below for more detail.

For a more detailed example, download the DataDraw source code. DataDraw uses a DataDraw generated database! See its definition in Appendix A.

7 Installing and Running DataDraw

7.1 System requirements

DataDraw is very light weight and can be used on Windows, Linux, Solaris or even embedded platforms. The earliest versions ran on DOS, on IBM machines with 640K of memory and 12MHz 286 processors.

7.2 Compiling from Source

Until DataDraw is more widely adopted, you will likely need to compile it from source to use it. On a Linux machine, do the following:

```
$ tar -xvzf datadraw-3.x.x.tar.gz
$ cd datadraw-3.x.x
$ ./configure
$ make
$ su
$ make install
$ exit
```

Note that 'x.x' should be replaced with the version number of your copy of DataDraw. This should create the 'datadraw' executable and copy it to /usr/local/bin/datadraw. If you would like to install it elsewhere, pass the "--prefix=<dir>" flag to the configure script.

Alternatively, you can check out and build from the most recent source code using:

```
$ svn co https://datadraw.svn.sourceforge.net/svnroot/datadraw/trunk datadraw
$ cd datadraw
$ ./autogen
$ ./configure
$ make
$ su
$ make install
$ exit
```

7.3 Command Line Arguments

DataDraw's command line has the following format:

```
datadraw [options]... module
```

Module files must end with a '.dd' suffix. The '.dd' suffix will be supplied if not given on the command line.

The 'datadraw' executable accepts the following command line arguments:

```
-h file      -- Use file as the output header file
-I path      -- Add a directory to the module search path
```

-m -- Start the database manager to examine datadraw's database
-p -- Set the module as persistent.
-s file -- Use file as the output for the source file
-u -- Set the module as undo_redo

DataDraw will create two files: dbdatabase.c and dbdatabase.h, where 'db' is replaced with the module prefix you defined in your database definition file.

7.4 Module Path

DataDraw applications can be very large, with multiple projects exceeding 600K lines of C code. Such projects are built in a very modular way. There are common databases, persistent or not, and volatile databases for each tool that runs off the common databases.

Each common database and each tool has its own database.dd file in its source directory. Since a tool's database description file typically extensively depends on the common databases, DataDraw must be able to find them to generate code. By default, DataDraw looks only in the current directory. There are two ways to help DataDraw find imported modules.

First, you can use the '-I directory' option. However, if you want DataDraw to know this information in a more automatic way, consider setting the DD_MODPATH environment variable. Directories in this variable are separated with ':' characters. For example, in your .bash_profile (if you use bash), you could add:

EXPORT DD_MODPATH=source/maindatabase:source/addtionaldatabase

8 Linking to Your Application

Building a DataDraw application requires the following steps:

- Include dbdatabase.c, dbdatabase.h and ddutil.a in your project
- Add DataDraw's 'util' directory to your include path for compilation
- For volatile databases call dbDatabaseStart(), where 'db' is your module prefix
- For persistent databases see below for more detail.
- When exiting, call dbDatabaseStop(), especially if you have a persistent database

If you have multiple modules in your application, start any persistent database when your application starts, and stop them when it stops. For any volatile tool data, start their databases when the tool starts, and stop them when they are done.

Since DataDraw requires the 'util' module, you will automatically have it ready for other uses. It has many helper utility functions found useful over many years of development. Check out the “Utility Library” section below for an in-depth description.

8.1 Additional Steps for Persistent Databases

If all you want is a way to save your program's data to disk, ignore this section, and just call the Load/Save functions provided in the C API. This provides a very fast binary read/write to disk of the entire database in one file. See Binary Load/Save later on in this document for how to do this.

First, instead of linking with ddutil.a, link with ddutilp.a. Then, to use a persistent database, your application needs to either initialize it or load it from disk. Assuming “pr” is your module prefix and “graph_database” is the path to your database, you should load or initialize your database with code

like this:

```
utStart();
prDatabaseStart();
prTheRoot = prRootAlloc();
utStartPersistence("graph_database", true, true);
```

This also assumes you have a root object in your database that you use to find all the other objects and to keep track of your global data. The first parameter to utStartPersistence tells DataDraw where to save your data. The second says whether you want it saved in binary or ASCII. The binary form is compatible with utLoadBinaryDatabase, and the ASCII form is compatible with utLoadTextDatabase. The binary version is much faster but the text version can be more convenient. The third parameter says whether or not you want to automatically keep a backup copy of the database.

You need to occasionally tell DataDraw when the database is at a stable point, such as when a transaction has been completed. Call the "utTransactionComplete" to indicate this. All database modifications made after the last call to utTransactionsComplete will be discarded the next time your application starts. See Transaction Processing below for more details on this. This function takes one parameter, "flushToDisk". If true, recent writes are flushed to disk right away. Otherwise, they are buffered in memory to improve disk write speeds.

To further speed up writing changes to disk, DataDraw only writes changes to one file, "recent_changes", which grows so long as you continue making changes. When you call utTransactionComplete, if the recent_changes file has become greater than 25% of the total size of the database, then the changes will be applied to disk and the recent_changes file deleted.

Finally, when your application is shutting down, be sure to call "utStopPersistence()". This causes all recent writes to the database to be flushed to the recent_changes file, and closes all open database files.

8.2 Additional Steps for Infinite Undo/Redo

Whether or not your database is persistent, you can use DataDraw's infinite undo/redo feature. Instead of linking with ddutil.a, link with ddutilu.a (for non-persistent) or ddutilup.a (for persistent). Also add the "undo_redo" keyword on the end of your module declaration, like this:

```
module db Database undo_redo
```

This will cause DataDraw to generate the undo/redo API calls you need. Be sure to also specify the "persistent" keyword if you want a persistent database with undo/redo.

Using the API is simple. Use the utTransactionComplete() command to indicate undo/redo stable points in the database. Then, to undo the last change, just call

```
utUndo(numChanges)
```

where "numChanges" is the number of undo commands you want to execute (typically just 1). To redo the changes after an undo, just call

```
utRedo(numChanges)
```

Be sure to only call utUndo after completing a transaction. The database is considered in an erroneous state otherwise and datadraw exits - your database gets fixed the next time your application runs by dropping modifications beyond the last complete transaction.

With a persistent database, your undo/redo changes will be written to the recentChanges file. The database will not have a chance to be compacted until you tell DataDraw that you no longer need the

undo buffer. Do this with:

```
utCompactDatabase();
```

This will compact the database and reset the undo/redo buffer.

9 Database Administration, Backups and Viewing

DataDraw provides a simple database administration utility for managing your data. To invoke it, your program simply needs to call:

```
utManageDatabase();
```

It uses a command-line interface to view and backup data. Commands supported are

- create <module> <class> – allocate a new object and return it's object number
- compact – Compact the database and delete the recent_changes file
- destroy <module> <class> <object number> – Destroy an object
- help - this command
- list – list the modules in the database, their object counts and memory usage
- list <module> – list classes in the module, their object counts and memory usage
- list <module> <class> – list fields of a class
- quit - quit the database manager
- set <module> <class> <object number> = comma separated values – set all fields of an object
- set <module> <class> <object number> <field> = <value> – set a value
- show <module> <class> – show all field values of all objects of the class
- show <module> <class> <object number> – show an object's fields
- show_hidden <true or false> - Enable/disable listing of DataDraw internal fields
- load_binary <file> - Read the data from the binary database file into the database
- save_binary <file> - Write out the database in binary format to the file
- load_text <file> - Read the data from the text database file into the database
- save_text <file> - Write out the database in text format to the file

There are also two utility functions that allow your application to read/write ASCII database backups:

To backup:

```
utSaveTextDatabase(FILE *file);
utLoadTextDatabase(FILE *file);
```

Your application may benefit by command-line switches to access these features directly. Consider passing stdin and stdout for the FILE parameters.

Another way to do a backup is simply to make a copy of the database. However, if you use binary format, any change to your database definition will cause your binary backups to fail to load. With text backups, load_text warns when you are missing fields and sets them to a reasonable default value. It also warns if fields in your database no longer exist and it drops such data.

9.1 The admindata Migration Utility (Preliminary)

This tool is under development, but should be available before you ever need it. Here is its preliminary documentation.

Sometimes you may wish to modify your database definition and recompile your application.

Unfortunately, this makes your application incompatible with any existing databases you have. The recommended way to migrate data is to write out an ASCII file in a custom data format and to write a parser for that format which remains backwards-compatible.

However, in the real world, many programs simply don't have that nice backwards compatible custom data format. If you need to munge your data to make it compatible with a new version of a DataDraw based application, use the 'admindata' utility. It reads in your ASCII backup file and DataDraw database file, and runs a TCL shell which lets you modify the data. When you're done, you can write the modified database back out in ASCII. The TCL commands you can use include:

- add <module>
- add <module> <class>
- add <module> <class> <field> <type>
- drop <module>
- drop <module> <class>
- drop <module> <class> <field>
- alloc <module> <class>
- free <module> <class> <object number>
- destroy <module> <class> <object number>
- get <module> <class>
- get <module> <class> <object number>
- get <module> <class> <object number> <field>
- set <module> <class> <class table>
- set <module> <class> <object number> <object value list>
- set <module> <class> <field> <object number> <field value>
- get_type <module> <class> <field>
- set_type <module> <class> <field>

With admindata, you can write TCL scripts to migrate your data to the new format. The “set_type” function tries to be smart about converting data. It uses standard C cast conversions to switch between types. If you change an object number size, every reference of that type in the database is also converted.

The “destroy” command cascade-deletes other objects, while the “free” command simply unlinks the object. Be careful with the “free” command, as it can easily create dangling references.

10 Arrays

DataDraw provides both fixed size and dynamically sized arrays. Just put the “array” keyword before a field declaration in a class. In particular, strings are represented with arrays of char. For example, you could create a string class:

```
class String
        array char value
```

This would create a database class with a variable sized string... kind of silly, so I don't actually recommend doing it. If you want to write a killer string class that takes over 1000 lines of code, go learn C++. The language was practically designed to build string classes. If you just want a fixed sized array, you can declare it like:

```
class Fixstring
        array char value[LENGTH]
```

In this case, LENGTH is defined in a separate header file. When you declare a dynamic array, DataDraw automatically inserts some helper fields into your class. Consider the following example:

```
class Card

class Deck // As in a deck of cards
    array Card cards
```

In this example, class Deck will get an additional field, just as if you had defined it yourself, like this:

```
class Deck
    uint cardIndex // This is the index into the card heap of the first card
    uint numCards // This is the number of cards allocated in the heap
```

If instead, you only wish to support decks of 52 cards, you could have specified a fixed array size, and the additional fields would not be generated. In the C API, additional functions will be generated for accessing the array and resizing it. For more information, check the arrays section in the C API chapter.

11 Relationships

Relationships in DataDraw are highly efficient, and DataDraw's real strength. Compared to plain old C programming, the convenience of automatic support for things like doubly-linked lists is huge. Compared to C++ collections, DataDraw relationship are more efficient, both in speed and memory, safer, and automatically maintained.

Relationships in DataDraw incorporate one of the most powerful and important capabilities found in most SQL engines: the ability to cascade delete objects automatically. In fact, there is exact zero reason ever to write a destructor function ever again, for any application based on DataDraw. DataDraw automatically destroys dependent objects and fixes up all the object references. If for some reason you need to do special processing when an object is destroyed, you can register a destruction hook with the database which will be called just before the object is removed from the database.

Relationships are between two classes: a “parent” and a “child”. Consider the following example:

```
relationship Company Employee linked_list
```

If we were to model a company with employees in C++, we'd be tempted to use a linked_list container class. These classes typically allocate objects containing a next pointer and a void pointer to point to elements in the list. DataDraw, in contrast, directly embeds the next pointer in the child class, eliminating the void pointer. In addition, it embeds a back-pointer from the child object to the parent, so that when the child is destroyed, it can remove itself from the parent. You don't have to do it manually. It's done automatically when you call the function to destroy the child object.

In some cases, you know that a child object will never be destroyed while it is still in a relationship with a parent object. In this case, you may not want the back-pointer field. You can specify this with the 'child_only' relationship attribute. For example:

```
relationship Company Employee linked_list child_only
```

Though rare, in some cases you only want the back pointer, since the parent class never needs access to its children. In that case, specify the “parent_only” relationship attribute.

In some cases, you will need named relationships. This is true in the case of a directed graph data

structure. Both the parent and child classes can be labeled in a relationship. Here's the graph example:

```
class graph
class node
class edge
relationship graph node doubly_linked mandatory
relationship node:from edge:out doubly_linked mandatory
relationship node:to edge:in doubly_linked mandatory
```

Note the ":" labels. These labels say that one list contains all out edges from a node and the other contains all in edges to a node. Whenever multiple relationships exist between the same two classes, they must have different labels.

Also note the "mandatory" relationship attributes. Mandatory relationships are almost the same as "cascade" relationships. Cascade relationships cause all child objects to be destroyed when the parent is destroyed. Mandatory only differs in debug mode. If a child is destroyed that does not have a parent, an error condition will be flagged. Semantically, mandatory relationships are those which the children must be in to be valid objects. Nodes, for example, exist in graphs and not otherwise. Edges are always between two nodes. An edge without nodes makes no sense.

The relationship types are:

- pointer – the parent and child simply cross point to each other
- linked_list – the parent has a singly linked list of children
- tail_linked – the parent has a linked list of children, and also a pointer to the last child
- doubly_linked – the parent has a doubly linked list of children
- array – The parent has dynamically sized array of children
- hashed – The parent has a hash table of children, queried any combination of child fields
- heap – The parent has a binary heap of children
- ordered_list – The parent has an ordered list of children

We'll cover them one at a time.

11.1 Pointer Relationships

Pointer relationships simply embed a single field in the parent and child classes. These fields are just references to each other. The field name in the parent is:

```
LabelChild
```

Where "Label" is the optional label you specified in the relationship, and "Child" is the name of the child class. The field name in the child is:

```
LabelParent
```

which is similarly derived. So, if an Employee class is assigned to a Cubicle in a pointer relationship, it would be declared like:

```
relationship Cubicle:assigned Employee:trapped
```

This would create two fields, just as if they had been declared like:

```
Class Cubicle
        Employee TrappedEmployee

Class Employee
```

```
    Cubicle AssignedCubicle
```

The difference, however, is that the destructor generated for Cubicle knows to clear its employee's cubicle pointer, and vise versa. Had these fields simply been directly embedded in the classes, the destructors would not have known what to do with them! This makes manually embedding pointers in classes very dangerous. Extra care is required when using pointers in classes.

11.2 Linked List Relationships

Linked list relationships are quite simple. If a Node has a relationship to outgoing Edges, it might be declared like this:

```
relationship Node:from Edge:to linked_list mandatory
```

In this case, the following fields are inserted into the classes:

```
class Node
    Edge FirstOutEdge

class Edge
    Node FromNode
    Edge NextNodeOutEdge
```

These fields can be accessed just like any other field you define in your class. In addition, for all relationships that allow multiple children, an iterator is automatically generated, so you don't have to access the “Next” fields manually in your C code. Also, functions to insert and remove objects to and from the list are generated. This is described in the “C API” section later.

Use linked list relationships when you know that objects will not often be removed from them and when you don't mind always adding objects at the head of the list. Basic linked lists use the least memory of one-to-many relationships, but removing an object from a linked list runs very slowly: the entire list may have to be scanned in order to find the previous object in the list.

11.3 Tail Linked List Relationships

Tail linked lists embed the same fields as linked lists, with one additional field. Again, using the Node/edge example, we would also have:

```
class Node
    Edge LastOutEdge
```

Use tail linked lists when you want to be able to append objects to the list. This is commonly done to preserve the order objects are processed. However, removal from a tail linked list is just as slow as removal from a linked list.

11.4 Doubly Linked List Relationships

Doubly linked lists use a bit more memory than linked lists, because every child has an additional pointer in it. However, removal of an object runs very quickly, in constant time.

The added fields are identical to the tail linked list, except that one more has been added to the child class. Again, with the Node/Edge example, we would have:

```
class Edge
```

```
    Edge PrevOutEdge
```

Use doubly-linked lists when removal speed counts. Doubly linked lists are heavily used in EDA applications.

11.5 Array Relationships

Array relationships are quite different than linked lists. If we have a Node class with an array of outgoing Edge objects, we might declare the relationship like:

```
relationship Node:From Edge:to array mandatory
```

This creates the following fields:

```
class Node
    array Edge ToEdges
    uint UsedEdge // This is used by the append function to automatically resize your array

class Edge
    Node FromNode
    uint FromNodeIndex
```

Note that "FromNodeIndex" is set automatically when you insert an edge into the array. It is used to help the destructor remove the Edge from the relationship.

Also note that all array properties also generate additional fields you can access. This is discussed above in the "Arrays" section.

11.6 Hashed Relationships

Hashed relationships are the most interesting of the lot. You get a bunch of fields added to your classes. Suppose we have the following relationship:

```
relationship Graph Node hashed mandatory
```

This gives Nodes names, and creates a symbol-based hash table of Nodes on Graph. The fields look like:

```
Class Graph
    array Node nodeTable
    uint numNodes
    Node firstNode
    Node lastNode

Class Node
    sym Sym
    Graph graph
    Node nextTableNode // Pointer to next node in same position in nodeTable
    Node nextNode
    Node prevNode
```

Hash tables normally have a super-set of the fields used by doubly-linked lists. This allows objects to be added to a hash table relationship in order, and even if they don't have an assigned symbol.

Unnamed objects are added to the doubly linked list, but not put into the table. However, if your application has no need for a predictable ordering of elements in the hash table, you can provide the "unordered" attribute, and the doubly-linked list fields will go away. Our unordered example would be declared as:

```
relationship Graph Node hashed mandatory unordered
```

The fields look like:

```
Class Graph
    array Node nodeTable
    uint numNodes

Class Node
    sym Sym
    Graph graph
    Node nextTableGraphNode // Pointer to next node in same position in nodeTable
```

In the generated C files, code will be created to find a Node object, given its owning Graph and its name. Use hash table relationships when you have objects identified by unique names, or some other unique combination of properties on the objects.

Sometimes you may want a hash table based on keys other than a symbol, though symbols are by far the most common application. In this case, you can specify a key as a set of fields on the class. For example, the consider the following relationship:

```
class Graph

class Node
    array char name
    int32 x
    int32 y

relationship Graph Node:XY hashed x y child_only
relationship Graph Node hashed name mandatory
```

This will create a set of fields just like before, without adding a symbol to Node. A fast query function will be created for finding Nodes on Graphs given x and y coordinates. Another query function will be created to look up a node by it's name.

11.7 Heap Relationships

Heap relationships implement efficient binary heaps using arrays. Heaps are binary trees of elements with a special property: the value of each element in the tree is at least as high as any of it's children. Binary heaps can be implemented efficiently in arrays using a simple relationship: the left child of an element is at twice the index of the current element, and the right child is one past the left. Adding a elements to a heap in random order is on average a constant time operation. Removing the top element is always a O(log N) operation. Suppose we want to sort a deck of cards. A Deck class could have a heap of Card objects. We might declare the relationship like:

```
relationship Deck Card heap mandatory
```

This creates the following fields:

```
class Deck
    array Card cards

class Card
    Deck deck
    uint32 cardIndex
```

Each time a card is appended to the heap, it will float up in the heap until its value is at least as high as any of it's children. To sort the deck, simply pop cards off the heap until the deck is empty.

11.8 Ordered list Relationships

Ordered list relationships implement efficient dynamically balanced binary trees using “red-black trees”. The important thing is that you can always count on your objects being in proper order.

A reasonable ordered list example would be the cards in a player's hand, which should generally be sorted:

```
enum Suit
    CLUB
    DIAMOND
    HEART
    SPADE

class Player

class Card
    Suit suit
    uint8 value // 2-14... 14 is ACE

relationship Player Card ordered_list suit value
```

Like hash tables and heaps, users can specify the keys used for sorting. If none are specified, the user must provide a custom comparison function. In this case, cards will be sorted from lowest to highest first by suit, and then by value. Also, a function is created to find a card by it's suit and value, just like with hash tables.

This relationship creates the following fields:

```
class Player
    Card root

class Card
    bool isRed // Used by red-black trees to balance the tree
    Card parentPlayerCard
    Card leftPlayerCard
    Card rightPlayerCard
```

11.9 Properties Relationships

When a class is defined with properties such as in the following example:

```
class Player
        Card root
```

It is merly equivalent to the following:

```
class Player
class Card
relationship Player Card:root child_only
```

Except that C access macros are slightly different (see section *Accessing Properties of Objects* bellow for details).

Properties can have attributes like relationships, which are: cascade, sparse and view. Cascade, sets destruction of a child class upon destruction of the owning class. Sparse indicate how memory shall be managed for the relationship. See section 20.15 on Sparse Data for details. And view indicates that this field is not managed by datadraw but access macros are provided at the C level. Let's look at an exemple:

```
module Chain ch

typedef dummy = "0"

class Circle
   double x
   double y
   double r
   double left view
   double right view
   double top view
   double bottom view

class Cylinder
   double h
   Circle base

class Root

relationship Root Cylinder:Leftmost heap base.left

//
// /* user is expected to provided the following in a c file: */
// double chCircleGetLeft(chCircle circle) {
//     return chCircleGetX(circle) - chCircleGetR(circle);
// }
// /* or provide the following in chtypedef.h: */
// #define chCircleGetLeft(c) (chCircleGetX(c)-chCircleGetR(c))
//
```

11.10 Relationship keys

Three types of relationships can be indexed using keys: hashed relationship, heap relationship, and ordered_list relationship.

11.10.1 Multiple keys

A relationship can organize its internal data using multiple keys. For example, a circle class could be indexed given its center coordinates:

```
class Circle
        uint32 x
        uint32 y
        uint32 r
relationship Root Circle hashed x y
```

11.10.2 Key chaining

A key specification can access other relationship to access its data. For example, a circle class could be indexed given its center coordinates:

```
class Point
        uint32 x
        uint32 y
class Circle
        Point point
        uint32 r
relationship Root Circle hashed point.x point.y
```

12 Unions

DataDraw supports C-style unions, with a catch. DataDraw needs to know what kind of values you have in your class, so it can do things like print it out in ASCII. To use a union, you must specify a property in your class that determines the type of the union.

For example, a generic drawn object might need a union of pointers to provide access to various kinds of shapes:

```
enum ShapeType
        LINE
        CIRCLE
        RECTANGLE

class Shape
        ShapeType type
        union type
```

```
Line line cascade: LINE
Circle circle cascade: CIRCLE
Rectangle rectangle cascade: RECTANGLE
```

This declares that the shape object has a pointer to a specific type of drawn object, and that when the shape is destroyed, so should the child object.

Array properties are not allowed in unions, since their size varies. Bit types are converted to bool. Unions are initialized based on their first property, which should be correct, since the enumerated type they depend on is initialized to zero.

13 Dynamic Extension

This feature is one of the main reasons DataDraw is used in EDA applications, rather than some sort of C++ “persistent object base”.

Consider a typical EDA system: we will have a common persistent database to model a netlist. This data structure will virtually define the architecture of the entire system. A simplified netlist database could look like:

```
module Netlist nl
class Netlist
class Instance
class Port
class Net
relationship Netlist Instance hashed mandatory
relationship Netlist Net hashed mandatory
relationship Instance port hashed mandatory
relationship Net Port doubly_linked
```

This simple database allows me to create netlists and manipulate them. However, when my application starts, the netlist is loaded into the main database. All the tools that work off this database will need to attach additional fields to nets, ports, and instances.

If the main database was built using C++ classes, I'd face some difficulties. In particular, the main method of adding fields to a class in C++ is inheritance. But my objects already exist in the database. C++ programmers are reduced to using one of two methods to extend objects:

- Don't use inheritance. Emulate dynamic extension manually with void pointers in the database.
- Use inheritance, and copy the database into a local database that includes the extensions needed

Both techniques are commonly used. Both suck. Neither simplifies life by simply allowing you to extend objects that already exist.

Dynamic extension in DataDraw is trivial. Simply specify in your local database what class you are extending. For example, if I have a tool that needs to add a “level” attribute to instances, and a “delay” attribute to nets, it can be done like this:

```
module Mytool tl
import Netlist

class Instance:Netlist
        uint level
class Net:Netlist
```

```
double delay
```

These class declarations to not create any new classes or objects! All they do is add new fields to the classes already defined in the database. When you call tlDatabaseStart(), the new fields will be allocated in the Netlist database automatically, and they will be freed when you call tlDatabaseStop(). In your code, you will simply continue to use Netlist Inst and Net classes and objects, but you will also have the additional fields.

Classes with local extensions can be used in relationships just as before. For example, if you have a Path class, it could be related to Nets:

```
class Path // Keep track of a single path through a netlist
relationship Path Net linked_list
```

This allows your tool to build paths that include nets without worrying about converting data back and forth from the database. DataDraw makes where the data is defined nearly invisible. In fact, the only clue in the C API is the module prefix: functions are always prefixed with the local tool prefix. This means that functions that access local fields on Inst and Net will be prefixed with “tl” in this example.

Not only is dynamic extension convenient, it is fast. There is no difference in speed when accessing extended fields vs. main database fields. It's even faster than accessing fields in traditional C structures.

14 Schemas and DataView

When programs get very large, there can be hundreds of classes in the common database. There needs to be a way to organize them into logical sections. For viewing class properties, use a text editor. However, for visualizing complex class relationships, it's better to use a class diagram called a “schema”. To declare a new schema within a module, simply use

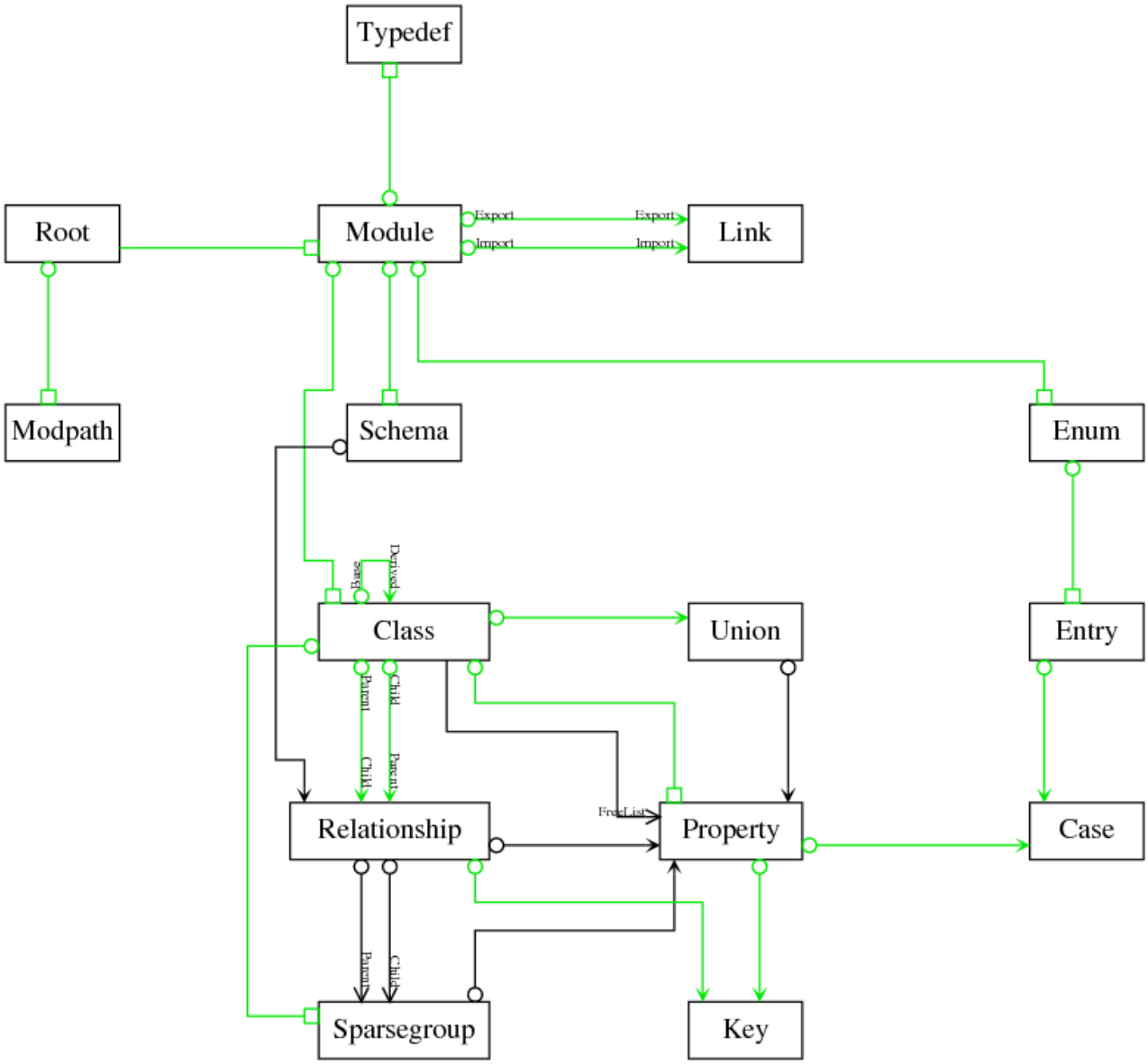
```
schema Name
```

Where “Name” is whatever you want to call the schema. Relationship declarations following this will be part of this schema. By default, all relationships not in any declared schema belong to a schema of the same name as your module. For example in an EDA database, you might have a “Netlist” schema, which describes netlists, and an “Attribute” schema, which shows how you attach attributes to various netlist objects. If you mixed these class diagrams together, it would reduce readability.

To view your individual schemas, use DataView. DataView will automatically generate class diagrams for your schemas as postscript files. For example, to view DataDraw's own schema, you could use the following commands on linux:

```
$ cd datadraw/src
$ dataview Database.dd
```

This created Database.ps, which you can print directly, or view with postscript viewers like evince.



The boxes represent classes, and the arrows are relationships. The ends contain both the relationship labels and shapes that indicate the type of relationship. The bubbles are parent pointers, the light arrows are simple pointers, the full arrows are linked lists of some sort, and the empty boxes are hashed relationships. Arrays and heaps would be draw as boxes with an 'X' in them. Blue relationships are cascade delete, and green ones are mandatory.

We found a funny thing when trying to teach people to use DataDraw 1.0 and 2.0. Programmers get used to a way of coding and prefer to continue working this way. Possibly more than with any other profession, programmers are used to editing text files, rather than drawing pictures. We've changed DataDraw to reflect this, and now generate databases from database description files, rather than the other way around.

The dataview command takes the following parameters:

-p -- Optimize for printing, rather than viewing. Don't launch a viewer.
-v viewer -- Launch the specified postscript viewer, rather than the default of evince

By default, schemas are optimized for viewing on a screen, and the evince viewer is called automatically to view resulting postscript files. If you want to print a schema on letter sized paper, use the -p flag, which will size the schema properly. If you prefer some other postscript viewer to evince, use the -v flag to specify it.

15 Cache Efficiency

You may have read several times by now that DataDraw claims to be faster than native C code using tradition pointers to structures. This is true. In tests on various compute intensive EDA applications, DataDraw sped up tools anywhere from 10-20%, averaging about 15%.

The reason for this is vastly improved cache efficiency. When a typical inner loop goes through lists of objects, the fields needed are loaded into the cache, along with the ones that are not needed. Usually, most of the fields ending up in the cache are never accessed. With DataDraw, like data is stored together in memory. For example, if a Net class has a float called Delay, in memory the Delay fields are all stored together.

So, in a typical inner loop, if you access a field like Delay, you'll fill up your cache with Delay data, rather than useless bits your loop doesn't use. This makes DataDraw applications faster than traditional C applications.

In some cases, it is desirable to cache multiple fields of an object together. For example, if your inner loop accesses three fields of an object, you may want them collocated in memory so that the first cache miss will load them all. Consider the inner loop of a binary tree search. Here's a database description:

```
module Tree tr

class Node
        uint32 key
        cache_together key leftNode rightNode

relationship Node:Parent Node:Left cascade
relationship Node:Parent Node:Right cascade
```

With these data structures, we could write a binary search like:

```
trNode trFindClosestNode(
        trNode currentNode,
        uint32 key)
{
        trNode prevNode;

        do {
                prevNode = node;
                if(key > trNodeGetKey(currentNode)) {
                        currentNode = trNodeGetRightNode(currentNode);
                } else {
                        currentNode = trNodeGetLeftNode(currentNode);
```

```
            }
        } while(currentNode != trNodeNull);
        return prevNode;
    }
```

This loop may likely dominate the binary tree performance. The cache_together directive causes DataDraw to keep the key, leftNode, and rightNode fields together in memory, dramatically improving performance. In a red-black tree benchmark of DataDraw's ordered_lists performance improved 50% when inner loop fields were kept together, making DataDraw's ordered_lists the fastest red-black tree implementation we know of.

16 64-Bit Performance

Can you tell that the authors of DataDraw are performance freaks? They are, and they ran into 64 bit computing when many people were still transitioning from 16-bits to 32.

Here's the problem they ran into: Everyone was expecting to be able to run bigger designs more quickly using 64-bit machines. It didn't happen. Instead, the programs used more than 50% more memory and ran 20% slower. So for example, an engineer might estimate he needs 5 gig of memory based on his 32-bit experience, but he'll soon find out that he actually needs 8.

Here's why: In typical large EDA databases, most data is in the form of pointers, not data fields. If 80% of your data was in terms of 32-bit pointers, and you move to a 64-bit machine, your data structures grow in size 80%. That means you need to buy a lot more memory to do the same job your old 32-bit computer could do. It also means that your cache will be even less useful, because your data no longer fits into it well. This is the main reason for the slow-down in run-times on 64-bit machines.

DataDraw solves these problems. 64-bit pointers are only used to point to the beginning of data arrays. From there, 8, 16, 32, or 64 bit integers are used to index into the arrays to access the data. The index is the object's “reference”. Most objects simply use 32 bit references (the default). In fact, no one to date has needed a 64 bit object reference, since no DataDraw application has ever had to load more than 4 billion objects of any given class, though it will surely happen one day.

To specify the size of an object reference, use the “reference_size” class attribute. For example

```
class BoardLayer reference_size 8 // Who needs more than 255 layers on a PC board?
```

This would allow layers in a PC board database to be referenced with 8-bit values. That can save a lot of memory.

To see clearly the memory benefit of DataDraw on 64-bit machines, try compiling with and without DD_DEBUG defined. When DD_DEBUG is defined, all object references are actually 64-bit pointers, and without it, they are actually integers of the width you specify (32-bit by default). On a recent EDA benchmark, 2.2 gigabytes of memory were needed in release mode, while 3.8 gigabytes were needed in debug mode. For this application, DataDraw allowed the program to run in 58% of the memory required by a typical pointer-based C application. This not only provides a dramatic memory savings, but a nice cache performance boost as well.

17 Debugging DataDraw Applications

Since DataDraw is typically used for all of a program's data structures, rather than just persistent data, it is important to have debugging aids.

When you compile your application with the “DD_DEBUG” flag defined (pass -DDD_DEBUG to gcc), DataDraw does extra checking. In particular, it checks that all object references are valid before used, and that objects are not deleted twice nor accessed after deleted. Array bounds are also checked. Programmers who use DataDraw's debugging capabilities find little need for tools like Purify, since memory rarely gets corrupted.

When you compile your program with the “DD_DEBUG” flag, be sure to link to the -dbg version of the ddutil library. For example, rather than linking against ddutilp.a, link against ddutilp-dbg.a.

Additional functions are included in the C API when you compile in debug mode. You can call these from your debugger. In particular, you can call functions of the form:

```
dbShow<class>(object)
```

So, for example, if you have an object reference of type Person stored in a local variable named “person”, you could view its fields using the gdb debugger with:

```
call dbShowPerson(person)
```

If you want to access fields directly, it's fairly simple. Each class generates a global variable of the form <prefix><class>s. For example, a “Net” class in a module with a “db” prefix generates a global “dbNets” variable. Its value is the structure containing arrays for all properties of the class. So, for example if the Net class has a “Delay” field, and you want to know the delay on the net with object reference 1234, you can see it in gdb with:

```
print dbNets.Delay[1234]
```

To see all the fields available, just print dbNets. The DataDraw API also declares one global variable per tool: <prefix>RootData. It has all the pointers to arrays of field data and some bookkeeping variables. Usually, it's not used in debugging, but if for some reason you need to know the number of allocated or used objects of various classes, just print it out.

To simplify debugging, the DD_DEBUG flag also makes it possible to call any DataDraw access macro directly. For example, the following two commands will each tell you the age of a person:

```
print dbPersons.Age[(int)person]
print dbPersonGetName(person)
```

Set functions are also available. So, the following two commands are equivalent:

```
set dbPersons.Age[(int)person]=42
call dbPersonSetAge(person, 42)
```

The debug functions can be cascaded, so the following would be the same:

```
set dbPersons.Age[(int)dbPersons.Mother[(int)person]] = 89
call dbSetPersonAge(dbPersonGetMother(person), 89)
```

You will probably notice that references are integers rather than pointers. This is different than what you are probably used to, but one nice thing is that they do not change from run to run. This greatly simplifies debugging. They are also smaller and easier to remember or write down than pointers.

Another handy utility is the built-in database manager, which you can invoke in gdb with:

```
call utManager()
```

This lets you examine and modify your data, or even dump it all out as ASCII to a file. It also tells you how much memory your databases consume, class by class. A couple of handy functions to place

break-points in are utExit_ and utError. When compiled with the DD_DEBUG flag, the DataDraw database calls these functions when it finds problems.

With DD_DEBUG enabled, your program will not only run slower, but it may consume more memory, especially on 64-bit machines. This is because DD_DEBUG causes all object references to be 64-bit in order to detect type mismatches. If this causes a problem for you, consider turning on DD_NOSTRICT, which will allow you to run your program in the same memory footprint as your release version. If you use DD_NOSTRICT, you must link against the non-debug ddutil libraries.

18 Transaction Processing

Some systems perform high value transactions, such as taking orders for products bought on-line. It is rather inconvenient when such a database gets hosed. DataDraw provides a way to help prevent this.

Users may call the dbTransactionComplete function to indicate that the database has reached a stable point (assuming your module prefix is “db”). When dbDDRStart is called for a persistent database, pass “true” for the “deleteIncompleteTransactions” parameter. When loading the database from disk, DataDraw reads the recent history of changes. Any changes past the last time dbTransactionComplete was called will be ignored.

To do proper transaction based processing, you need to be able to deal with multiple simultaneous transactions. Here's the DataDraw recommended way:

Create a volatile database for gathering transaction data. For clarity, let's assume the transaction is an order for some product. Gather all of the order information needed in this volatile database (name, credit card, etc). Then, when the transaction is ready to be committed, write all the data back to the persistent database. Finally, call dbTransactionComplete.

Assuming you are running single threaded, like any true speed-freak hacker should, all database modifications between dbTransactionComplete calls will represent individual transactions. Well, that's not quite true... now that we have Core Duo processors, maybe you should have two threads.... In this case, you'll need to lock the database before writing to it. DataDraw does not support this directly: you'll need to deal with mutexes on your own, which you should already know how to do, since you're writing a multi-threaded application.

19 Persistent Database Format

DataDraw conveniently saves your database in the exact same binary format used in binary load/save. It is in the file called “database”. Changes to the database are recorded in the file “recentChanges”. Whenever “recentChanges” is large enough (currently 25% of the size of the database), “database” is overwritten and “recentChanges” emptied.

This is done for two reasons. First, it greatly speeds up the database, since only one file is accessed to commit any changes and all writes are done at the end of this file. Second, it provides a simple way to deal with transaction processing, since recent changes that are not committed can be ignored the next time the database is loaded.

Arrays are a bit different than other fields. Arrays are actually little heaps, similar to the ones supported by malloc. A file containing array data is a concatenation of blocks. Blocks are either allocated to an object, or they are free memory. Each block contains:

A reference to the object owning the block, or null if freed
The data elements if not freed, or the length of free space followed by space if freed

To help with data alignment in memory, the field is padded with 0's to make its size a multiple of the data element size.

New data for arrays is always allocated on the end of the heap. If there is no room, and the heap has less than 25% free memory, then the heap is made bigger and the array is allocated on the end. Otherwise, the heap first compacted, so that all free memory is on the end in one large free block. This method results in O(C + N) average allocation time, where C is a constant, and N is the length of data being allocated. This is possible because the allocator is able to compact data on-the-fly, unlike data in a C heap.

For multi-byte fields, data is written to the database in the order used by the host machine. This means that binary databases may not be compatible between CPU architectures.

20 The C API

The C API is simple and straightforward. All data is accessed through functions and macros generated by DataDraw.

To simplify discussion of examples, this section assumes we have defined the following netlist database:

```
module Netlist nl
class Netlist
class Instance
class Port
class Net
relationship Netlist Instance hashed mandatory
relationship Netlist Net hashed mandatory
relationship Instance Port doubly_linked mandatory
relationship Net Port doubly_linked
```

20.1 Object References

Objects are manipulated by passing their “references” to functions and macros that make up the C API. References are much like structure pointers, but what they actually are is buried under the API. In reality, they're integers. An object reference variable is declared with types like:

```
<prefix><Class>
example: nlNetlist netlist; /* This would be a reference to a Netlist object in module “nl” */
```

20.2 Null References

Every class has a unique NULL value declared for it, of the form <prefix><class>Null. For example, in module “nl”, a class named “Net” would have a NULL value called “nlNetNull”.

If you need to test to see if an object exists, compare its reference to the NULL value for the class. For example:

```
if(nlPortGetNet(port) != nlNetNull) {
        ...
}
```

20.3 Accessing Properties of Objects

Fields of objects are read with macros of this form:

<prefix><class>Get<field>(object)

For example, nlNetGetDelay(net) returns the delay field associated with a net. Setting has a similar format:

<prefix><class>Set<field>(object, value)

For example, nlNetSetDelay(net, 10.0) sets the delay of a net to 10.0.

This syntax is also used to get/set pointer fields in the database. For example, to set the next net port pointer of a port directly, use:

```
/* Remember, the NextNetPort field is automatically created. See Linked Lists for details. */
nlPortSetNextNetPort(port, nextPort);
```

There is one exception to how data is accessed. If the field is Boolean, the access format is simpler:

<prefix><class><field>(object)

However, the Set format is the same as for other types. For example, nlNetVisited(net) would return true if the Visited flag on the net were set. To set it, use nlNetSetVisited(net, value).

20.4 Enumerated Types

This couldn't be simpler... Enumerated types declared in a database description file are simply declared in the generated header file. For example, if the nldabase.dd description says

```
enum InstanceType INST_
        NAND
        NOR
        INV
        FLOP
```

Then the header file will declare:

```
enum nlInstanceType {
        INST_NAND,
        INST_NOR,
        INST_INV,
        INST_FLOP
}
```

20.5 Symbols

Symbol fields are automatically added to your classes when you use hashed relationships. This function is used to create symbols:

```
utSym utSymCreate(char *name);
```

If you pass the same name to this function twice, the second call returns the symbol created the first time. Symbols are so often used as names in hashed relationships that if you use a hashed relationship, DataDraw will automatically generate macros of the form:

<prefix><class>GetName(object)
<prefix><class>SetName(object, name)

For example, you can call nlNetGetName(net), and the value of the net's symbol will be returned as a char *. You can set the name with nlNetSetName(net, "N1")

20.6 Typedefs

Typedefs declared in a database description are provided by you, not DataDraw. To enable DataDraw to manage fields of types you declare, you must create a special header file, called "dbtypedef.h" (assuming "db" is your module prefix).

That's all it takes. Once declared, custom field's types can be used just like any built-in type.

20.7 Default Constructors

To create objects, call their default constructors. Their format is <prefix><class>Alloc(). For example, nlNetAlloc() creates a new Net object in the "nl" database. Default constructors initialize all fields to 0 or equivalent (false for bool, etc). To speed up allocation, you can use <prefix><Class>AllocateRaw(), however, since it does not initialize your object, its use should be limited to speed critical loops. To make class specific constructors, you will write code that calls the default constructor and then initializes the objects fields. By convention, these constructors you write should have the form <prefix><class>Create(...). For example,

```
/* Create a new net object */
nlNet nlNetCreate(
        nlNetlist netlist,
        utSym sym)
{
        nlNet = nlNetAlloc();

        nlNetSetSym(net, sym);
        nlNetlistAppendNet(netlist, net);
        return net;
}
```

20.8 Destructors

If you use DataDraw properly, you will never have to write another destructor function. DataDraw writes them for you. Their syntax is:

void <prefix><class>Destroy(object)

For example, nlNetDestroy(net) destroys the net and any cascade or mandatory children objects, and patches up all the object references in all the relationships.

If you are a total speed demon, you may bypass DataDraw's elegant destructors and simply free an object:

void <prefix><class>Free(object)

It is rarely wise, but in some critical loops it can be useful.

If you use the “create_only” memory management style for a class, it turns out you can actually free your objects, but only all at once. The following macro frees them all:

void <prefix><class>FreeAll()

You can then start over creating them. By the way, default constructors for create_only objects are super-fast.

20.8.1 Destructor Hooks

Though rare, sometimes our application has to do special processing when an object is destroyed. For example, if you do reference counting, you will want to decrement a reference counter when a parent object is destroyed. This can be done with constructor hooks:

<prefix><class>SetDestructorCallback(function)
<prefix><class>GetDestructorCallback()

20.9 Manipulating Relationships

Relationships are manipulated with the following commands:

<prefix><parent>Insert<child label><child>(parentObject, childObject)
<prefix><parent>Append<child label><child>(parentObject, childObject)
<prefix><parent>InsertAfter<child label><child>(parentObject, prevChildObject, childObject)
<prefix><parent>Remove<child label><child>(parentObject, childObject)

For example:

```
nlInstInsertPort(inst, port); /* Insert a port on the head of the list */
nlInstAppendPort(inst, port); /* Append a port to the end of the list */
nlInstInsertAfter(inst, prevPort, port); /* Insert the port after prevPort */
nlInstRemovePort(inst, port); /* Remove the port from the list */
```

Linked_list relationships do not have an “Append” function; otherwise, all these functions are available for linked_list, doubly_linked, tail_linked, and hashed relationships. Pointer and ordered_list relationships have only the Insert and Remove functions, as do unordered hashed relationships.

Hashed relationships and ordered_lists also provide a way to find objects in the relationship:

<prefix><parent>Find<child label><child>(parentObject, <key value>...)

If a hashed relationship has no specified key, a sym field is created, and a rename function is generated:

<prefix><child label><child>Rename(childObject, sym)

Ordered lists also provide a function to find the element matching the key either exactly if present in the list, or just previous to where such an element would be in the list:

<prefix><parent>FindPrev<child label><child>(parentObject, <key value>...)

Normally, you set the symbol for a child object and simply insert it into the hashed relationship. To find an object given its symbol, you can use the Find lookup function. For example,

inst = nlNetlistFindInst(netlist, utSymCreate(“U1”));

This will find the inst named “U1” in the netlist. To rename it, you could use:

nlInstRename(inst, utSymCreate(“U2”));

For array relationships, the following is used instead:

<prefix><parent>Insert<child label><child>(parentObject, index, childObject);

Note that the Append and Remove functions are the same as for other relationships. For example, if in the "nl" module, Bus has and array of Net, we would have:

```
nlBusInsertNet(bus, index, net);
nlBusAppendNet(bus, net);
nlBusRemoveNet(bus, net);
```

In this case, the nlBusGetNumNet(net) function tells you how many nets were allocated on the bus. The nlBusGetUsedNet(net) function tells you "end" of the array, in the sense that an append function will add the next net there.

The Append function for array relationships is particularly useful. It automatically increases the size of the array as you append objects, so no manual resizing of the array is required.

Heaps have some extra functions. If a bus had a heap of nets, then the extra functions would be:

```
nlBusPeekNet(bus);
nlBusPushNet(net, bus);
nlBusPopNet(bus);
nlBusUpdateNet(bus, net);
```

The push function pushes elements onto a heap and floats them up until their value is at least as good as all it's children. Peek reveals which net will be returned if pop is called. Pop removes and returns the best element in the heap. The usual remove function will also update the heap. Update should be used if any data on a net would change its ordering. To insert and remove elements from the heap, just use:

```
nlBusAppendNet(bus, net);
nlBusRemoveNet(bus, net);
```

In addition to the provided functions you must also provide a function called:

int nlBusCompareNet(net1, net2);

This should return a negative number if net1 should be popped first. It should return a positive number if net2 should be popped first. It may return 0 if either is considered acceptable.

20.10 Iterators

DataDraw provides simple iterators for your relationships. The form is:

```
<prefix>Foreach<parent><child label><child>(parent, child) {
        /* ... your loop body here */
} <prefix>End<parent><child label><child>;
```

In practice it looks like:

```
nlForeachNetPort(net, port) {
        /* do something with port here */
} nlEndNetPort
```

It is not wise to modify the list while iterating over it. If you need to remove an element from the list, use the SafeForeach iterators:

<prefix>SafeForeach<parent><child label><child>(parent, child) {

```
        /* ... your loop body here */
    } <prefix>EndSafeForeach<parent><child label><child>;
```

which look like:

```
    nlSafeForeachNetPort(net, port) {
        if(needToRemovePort(port)) {
            nlNetRemovePort(net, port);
        }
    } nlEndSafeForeachNetPort
```

If your class uses the create_only memory management style, then an iterator is created that allows you to traverse all the objects of that class, in the order in which they were created:

```
    <prefix>Foreach<class>(object) {
        /* ... your loop body here */
    } <prefix>End<class>;
```

In practice it looks like:

```
    nlForeachNetlist(netlist) {
        /* do something with netlist here */
    } nlEndNetlist;
```

20.11 Array Manipulation

Array properties are get, set and allocated with these functions:

```
    <prefix><class>Geti<field>(object, index)
    <prefix><class>Seti<field>(object, index, value)
    <prefix><class>GetNum<field>s(object)
    <prefix><class>Alloc<field>s(object, numValues)
    <prefix><class>Resize<field>s(object, numValues)
    <prefix><class>Free<field>s(object)
    <prefix><class>Set<field>(object, array, numValues)
```

For example, if an instance has an array of ports, it could be manipulated like:

```
    nlInstanceAllocPorts(instance, numPorts);
    nlInstanceGetNumPorts(instance); /* Returns number of allocated ports */
    nlInstanceResizePorts(instance, newNumPorts);
    nlInstSetiPort(instance, index, port);
    nlInstGetiPort(instance, index);
    nlInstFreePorts(instance);
    nlInstSetPort(instance, portArray, numPorts);
```

There's one more way to manipulate arrays, but be careful with it. The macro:

```
    <prefix><class>Get<field>s(object)
```

returns a pointer to the data in the array directly in memory. This is useful when calling qsort, for example. However, be aware that DataDraw moves this data around on its own without telling you. If you use this macro to directly access data, be sure not to allocate or free any array data until you're done using the pointer.

For fixed sized arrays, simply lose the functions we have a simpler set of functions:

<prefix><class>Geti<field>(object, index)
<prefix><class>Seti<field>(object, index, value)
<prefix><class>Set<field>(object, array, numValues)
<prefix><class>Get<field>s(object)

20.12 Persistence, and Undo/Redo

The following commands are used to control persistence and undo/redo. See the "Additional Steps" sections above for a more detailed description.

```
bool utStartPersistence(char *directory, bool useTextDatabaseFormat, bool keepBackup);
void utStopPersistence(void);
uint32 utUndo(uint32 numChanges);
uint32 utRedo(uint32 numChanges);
void utStartUndoRedo(void);
void utStopUndoRedo(void);
void utTransactionComplete(bool flushToDisk);
void utLoadBinaryDatabase(FILE *file);
void utSaveBinaryDatabase(FILE *file);
void utLoadTextDatabase(FILE *file);
void utSaveTextDatabase(FILE *file);
```

The values returned by utUndo and utRedo are the number of transactions undone or redone.

20.13 Miscellaneous

There some additional useful macros:

<prefix>Allocated<class>()
<prefix>Used<class>()

These are used to find out how much memory has been allocated for a class and how much of that memory has been used so far. DataDraw keeps a pool of free objects that it allocates from, so that it won't have to call malloc every time you create an object. There is also a pair of macros for each class for converting object references to integers and back:

<prefix><class>2Index(object)
<prefix>Index2<class>(index)

For example, to get an integer for a "Net" object in the "nl" module, use nlNet2Index(net). To convert the other way, use nlIndex2Net(index).

There are also some useful macros to copy the properties of a given object into a new object of the same class. To do so:

<prefix><class>CopyProps(<oldObj>, <newObj>)

20.14 Array Class Types

It is very common to use dynamic arrays for holding object references. DataDraw automatically creates these little helper classes for you if you specify the array class attribute in the class definition. For example, to have a helper array class generated for class Net, use:

```
class Net array
    ...
```

The effect is to automatically generate a helper class for manipulating dynamic arrays of nets. The class generated has this form:

```
<prefix><class>Array
example: nlNetArray
```

They are exactly like classes that had been declared like

```
class NetArray
relationship NetArray Net array child_only
```

To use them, you write code like:

```
nlNetArray netArray = nlNetArrayAlloc(numNets);
nlNetArrayAppendNet(netArray, net);
nlNetArrayAllocNets(netArray, numNets);
nlNetArraySetiNet(netArray, index, net);
nlNetArrayGetiNet(netArray, index);
nlNet *nets = nlNetArrayGetNets(netArray); /* For use in qsort, for example */
nlNetArrayFree(netArray); /* Don't forget to free them! */
```

Most commonly, the append function is used to automatically grow the size of the array, so no allocation or resizing needs to be done manually.

20.15 Sparse Data

Sometimes you may want to allocate a data for a field on a class for a small percentage of objects. In this case, you may specify the “sparse” field attribute. For example,

```
class Net
    bool isPower sparse
```

Instead of allocating a boolean for every net in the database, only nets for which IsPower is set would take up memory. Internally, sparse fields are stored in a hash table. It is implemented by adding the following classes to your database:

```
class DatadrawRoot create_only

class SparseNetIsPower
    Net netKey
    bool value

relationship DatadrawRoot SparseNetIsPower hashed net
```

If an object is not in the hash table, the default initialization value for the field is returned. Relationships can be declared sparse as well, in which case all class properties generated to support the relationship will be sparse. For example:

```
relationship Net Port linked_list sparse
```

Sparse class extensions can also be declared:

```
class Net:Netlistdb sparse
```

```
        bool isPower
        ...
```

In this case, Net is a local extension of a Net class in database “Netlistdb”. There may be millions of nets, but we may only need extra data on a few. This causes only the extended net data we write to be stored in memory, rather than adding the fields to every net.

20.16 Attribute Class Types

Like array class types, we sometimes need to add generic attribute lists to objects so that we can attach arbitrary data to objects at runtime. To add an linked list of attributes to your class, you add the “attributes” keyword the class definition line. For example, to add an attribute list to class Net, you could write:

```
class Net attributes
    ...
```

The effect is to automatically generate a helper class for manipulating genereic attributes. Only two attribute helper classes are added to the database, which keeps a hash table of attributes for the entire module. Assuming your module prefix is “nl”, the following class is added:

```
enum AttributeType NL_
    INT64
    DOUBLE
    BOOL
    SYM
    STRING
    BLOB

class Attrlist // List of attributes

class Attribute
    AttributeType type
    union type
        int64 intVal: NL_INT64
        double doubleVal: NL_DOUBLE
        bool boolVal: NL_BOOL
        sym Sym: NL_SYM
    array uint8 data // This stores string and blob data

relationship Attrlist Attribute hashed mandatory
```

For each class that has attributes, the following sparse relationship is added:

```
relationship <class> Attrlist child_only cascade sparse
```

For each class declared with attributes the following helper functions are defined:

```
<prefix>Attribute <prefix><class>FindAttribute(object, utSym attributeIdentifier)
<type> <prefix><class>Get<typeName>Attribute(object, utSym attributeIdentifier)
<prefix><class>Set<typeName>Attribute(object, utSym attributeIdentifier, <type> value)
```

Type/typeName pairs are:

int64	Int64
double	Double
bool	Bool
utSym	Sym
char *	String
uint8 *	Blob

So, for example, if you want to set some attributes on an object of type nlNet, you could use:

```
nlNetSetInt64Attribute(net, utSymCreate("answer"), 42); /* THE answer */
if(nlNetGetBoolAttribute(net, utSymCreate("isPower"))) ...
```

Blobs are binary data, so the set function takes an additional parameter: the length. You can also iterate over an objects attributes, using a attribute variables of type utAttribute. Attribute iterators attributes have the form:

```
<prefix>Foreach<class>Attribute(object, attribute) {
        /* ... your loop body here */
} <prefix>End<class><Attribute>;
```

In practice, they look like:

```
nlAttribute attribute;
nlForeachNetlistAttribute(netlist, attribute) {
        /* do something with attribute here, like switch on it's type */
} nlEndNetlistAttribute;
```

Attributes can be copied from one object to another with the function:

```
<prefix><class>CopyAttributes(<oldObj>, <newObj>);
```

This is called automatically from the CopyProps function.

20.17 Binary Load/Save

Many C++ programmers waste time overloading the >> and << operators so they can do binary load/save to disk. DataDraw not only automates this 100%, it makes it much faster and requires no ongoing maintenance. That said, simple binary dumps make a very poor save format. If you change any fields in your database, it will no longer be backwards compatible. If you take the easy way out and use a simple binary dump, you may spend much of the rest of your life writing file format conversion utilities. A better way is to write a custom reader and writer, with a documented file format that can be supported well into the future. However, most projects like to start out using the free load/save format :-)

All you do is call:

```
bool utSaveDatabase(char *fileName);
bool utLoadDatabase(char *fileName);
```

When you just need it quick, it can't be beat.

Be sure that you keep all your global values in the database, rather than as global variables, so that they will be saved and loaded with your database. It is common to create a “Root” class for global data, as well as top-level relationships. If you only create one “Root” object, and if you declare the Root class “create_only”, then it can always be accessed with dbFirstRoot(), assuming your module prefix is “db”.

Another issue to be aware of is using DD_DEBUG. When this flag is set, reference types are defined as pointers, rather than integers of the size you specified with the reference_size class attribute. This causes your program to consume more memory, and any binary databases saved while DD_DEBUG is enabled will be larger and incompatible with your program when compiled without DD_DEBUG. For this reason, there is an additional flag you can set, DD_NOSTRICT, which causes your program to run with full debug enabled except for strict type checking, but with binary compatibility. If you use DD_NOSTRICT, now and then you should compile your program without DD_NOSTRICT to help you find any type mismatches you may have accidentally introduced. With DD_NOSTRICT, or without DD_DEBUG, you can pass a dbDog object to a program that expects a dbCat object, without any warnings.

20.18 A Complete Example

Let's complete the simple netlist database example. Here's the database definition file:

```
module Netlist nl
class Netlist
class Instance
class Port
class Net
relationship Netlist Instance hashed mandatory
relationship Netlist Net hashed mandatory
relationship Instance Port doubly_linked mandatory
relationship Net Port doubly_linked
```

Here's a simple main.c program that uses it:

```
#include “nldatabase.h”

/* We have to write our own constructors :-(  DataDraw can't read our minds */

/* Create a new instance object */
nlInstance nlInstanceCreate(
        nlNetlist netlist,
        utSym sym)
{
        nlInstance = nlInstanceAlloc();

        nlInstanceSetSym(instance, sym);
        nlNetlistAppendInstance(netlist, instance);
        return instance;
}

/* Create a new net object */
nlNet nlNetCreate(
        nlNetlist netlist,
```

```
        utSym sym)
{
        nlNet = nlNetAlloc();

        nlNetSetSym(net, sym);
        nlNetlistAppendNet(netlist, net);
        return net;
}

/* Create a new port object */
nlPort nlPortCreate(
        nlInstance instance
        utSym sym)
{
        nlPort = nlPortAlloc();

        nlPortSetSym(port, sym);
        nlInstanceAppendPort(instance, port);
        return port;
}

int main(void) {
        nlNetlist netlist;
        nlInstance instA, instB;
        nlNet net;
        nlPort portA, portB;

        nlDatabaseStart();
        netlist = nlNetlistAlloc();
        instA = nlInstanceCreate(netlist, utSymCreate("instA"));
        portA = nlPortCreate(instA, utSymCreate("portA"));
        instB = nlInstanceCreate(netlist, utSymCreate("instA"));
        portB = nlPortCreate(instB, utSymCreate("portB"));
        net = nlNetCreate(netlist, utSymCreate("net"));
        nlNetAppendPort(net, portA);
        nlNetAppendPort(net, portB);
        /* Do whatever you like with the netlist here... */
        nlNetlistDestroy(netlist); /* This gets rid of everything we just built... just for fun */
        nlDatabaseStop(); /* This gets rid of everything also */
        return 0;
}
```

21 The Utility Library

The utilities in ddutil.a have been developed over 16 years to provide basic functions that are not available on all popular computing platforms, and to help take care of some tasks that aren't provided for in the standard C libraries. It provides some basic error handling capability and fairly powerful memory checking.

To use the utility package, be sure to call utStart() first. If you would like some final error checking to be done on memory, you can call utStop(bool reportTimeAndMemory) before exiting. If the reportTimeAndMemory flag is true, utStop will report the run-time and memory usage while shutting down the utility package.

21.1 Data Types

DataDraw supports several built-in types that aren't exactly like the built-in types in C. These new types are:

uint, uint8, uint16, uint32, uint64
int, int8, int16, int32, int64
bool
utSym

The utSym type is the same as “sym” in the database description language. The “bool” is actually just char, rather than int, to save memory. This can occasionally force you to cast the result of a relational operator to bool in an assignment. There are also several constants defined for these types:

true, false – These are bool
INT8_MAX, INT16_MAX, INT32_MAX, INT64_MAX – These are maximum values
INT8_MIN, INT16_MIN, INT32_MIN, INT64_MIN – These are minimum values
UINT8_MAX, UINT16_MAX, UINT32_MAX, UINT64_MAX – These are maximum values
UINT8_MIN, UINT16_MIN, UINT32_MIN, UINT64_MIN – These are minimum values

A couple of handy constants are declared to help parse paths on both Linux and Windows:

UTDIRSEP – This is \ on Windows, and / otherwise
UTPATHSEP – This is ; on Windows, and : otherwise

21.2 Memory Access

DataDraw programs rarely reallocate memory, which allows them to have full memory debug code on all the time. DataDraw provides wrappers around calloc, malloc and free for this purpose. What it does is verify that all memory is freed before utClose is called, verify that no pointer is freed twice, and it provides “pickets” at the beginning and of all memory blocks allocated to help detect when we write past the end or beginning of a memory block. These functions are slow compared to malloc and free, so don't use them to allocate objects one at a time! The functions are:

```
void *utMalloc(int sStruct, int size); /* Allocates memory, but does not clear it */
void *utCalloc (int sStruct, int size); /* Allocates memory, initialized to 0's */
type *utNew(type); /* Allocates a structure large enough to hold the type */
type *utNewA(type); /* Allocates an array of 'type' */
char *utAllocString(char *string); /* Creates a copy of the string using ntNewA */
```

To check for memory leaks, just call utClose() before exiting. Any memory allocated with one of the above functions must be freed before calling utClose(), or a memory leak error will be reported.

21.3 Symbol Tables

DataDraw symbols are stored in symbol tables within the utility library. In your application, the type utSym is implemented for any 'sym' type in a database description file. Functions (methods) for utSym are:

```
utSym utSymCreate(char *name);
utSym utSymCreateFormatted(char *format, ...); /* Takes printf style formats */
```

The value utSymNull is the NULL value for the utSym class.

21.4 Random Numbers

If you are building a portable application, you may need a pseudo random number generator so that your application can use the same pseudo random sequences on any platform. The utility library uses an industry standard random number generator written by Takuji Nishimura. See utrand.c for more details. Functions provided are:

```
void utInitSeed(uint seed);
uint utRand(void); /* Return a random 32-bit unsigned int */
uint utRandN(uint n); /* Return a random 32-bit unsigned int between 0 and n – 1 */
bool utRandBool(); /* Return true or false, randomly */
uint8 *utRealRandom(uint32 length); /* Return truly random data, from entropy pool */
```

21.5 Message Logging

It is often useful for an application to create a log file while it runs. The following commands support log files:

```
utInitLogFile(char *fileName); /* Call this once to creat the log file */
utLogDebug(char *format, ...); /* Just like fprintf to the log file... used for debug messages */
utLogMessage(char *format, ...); /* Like utLogDebug, but adds '\n' at the end */
utLogTimeStamp(char *format, ...); /* Like utLogMessage, but writes out the time first */
uint32 utStartTimer(char *format, ...); /* Like utLogTimeStamp, but also starts a timer */
utStopTimer(uint32 timerID, char *format, ...); /* Like utStart timer, but reports elapsed time */
utWarning(char *format, ...); /* Like utLogMessage, but prepends “WARNING” */
utError(char *format, ...); /* Like utWarning, but prepends “ERROR” and calls utLongjmp() */
utCriticalError(char *format, ...); /* Like utError, but exit instead of utLongjmp */
utExit(char *format, ...); /* Link utCriticalError, but report the file and line number */
utAssert(bool value); /* Like utError, but exits only if value is false */
```

The utStartTimer function returns a timerID, which needs to be passed to utStopTimer. This is used to verify that start/stop timer calls are nested evenly, which can be hard to track down otherwise.

21.6 Error Handling

The utility library supports hierarchical error handling. Only three functions are needed:

```
bool utSetjmp(void);
void utLongjmp(void);
void utUnsetjmp(void);
```

This greatly simplifies error handling compared to raw setjmp/longjmp code. To use it, just call utSetjmp() at the start of your tool and utUnsetjmp before you return. If you encounter an error condition, just call utLongjmp(). Even better, just call utError, which reports an error message and calls utLongjmp() for you.

A typical tool that needs some error handling would look something like:

```
bool myTool(void)
{
        myDatabaseStart(); /* Your tool uses a DataDraw database, right? */
        if(utSetjmp()) {
                /* If you get here, it was an error condition */
                myDatabaseStop();
                return false;
        }
        /* Your tool does it's thing here */
        utUnsetjmp();
        myDatabaseStop();
        return true;
}
```

Some error conditions represent bugs in the code, such as when NULL is passed to a routing that expects a valid string. These errors should be reported with utExit(), since this function tells the user what file and line number the error occurred on. Other errors are actually user errors, such as when a file cannot be found, but they critical enough that the program cannot continue. In this case, call utCriticalError(), which simply reports the error and exits.

21.7 String Manipulation

The utility library provides a set of string buffers that can be used to simplify working with variable sized strings. There are 32 string buffers which grow if needed. The idea is that often you need just a few strings, and it's a pain to allocate buffers for them with malloc. This is one reason why so many programs have problems with buffer overflows.

These functions are highly recommended, but be careful when using them, since they only return temporary buffers. If you use them, and run into trouble where a returned value gets overwritten, it's probably because you kept it around too long, and the buffer was reused. In such cases, allocate a buffer with malloc and copy the string to it. Functions provided are:

```
char * utStrcat (char *string1, char *string2); /* Return the concatenation of two strings */
char * utStrncat (char *string1, char *string2, U32 length); /* Similar to strncat */
/* Replace the suffix after the last '.' character with a new suffix */
char *utReplaceSuffix(char *originalName, char *newSuffix);
char *utSuffix(char *name); /* Return the suffix of a string */
char *utBaseName(char *name); /* Return the name without a directory prefix */
char *utDirName(char *name); /* Return the directory name, without the file name */
/* Expand any ${variable} strings with values found in the environment */
char *utExpandEnvVariables(char *string);
char *utSprintf (char *format, ...); /* Create a string from the printf style format */
char *utVsprintf(char *format, va_list ap); /* Like vsprintf */
void utSetEnvironmentVariable(char *name, char *value); /* Set an environment variable */
char *utGetEnvironmentVariable(char *name); /* Get an environment variable */
char *utFindHexString(uint8 *values, uint32 size); /* Convert bytes to hex string */
bool utReadHex(uint8 *dest, char *value, uint32 size); /* Convert hex string to bytes */
bool utParseInteger(int64 *dest, char *string); /* Like strtol, using '0' base */
char *utConvertDirSepChars(char *path); /* Convert paths to local machine dir separators */
```

21.8 File/Directory Information

The following commands can be handy when you just need some file information.

```
char *utGetcwd(void);
bool utChdir(char *dirName);
bool utFileExists(char *fileName);
bool utDirectoryExists(char *dirName);
bool utAccess(char *name, char *mode);
uint64 utFindFileSize(char *fileName);
char *utExecPath(char *name);
char *utFullPath(char *relativePath);
char *utFindInPath(char *name, char *path);
void utTruncateFile(char *fileName, uint64 length);
```

The utAccess command returns true if the mode is supported, which can be “r”, “w”, or “x”.

21.9 Miscellaneous

Some handy macros:

```
utAbs(a) – return a if a >= 0, otherwise -a
utMin(a, b) – return a if <= b, otherwise b
utMax(a, b) – return a if >= b, otherwise b
```

If you've gotten this far in this manual, you're probably a hard-core programmer. This being the case, I'll introduce you to a new looping construct that should have been built into C in the first place:

```
utDo {
        do-body
} utWhile(condition) {
        while-body
} utRepeat;
```

The utDo, utWhile and utRepeat macros support this new looping construct. What happens is that the do-body is executed and then the condition is evaluated. If true, the while-body is executed, and we then repeat, starting at the do-body. This handy looping construct eliminates the vast majority of cases where you would be tempted to place an assignment in a while condition. Consider this classic example:

```
while((c = getc(file)) && c != EOF) {
        /* Process character */
}
```

Many of us are uncomfortable allowing assignments in conditions because of the common bug of writing “=” when we mean “==”. This code is typically rewritten thus:

```
c = getc(file);
while(c != EOF) {
        /* Process character */
        c = getc(file);
}
```

While this only introduces one extra line of code, in more complex examples, the do-body can be very

complex, and duplicating it twice is ugly. The utDo-utWhile-utRepeat loops fix this.