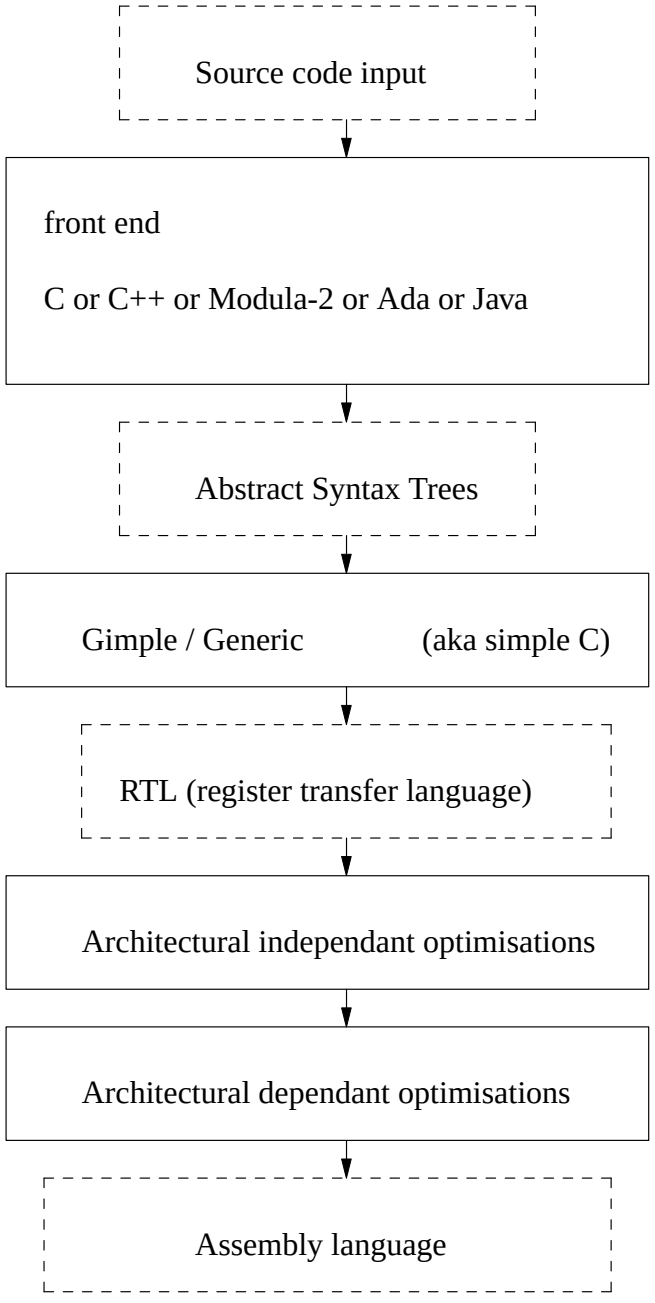
Optimisers: GCC and friends

- the GNU Compiler Collection consists of a number of compilers which can be built to natively support a variety of targets
  - the compilers could also be configured to cross compile - for non native targets
  - 71 architectures (x86_64, arm, risc-v, sparc, avr) etc
  - multiple platforms (GNU/Linux, OSX, Windows, Solaris, AIX) etc
- variety of languages: C, C++, Ada, Java, Modula-2, Fortran, D, Go
- the compiler has a vast number of optimiser options
  - some architecture specific, some generic
- compiler also has debugging and profiling options
  - highly useful to detect hot spots in your code

Structure of GCC



How to profile your code

- the gcc compilers all have the -pg option which enables profile generation of code
  - beware that it generates extra instructions to achieve instrumentation
  - beware of the Heisenberg principle

- nevertheless it is easy to use and very effective for profiling static programs

- however `pge` is built as a dynamic shared library so a number of these easy to use options are off limits

GCC and tips

- GNU Compiler Collection consists of many language front ends to the gnu compiler
- here we will look at some of the common options to `gcc` and `g++`
- these slides are simply a taster and huge simplification of how GCC might be used

GCC debugging

- all front ends (in our case: `gcc`, `g++` and `gm2`) accept `-g -O0` which tell the compiler not to optimize and emit debugging information for `gdb`

GCC debugging

- turn on all warnings by: `-Wall`
- so our command line to compile `hello.c` is:
-
```
$ gcc -g -O0 -Wall -c hello.c
```
- notice that this compiles `hello.c` but does not link it
- to link this we can:
-
```
$ gcc -g hello.o
```

GCC debugging

- we could combine the last two steps by:

```
$ gcc -g -O0 -Wall hello.c
```

Debugging your code

```
$ gdb a.out
(gdb) break exit
(gdb) run
(gdb) quit
```

- set break points, single step code, finish functions, invoke functions as necessary

```
(gdb) print t
(gdb) break pf
(gdb) print pf(t)
(gdb) next
(gdb) step
(gdb) finish
```

Valgrind

- no excuse for not using this program (for static programs)!
- it requires no effort to run your executable in valgrind
-
```
$ valgrind ./a.out
```
- `valgrind` is a memory mismanagement detector, it can detect using memory which has not been allocated or has been freed

What is wrong with this code?

```
#include <stdlib.h>

void myfunc (int n)
{
   int* a = malloc(n * sizeof(int));

   a[n] = 0;
}

int main ()
{
  myfunc (3);
  return 0;
}
```

Valgrind gives you a huge hint

```
$ valgrind ./a.out
==30984== Command: ./a.out
==30984==
==30984== Invalid write of size 4
==30984==    at 0x400511: myfunc (bad.c:7)
==30984==    by 0x400526: main (bad.c:12)
==30984==  Address 0x518b04c is 0 bytes after a block of size 12 alloc'd
```

Making your program go faster

- firstly profile your static code to check if there are any obvious inefficiencies

-
```
$ gcc -g -O0 -pg -c foo.c
$ gcc -g -pg foo.o
```

Making your program go faster

- again we could combine these two commands with
-
```
$ gcc -g -O0 -pg foo.c
```
- most large projects will involve a discrete compile and link step

Making your program go faster

- run your program as before
- ```
  $ ./a.out
  ```
- now invoke the profiler
- ```
  $ gprof a.out
  ```

Making your program go faster

```
Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls   s/call   s/call  name
 35.38     20.64    20.64 4771989280     0.00     0.00  IN
 25.59     35.56    14.93 1049864543     0.00     0.00  scan
 15.22     44.44     8.88 345772285     0.00     0.00  makeMove
  8.52     49.41     4.97 868833748     0.00     0.00  INCL
  7.34     53.69     4.28 10274416     0.00     0.00  evaluate
```

- we could choose to rewrite the functions `IN`, `scan` or `makemove`

Making your code go even faster

- use options: `-O1` or `-O2` or `-O3` on the command line to `gcc`
- these optimizations may vary according to architecture

Making your code go even faster

- for detail as to which optimizations they turn on use:

```
$ gcc -c -Q -O3 --help=optimizers | grep enabled
```

- to see the difference between `-O2` and `-O3` use:

```
$ gcc -c -Q -O3 --help=optimizers > /tmp/O3-opts
$ gcc -c -Q -O2 --help=optimizers > /tmp/O2-opts
$ diff /tmp/O2-opts /tmp/O3-opts | grep enabled
```

Making your code go even faster

- if you don't need full compliant math code, you could use the `-ffast-math` option (which will inline `sin`, `cos`, `tan` etc)

- ```
  $ gcc -O3 -ffast-math -c foo.c
  $ gcc -O3 -ffast-math foo.o
  ```
  ```

Tutorial/coursework hint

- try using `-ffast-math` in
- **git-pge/c/Makefile.am**

```
.c.lo:
	$(LIBTOOL) --tag=CC $(AM_LIBTOOLFLAGS) $(LIBTOOLFLAGS) \
	    --mode=compile gcc -c $(CFLAGS_FOR_TARGET) \
	    $(LIBCFLAGS) $(libgm2_la_M2FLAGS) \
	    -ffast-math $< -o $@
```

- and rebuild pge
  - try experimenting with other optimisation flags
    - `-O0`, `-O1`, `-O2`, `-O3`

Size of code generated

- you can always check the size of your code via:

```
$ size a.out
```

- also optimize for space via the option `-Os`

```
$ gcc -Os -c foo.c
$ gcc -Os foo.o
```

How to debug a shared library (PGE)

- sadly we cannot use `gcc -pg` to profile as `pge` is compiled into a shared library
- however we can use the tool `google-pprof` which will profile shared libraries

Add a profiling library during the shared library link stage (-lprofiler)

```
libpgeif.la:  $(MY_DEPS)
   ...
   $(LIBTOOL) --tag=CC --mode=link gcc -g _m2_pgeif.lo $(MY_DEPS) \
   pgeif_wrap.lo \
      -L$(GM2LIBDIR)/lib64 \
      -rpath `pwd` -liso -lgcc -lstdc++ -lpth -lc -lm -lprofiler \
      -o libpgeif.la
   cp .libs/libpgeif.so ../_pgeif.so
   cp pgeif.py ../pgeif.py
```

Add a profiling library during the shared library link stage (-lprofiler)

```
$ CPUPROFILE_FREQUENCY=10000 LD_PRELOAD=/usr/lib/libprofiler.so \
  CPUPROFILE=dump.txt ./localrun.sh ../git-pge/examples/springs/bridge.py
$ ls -l
$ google-pprof --text localrun.sh dump.txt_7987 | less
```

Add a profiling library during the shared library link stage (-lprofiler)

```
Total: 1346 samples
     248  18.4%  18.4%      248  18.4% SDL_SetTimer
     172  12.8%  31.2%      172  12.8% __dubsin
     109   8.1%  39.3%      109   8.1% __nanosleep_nocancel
      97   7.2%  46.5%      177  13.2% initEntity
      52   3.9%  50.4%       81   6.0% Indexing_GetIndice
      41   3.0%  53.4%       41   3.0% findChildAndParent
      29   2.2%  55.6%       29   2.2% Indexing_InBounds
      11   0.8%  64.9%      183  13.6% sloww
      10   0.7%  65.7%       10   0.7% coord_initCoord
      10   0.7%  66.4%       10   0.7% do_cos
      10   0.7%  67.2%      229  17.0% roots_findAllRootsQuartic
```

A graphical performance call tree

- ```
  $ google-pprof --gv localrun.sh dump.txt_8708
  ```

- which gives an indication of the call tree and performance implications
  ```

Profiling

- you will need to experiment with the optimization flags and also profile the shared library after each change
- a good idea to create a table of optimizations and also track the performance hot spots

How to debug your code

- generally you should turn off optimization when debugging your code
  - use `-O0 -g`
- this will produce precise code to line number and variable access
  - the code will go slower, obviously, which might in extreme cases change the bug behaviour compared to `-O3`
  - you will need to experiment and become comfortable with these tools
- your experience will enable you to tradeoff these issues with your own bugs

Taking a different language approach

- `pge` is written in Modula-2 and has been translated into C

- the Modula-2 compiler has additional debugging options which provide very exact source/code correlation
  - if requested it will insert extra redundant `nop` instructions so that end of statements can be single stepped

Taking a different language approach

- consider the C fragment

```
if (foo)
  {
     int x = 1;

     y = x + 1;
  }
```

- if this code were compiled with debugging `-g` and `-O0` and single stepped
  - a user would probably not be able to single step every line
  - the `{` line and the `}` do not correspond with any assembly code
- most languages have these syntax sugar statements which do not map onto real assembly instuctions

Taking a different language approach

- the Modula-2 compiler `gm2` has the `-fm2-g` option which will generate redundant `nop` instructions for the explicit purpose of providing an exact single step user experience

- oddly enough, on an AMD and Intel 64 bit machine, the performance penalty is almost unnoticeable

Whole program optimisation in gm2

- pge showed a 40% improvement (frames per second) on the armv7l with `-fm2-whole-program`

Adding Bungees into PGE

- so far springs, polygons and circle objects have been introduced into PGE
- recall that the spring has an at rest length $l0$ and the two objects are currently $l1$ distance apart
- a bungee is a modification of the spring object
  - it only pull objects together if $l1 > l0$

Bungee API

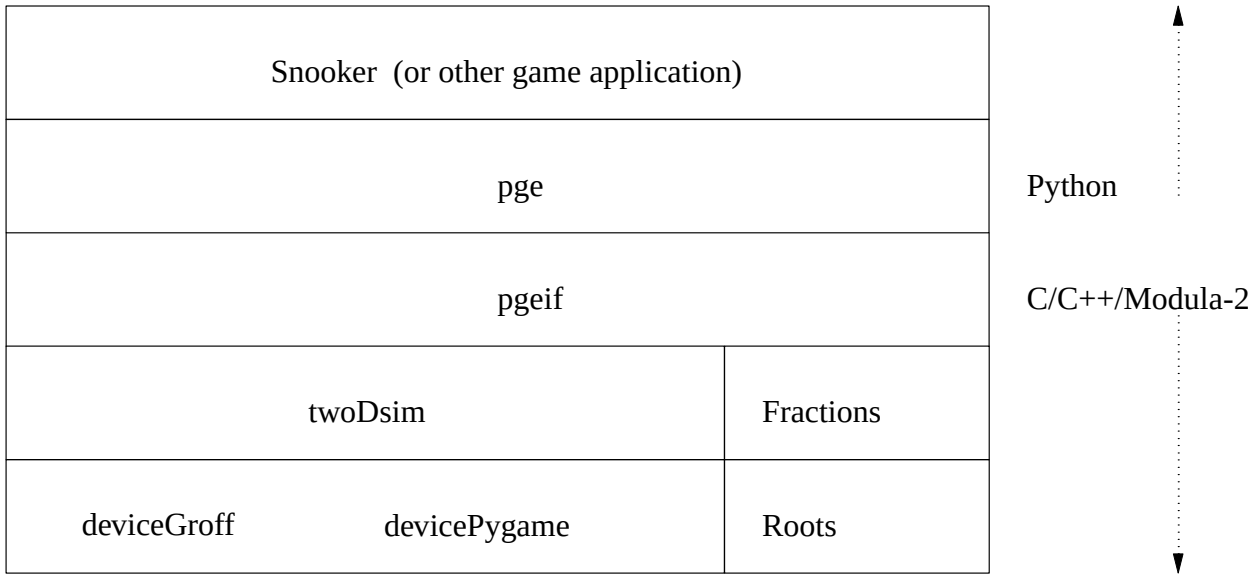
- in Python we could introduce the `bungee` method which is defined as:

- **Sandpit/pge/python/pge.py**

```
#
#  bungee - Pre-condition:  a spring object.  toBungee is a boolean.
#           Post-condition:  if toBungee is True convert the spring
#                               to a bungee
#                            else convert the bungee back into a
#                               regular spring.
#
def bungee (self, toBungee):
   # finish this method
   # it should check self is a spring
```

PGE Layers and associated files

- there are a number of layers in PGE



Layers and source files to be altered

- `pge/python/pge.py`
  - the user level python API file
  - this is the only PGE visible file to the user

- `pge/i/pgeif.i`
  - the swig interface (python calling C/C++ definition)
  - remember to edit both sections (C/C++ section and the Python section)
  - hint look for `%{` and `}%` delimiters

Layers and source files to be altered

- `pge/c/Gpgeif.h`
  - header file for `pgeif.c`
  - contains the external functions implemented inside `pgeif.c`

- `pge/c/pgeif.c`
  - its purpose is to allow, colours, polygons, circles, springs, to be given a unique integer
  - thereafter all references to objects will be achieved via the objects, id.
  - notice that inside `twoDsim.c` colours and circles are different

Layers and source files to be altered

- `pge/c/twoDsim.c`
  - the actual game engine, which implements polygons, circles, springs

- `pge/c/GtwoDsim.h`
  - the header file for `pge/c/twoDsim.c` which defines all external functions

Layers and source files to be altered

- all these files will need `bungee` references added to them
- start at the top `pge/python/pge.py` and work downwards
- follow per object gravity as a guide
- you will need to actually implement bungee's inside `twoDsim.c` (alter the behaviour of a spring)

Layers and source files to be altered

- hint
  - add an extra field to spring `isBungee` and set it to `FALSE` by default in `twoDsim_spring`

Tutorial

- use these slides to add bungees into your version of pge
- write some simple test code in Python to create a bungee spring
  - ensure that it also has a fps counter on screen
  - write down the fps
- now see if you can rebuild pge using some of the optimisation techniques discusseed in the slides
  - does the fps change?