Quantum Computer Outreach Project

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Global BTN_CHIP_NUM

read buttons

Global led_cycle_test (void)

This won't work now: write_display_driver(counter);

Global mat_mul (Complex M[2][2], Complex V[], int i, int j)

Because of the way the array types work (you can't pass a multidimensional array of unknown size) we will also need a function for 4x4 matrix multiplication.

Global read_external_buttons (void)

How long should this be?

button remappings...

Global setup_timer ()

distinguish between the two different timers here...

Global TLC591x_mode_switch (int mode)

mode switcher for LED Driver

Global write_display_driver (void)

How long should this be?

Chapter 2

Data Structure Index

2.1 Data Structures

Here are the data structures with brief descriptions:

Chapter 3

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3.1 File List

Here is a list of all documented files with brief descriptions:

Chapter 4

Data Structure Documentation

4.1 LED Struct Reference

Each LED has the following type.

```
#include <io.h>
```

Data Fields

- int **R** [2]
- int G [2]

  Red mapping array: [chip number, line number].
- int B [2]

  Green mapping array.
- unsigned _Fract N_R

  Blue mapping array.
- unsigned _Fract N_G

  The R brightness.
- unsigned _Fract N_B

  The G brightness.

4.1.1 Detailed Description

Each LED has the following type.

The type holds the information about the position of the RGB lines in the display driver array and also the brightness of the RGB lines. The counters are used by a timer interrupt service routine pulse the RGB LEDs at a specified rate.

The position of the LED lines are contained in an array

The type of the counter is *Fract to facilitate easy comparison with the N*$*$ variables which used the fractional type.

The documentation for this struct was generated from the following file:

- dspic33e/qcomp-sim-c.X/io.h

4.2 LED_GLOBAL Struct Reference

pin mappings Pins for LE and OE on port D OE = RD4 = uC:81 = J1:28 = J10:14 LE = RD3 = uC:78 = J1:40 = J11:18

```
#include <io.h>
```

Data Fields

- int strobe_leds

  Bit set the LEDs which are strobing.
- int strobe_state

  Bit zero is the current state (on/off)

4.2.1 Detailed Description

pin mappings Pins for LE and OE on port D OE = RD4 = uC:81 = J1:28 = J10:14 LE = RD3 = uC:78 = J1:40 = J11:18

Pins for SH and CLK_INH on port D SH = RD5 = uC:82 = J1:25 = J10:13 CLK_INH = RD8 = uC:68 = J1:58 = J11:25Global LED strobing state parameter

The documentation for this struct was generated from the following file:

- dspic33e/qcomp-sim-c.X/io.h

Chapter 5

File Documentation

5.1 dspic33e/qcomp-sim-c.X/algo.c File Reference

Contains quantum algorithms to be run.

```
#include "io.h"
#include "quantum.h"
#include "algo.h"
#include <math.h>
```

Include dependency graph for algo.c:

5.1.1 Detailed Description

Contains quantum algorithms to be run.

5.2 dspic33e/qcomp-sim-c.X/algo.h File Reference

header file for algorithms

This graph shows which files directly or indirectly include this file:

Macros

- #define **NUM_QUBITS** 3
- #define **STATE_LENGTH** 8

5.2.1 Detailed Description

header file for algorithms

5.3 dspic33e/qcomp-sim-c.X/config.h File Reference

General config settings #pragma for microcontroller.

This graph shows which files directly or indirectly include this file:

5.3.1 Detailed Description

General config settings #pragma for microcontroller.

Description: Include this once at the top of main

5.4 dspic33e/qcomp-sim-c.X/io.c File Reference

Contains all the functions for reading buttons and writing to LEDs.

```
#include "io.h"
#include "time.h"
#include "spi.h"
```

Include dependency graph for io.c:

Macros

- #define **DISPLAY_CHIP_NUM** 2
- #define **PERIOD** 500000
- #define BTN_CHIP_NUM 2

  Read external buttons.

Functions

- int led_color_int (int device, int R, int G, int B)

  Takes led number & RGB -> returns integer for sending via SPI to set the LED.
- int setup_io (void)

  Set up LEDs and buttons on port D.
- void __attribute__ ((__interrupt__, no_auto_psv))

  The max value for isr_counter.
- void setup_external_leds (void)

  Set external variable RGB LEDs.
- void stop_external_leds (void)

  Stop LEDs flashing.
- void set_strobe (int color, int state)

  Set an LED strobing.
- void toggle_strobe (int color)

  Toggle LED strobe.
- int set_led (int color, int state)

  Turn a particular LED on or off.
- int read_btn (int btn)

  Read the state of a push button.
- void leds_off (void)

  Turn all the LEDs off.
- void flash_led (int color, int number)

  Flash LED a number of times.
- void flash_all (int number)

  Flash all the LEDs a number of times.
- int update_display_buffer (int n, bool R, bool G, bool B)
- int write_display_driver (void)

  Turn on an LED via the external display driver.

- int TLC591x_mode_switch (int mode)

    Switch between normal and special mode.
- int set_external_led (int index, unsigned _Fract R, unsigned _Fract G, unsigned _Fract B)

    Updates color properties of global led array.
- int read_external_buttons (void)

    Update the buttons array (see declaration above)
- int led_cycle_test (void)

    Loop to cycle through LEDs 0 - 15.
- void varying_leds (void)

    Routine to test the set_external_led function.

Variables

- int buttons [16]

    Contains the button states.
- LED_GLOBAL led_global = {0}
- LED led [LED_NUM]

    The LED array – global in this file.
- int display_buf [DISPLAY_CHIP_NUM] = {0}

    Display buffer to be written to display driver.
- unsigned _Fract isr_counter = 0

    Counter for the interrupt service routine _T5Interrupt.
- unsigned _Fract isr_res = 0.01

    Counter value.
- const unsigned _Fract isr_limit = 0.95

    Counter resolution.

5.4.1 Detailed Description

Contains all the functions for reading buttons and writing to LEDs.

Author

J Scott

Date

8/11/18

5.4.2 Macro Definition Documentation

5.4.2.1 #define BTN_CHIP_NUM 2

Read external buttons.

The external buttons are interfaced to the microcontroller via a shift register. Data is shifted in a byte at a time using the SPI 3 module. The sequence to read the buttons is as follows:

1) Momentarily bring SH low to latch button data into the shift registers 2) Bring CLK_INH low to enable the clock input on the shift register 3) Start the SPI 3 clock and read data in via the SDI 3 line

The control lines SH and CLK_INH are on port D

Todo read buttons

5.4.3 Function Documentation

5.4.3.1 void __attribute__ ((__interrupt__, no_auto_psv))

The max value for isr_counter.

Interrupt service routine for timer 4

Interrupt service routines are automatically called by the microcontroller when an event occurs. In this case, _T5↩Interrupt is called when the 32 bit timer formed from T4 and T5 reaches its preset period. The silly name and sill attributes are so that the compiler can correctly map the function in the microcontroller memory. More details of interrupts and interrupt vectors can be found in the compiler manual and the dsPIC33E datasheet.

The job of this routine is to control the modulated brightnesses of the RBG LEDs. This routine is set to be called periodically with a very long period on the time scale of microcontroller operations, but very fast in comparison to what the eye can see. For example, once every 100us. Loop over all the LEDs (the index i).

Decide whether R, G or B should be turned off

Write the display buffer data to the display drivers It's important this line goes here rather than after the the final update_display_buffer below. Otherwise you get a flicker due to the LEDs all coming on at the start of this loop

Reset the counter

Turn on all the LEDs back on

5.4.3.2 void flash_all (int *number*)

Flash all the LEDs a number of times.

Parameters

number	

5.4.3.3 void flash_led (int *color,* int *number*)

Flash LED a number of times.

Flash one LED a number of times.

5.4.3.4 int led_color_int (int *device,* int *R,* int *G,* int *B*)

Takes led number & RGB -> returns integer for sending via SPI to set the LED.

Parameters

device	input LED number to change
R	red value between 0 & 1
G	green value between 0 & 1
B	blue value between 0 & 1

Returns

Returns int to be sent to LED Driver

convention RGB -> 000

Each LED takes 3 lines, assumes there are no gaps between LED channels "device" goes between 0 to 2^n -1

5.4.3.5 int led_cycle_test (void)

Loop to cycle through LEDs 0 - 15.

Todo This won't work now: write_display_driver(counter);

5.4.3.6 int read_btn (int *btn*)

Read the state of a push button.

Parameters

btn	

Note

How well do you know C

5.4.3.7 int read_external_buttons (void)

Update the buttons array (see declaration above)

SH pin

Todo How long should this be?

Todo button remappings...

5.4.3.8 int set_external_led (int *index,* unsigned _Fract *R,* unsigned _Fract *G,* unsigned _Fract *B*)

Updates color properties of global led array.

Parameters

led_index	
R	red value between 0 & 1
G	green value between 0 & 1
B	blue value between 0 & 1

Returns

0 if successful, -1 otherwise

Use the function to set the RGB level of an LED. The LED is chosen using the

Parameters

led_index.	The
R	param G and
B	are numbers between 0 and 1 (not including 1) indicating the amount of each color. The function returns 0 if successful and -1 otherwise.

5.4.3.9 int set_led (int *color,* int *state*)

Turn a particular LED on or off.

Parameters

color	
state	

5.4.3.10 void set_strobe (int *color,* int *state*)

Set an LED strobing.

Parameters

color	
state	

5.4.3.11 void setup_external_leds (void)

Set external variable RGB LEDs.

Initialise LED lines

Initialise parameters to zero

Initialise display buffer to zero

5.4.3.12 int setup_io (void)

Set up LEDs and buttons on port D.

< Set port c digital for spi3

Set the OE pin high

Set OE(ED2) pin

Set the SH pin high

Set SH pin

set CLK_INH high while buttons are pressed

5.4.3.13 int TLC591x_mode_switch (int *mode*)

Switch between normal and special mode.

The mode switch for the TLC591x chip is a bit tricky because it involves synchronising the control lines LE(ED1) and OE(ED2) on Port D with the SPI 1 clock. To initiate a mode switch, OE(ED2) must be brought low for one clock cycle, and then the value of LE(ED1) two clock cycles later determines the new mode. See the diagrams on page 19 of the datasheet

So long as the timing is not strict, we can probably implement the mode switch by starting a non-blocking transfer of 1 byte to the device (which starts the SPI 1 clock), followed by clearing OE(ED2) momentarily and then setting the value of LE(ED1) as required. So long as those two things happen before the SPI 1 clock finishes the procedure will probably work. (The reason is the lack of max timing parameters on page 9 for the setup and hold time for ED1 and ED2, which can therefore presumably be longer than one clock cycle.)

Parameters

mode	

Todo mode switcher for LED Driver

5.4.3.14 void toggle_strobe (int *color*)

Toggle LED strobe.

Parameters

color	

5.4.3.15 int update_display_buffer (int *n*, bool *R*, bool *G*, bool *B*)

Parameters

index	LED number to modify
R	Intended value of the R led
G	Intended value of the G led
B	Intended value of the B led

Returns

0 if successful

Could this get any worse!

This function is supposed to make the display writing process more efficient. It updates a global display buffer which is written periodically to the led display drivers. Instead of the display driver function re-reading the desired state of all the LED lines every time it is called, this function can be used to update only the lines that have changed.

There are quite a few potential bugs in here, mainly array out of bounds if the DISPLAY_CHIP_NUM is not set correctly or the LED RGB lines are wrong. (Or if there are just bugs.) Set or clear the red LED of the nth LED

Set or clear the red LED of the nth LED

Set or clear the red LED of the nth LED

5.4.3.16 int write_display_driver (void)

Turn on an LED via the external display driver.

Send a byte to the display driver.

On power on, the chip (TLC591x) is in normal mode which means that the clocked bytes sent to the chip set which LEDs are on and which are off (as opposed to setting the current of the LEDs)

To write to the device, use the SPI module to write a byte to the SDI 1 pin on the chip. Then momentarily set the LE(ED1) pin to latch the data onto the output register. Finally, bring the OE(ED2) pin low to enable the current sinking to turn on the LEDs. See the timing diagram on page 17 of the datasheet for details.

LE(ED1) and OE(ED2) will be on Port D Set LE(ED1) pin

Todo How long should this be?

5.4.4 Variable Documentation

5.4.4.1 int buttons[16]

Contains the button states.

Each entry in the array is either 1 if the button is pressed or 0 if not. The array is accessed globally using 'extern buttons;' in a ∗.c file. Read buttons array us updated by calling read_external_buttons

5.4.4.2 unsigned _Fract isr_counter = 0

Counter for the interrupt service routine _T5Interrupt.

These variables are for keeping track of the interrupt based LED pulsing. The type is _Fract because it is easier to directly compare two _Fracts than attempt multiplication of integers and _Fracts (which isn't supported) The limit is not 1 because _Fract types do not go up to 1.

It's probably a good idea to make sure the isr_res counter doesn't overflow (by ensuring that isr_res + isr_limit does not exceed 0.999..., the max value of unsigned _Fract).

5.4.4.3 LED_GLOBAL led_global = {0}

Parameters

led_global	Global LED strobing state parameter

5.5 dspic33e/qcomp-sim-c.X/io.h File Reference

Description: Header file for input output functions.

```
#include "p33EP512MU810.h"
#include "xc.h"
#include <stdbool.h>
```

Include dependency graph for io.h: This graph shows which files directly or indirectly include this file:

Data Structures

- struct LED_GLOBAL

  pin mappings Pins for LE and OE on port D OE = RD4 = uC:81 = J1:28 = J10:14 LE = RD3 = uC:78 = J1:40 = J11:18
- struct LED

  Each LED has the following type.

Macros

- #define red 0

  Locations of LEDs and buttons on Port D.
- #define **amber** 1
- #define **green** 2
- #define **sw1** 6
- #define **sw2** 7
- #define **sw3** 13
- #define **off** 0
- #define **on** 1
- #define LE 3

  Control for TLC591x chip on Port D.
- #define **OE** 4
- #define SH 5

  COntrol lines for SNx4HC165 chip.
- #define **CLK_INH** 8
- #define LED_NUM 4

  The number of external LEDs.

Functions

- int setup_io (void)

  Set up LEDs and buttons on port D.
- void setup_external_leds (void)

  Set external variable RGB LEDs.
- int set_led (int color, int state)

  Turn a particular LED on or off.
- int read_btn (int btn)

  Read the state of a push button.
- void leds_off (void)

  Turn all the LEDs off.
- void flash_led (int color, int number)

  Flash one LED a number of times.
- void flash_all (int number)

  Flash all the LEDs a number of times.
- void set_strobe (int color, int state)

  Set an LED strobing.
- void toggle_strobe (int color)

  Toggle LED strobe.
- int update_display_buffer (int led_index, bool R, bool G, bool B)
- int write_display_driver (void)

  Send a byte to the display driver.
- int set_external_led (int led_index, unsigned _Fract R, unsigned _Fract G, unsigned _Fract B)

  Updates color properties of global led array.
- int led_color_int (int device, int R, int G, int B)

  Takes led number & RGB -> returns integer for sending via SPI to set the LED.
- int led_cycle_test (void)

  Loop to cycle through LEDs 0 - 15.
- int read_external_buttons (void)

  Update the buttons array (see declaration above)

5.5.1 Detailed Description

Description: Header file for input output functions.

Include it at the top of any C source file which uses buttons and LEDs. It also defines various constants representing the positions of the buttons and LEDs on port D.

5.5.2 Function Documentation

5.5.2.1 void flash_all (int *number*)

Flash all the LEDs a number of times.

Parameters

number	

5.5.2.2 void flash_led (int *color*, int *number*)

Flash one LED a number of times.

Parameters

color	
number	

Flash one LED a number of times.

5.5.2.3 int led_color_int (int *device*, int *R*, int *G*, int *B*)

Takes led number & RGB -> returns integer for sending via SPI to set the LED.

Parameters

device	input LED number to change
R	red value between 0 & 1
G	green value between 0 & 1
B	blue value between 0 & 1

Returns

Returns int to be sent to LED Driver

convention RGB -> 000

Each LED takes 3 lines, assumes there are no gaps between LED channels "device" goes between 0 to 2^n -1

5.5.2.4 int led_cycle_test (void)

Loop to cycle through LEDs 0 - 15.

Todo This won't work now: write_display_driver(counter);

5.5.2.5 int read_btn (int *btn*)

Read the state of a push button.

Parameters

btn	

Note

How well do you know C

5.5.2.6 int read_external_buttons (void)

Update the buttons array (see declaration above)

SH pin

Todo How long should this be?

Todo button remappings...

5.5.2.7 int set_external_led (int *index*, unsigned _Fract *R*, unsigned _Fract *G*, unsigned _Fract *B*)

Updates color properties of global led array.

Parameters

led_index	
R	red value between 0 & 1
G	green value between 0 & 1
B	blue value between 0 & 1

Returns

0 if successful, -1 otherwise

Use the function to set the RGB level of an LED. The LED is chosen using the

Parameters

led_index.	The
R	param G and
B	are numbers between 0 and 1 (not including 1) indicating the amount of each color. The function returns 0 if successful and -1 otherwise.

5.5.2.8 int set_led (int *color,* int *state*)

Turn a particular LED on or off.

Parameters

color	
state	

5.5.2.9 void set_strobe (int *color,* int *state*)

Set an LED strobing.

Parameters

color	
state	

5.5.2.10 void setup_external_leds (void)

Set external variable RGB LEDs.

Initialise LED lines

Initialise parameters to zero

Initialise display buffer to zero

5.5.2.11 int setup_io (void)

Set up LEDs and buttons on port D.

$<$ Set port c digital for spi3

Set the OE pin high

Set OE(ED2) pin

Set the SH pin high

Set SH pin

set CLK_INH high while buttons are pressed

5.5.2.12 void toggle_strobe (int *color*)

Toggle LED strobe.

Parameters

color	

5.5.2.13 int update_display_buffer (int *n*, bool *R*, bool *G*, bool *B*)

Parameters

led_index	LED number to modify
R	Intended value of the R led
G	Intended value of the G led
B	Intended value of the B led

Returns

0 if successful

Parameters

index	LED number to modify
R	Intended value of the R led
G	Intended value of the G led
B	Intended value of the B led

Returns

0 if successful

Could this get any worse!

This function is supposed to make the display writing process more efficient. It updates a global display buffer which is written periodically to the led display drivers. Instead of the display driver function re-reading the desired state of all the LED lines every time it is called, this function can be used to update only the lines that have changed.

There are quite a few potential bugs in here, mainly array out of bounds if the DISPLAY_CHIP_NUM is not set correctly or the LED RGB lines are wrong. (Or if there are just bugs.) Set or clear the red LED of the nth LED

Set or clear the red LED of the nth LED

Set or clear the red LED of the nth LED

5.5.2.14 int write_display_driver (void)

Send a byte to the display driver.

Don't use this function to write to LEDs – use the set_external_led function

Send a byte to the display driver.

On power on, the chip (TLC591x) is in normal mode which means that the clocked bytes sent to the chip set which LEDs are on and which are off (as opposed to setting the current of the LEDs)

To write to the device, use the SPI module to write a byte to the SDI 1 pin on the chip. Then momentarily set the LE(ED1) pin to latch the data onto the output register. Finally, bring the OE(ED2) pin low to enable the current sinking to turn on the LEDs. See the timing diagram on page 17 of the datasheet for details.

LE(ED1) and OE(ED2) will be on Port D Set LE(ED1) pin

Todo How long should this be?

5.6 dspic33e/qcomp-sim-c.X/main.c File Reference

The main function.

```
#include "p33EP512MU810.h"
#include "xc.h"
#include "config.h"
#include "time.h"
#include "io.h"
#include "quantum.h"
#include "tests.h"
#include "spi.h"
#include "algo.h"
```

Include dependency graph for main.c:

Functions

- int main (void)

5.6.1 Detailed Description

The main function.

Author

J R Scott

Date

8/11/18

Contains an example of fixed precision 2x2 matrix multiplication for applying operations to a single qubit. The only operations included are H, X and Z so that everything is real (this can be extended later).

All the functions have now been moved into separate files. io.h and io.c contain functions for reading and controlling the buttons and LEDs, and quantum.h/quantum.c contain the matrix arithmetic for simulating one qubit.

Compile command: make (on linux). But if you want to program the micro- controller too or if you're using windows you're better of downloading and installing MPLAB-X https://www.microchip.com/mplab/mplab-x-ide.

Note

You also need the microchip xc16 compilers which are available from https://www.microchip.com/mplab/compilers

5.6.2 Function Documentation

5.6.2.1 int main (void)

Reading button state

The button states are written into an array of type BUTTON_ARRAY whose

Global variable for button state

Update the buttons variable

Do something if button 0 has been pressed...

<

Note

Really important!

5.7 dspic33e/qcomp-sim-c.X/quantum.c File Reference

Description: Contains matrix and vector arithmetic for simulating one qubit.

```
#include "io.h"
#include "quantum.h"
```

Include dependency graph for quantum.c:

Functions

- void **cadd** (Complex a, Complex b, Complex result)
- void **cmul** (Complex a, Complex b, Complex result)
- void make_ops (Complex X[2][2], Complex Y[2][2], Complex Z[2][2], Complex H[2][2])

  Create complex X, Y, Z and H.
- void zero_state (Complex state[ ], int Qnum)

  Initialise state to the vacuum (zero apart from the first position) Specify the dimension – of the matrix, i.e.
- void mat_mul (Complex M[2][2], Complex V[ ], int i, int j)

  2x2 complex matrix multiplication
- void qubit_display (Complex state[ ], int N)

  Display the state amplitudes on LEDs.
- void single_qubit_op (Complex op[2][2], int qubit, Complex state[ ], int Qnum)

  apply operator

5.7.1 Detailed Description

Description: Contains matrix and vector arithmetic for simulating one qubit.

5.7.2 Function Documentation

5.7.2.1 void make_ops (Complex *X[2][2]*, Complex *Y[2][2]*, Complex *Z[2][2]*, Complex *H[2][2]*)

Create complex X, Y, Z and H.

Parameters

X	Pauli X c-Matrix
Z	Pauli Z c-matrix
H	Hadamard c-matrix
Y	Pauli Y c-matrix

5.7.2.2 void mat_mul (Complex *M[2][2],* Complex *V[ ],* int *i,* int *j*)

2x2 complex matrix multiplication

Parameters

M	complex matrix
V	complex vector
i	integer first element of state vector
j	integer second element of state vector

Todo Because of the way the array types work (you can't pass a multidimensional array of unknown size) we will also need a function for 4x4 matrix multiplication.

5.7.2.3 void qubit_display (Complex *state[ ],* int *N*)

Display the state amplitudes on LEDs.

Parameters

state	Pass in the state vector
N	The total number of qubits

Note

Currently the function only displays superpositions using the red and blue colors.

The routine works by adding up the squares of the amplitudes corresponding to each state of a given qubit. Suppose there are three qubits. Then the state vector is given by

```
index     binary   amplitude
-----------------------------
  0        0 0 0       a_0
  1        0 0 1       a_1
  2        0 1 0       a_2
  3        0 1 1       a_3
  4        1 0 0       a_4
  5        1 0 1       a_5
  6        1 1 0       a_6
  7        1 1 1       a_7
-----------------------------
Qubit:     2 1 0
```

Consider qubit 2. The value of the ZERO state is formed by adding up all the amplitudes corresponding to its ZERO state. That is, indices 0, 1, 2 and 3. The ONE state is obtained by adding up the other indices: 4, 5, 6 and 7.

So the amplitudes for qubit 2 are

ZERO: (a_0)^2 + (a_1)^2 + (a_2)^2 + (a_3)^2 ONE: (a_4)^2 + (a_5)^2 + (a_6)^2 + (a_7)^2

Corresponding to the following indices:

ZERO: 0+0, 1+0, 2+0, 3+0 ONE: 4+0, 5+0, 6+0, 7+0

For qubit 1 the indices are:

ZERO: 0+0, 0+4, 1+0, 1+4 ONE: 2+0, 2+4, 3+0, 3+4

And for qubit 0 the indices are:

ZERO: 0+0, 0+2, 0+4, 0+6 ONE: 1+0, 1+2, 1+4, 1+6

The examples above are supposed to show the general pattern. For N qubits, qubit number k, the ZERO and ONE states are given by summing all the square amplitudes corresponding to the following indices:

ZERO: n + (2^(k+1) ∗ j), where n = 0, 1, ..., 2^k - 1 and j = 0, 1, ..., 2^(N-k-2)

ONE: n + (2^(k+1) ∗ j), where n = 2^k, 2^k + 1, ..., 2^(k+1) - 1 and j = 0, 1, ..., 2^(N-k-2)

The amplitudes are obtained by summing over both n and j. Notice that there is an edge condition when k = N-1. There, j apparently ranges from 0 to -1. In this case, the only value of j is 0. The condition arises because of the way that 2^(N-k-2) is obtained (i.e. such that multiplying it by 2^(k+1) gives 2^(N-1).) However, if k = N-1, then 2^(k+1) = 2^N already, so it must be multiplied by 2^(-1). The key point is that the second term should not ever equal 2^N, so j should stop at 0.

The above indices can be expressed as the sum of a ROOT and a STEP as follows:

index = ROOT + STEP

where ROOT ranges from 0 to 2^k-1. This corresponds to the n values that give rise to ZERO. The indices for ONE can be obtained by adding 2^k to root. The STEP = j is a multiple of 2^(k+1) starting from zero that does not equal or exceed 2^N. ROOT can be realised using the following for loop:

for(int root = 0; root < 2^k; root ++) { ... // ZERO index root; // ONE index root + 2^k; }

Then the STEP component can be realised as

for(int step = 0; step < 2^N; step += 2^(k+1)) { // Add the following to root... step; } Loop over all qubits k = 0, 1, 2, ... N-1

ROOT loop

STEP loop

Zeros are at the index root + step

Ones are at the index root + 2^k + step

update leds for each qubits average zero and one amps

5.7.2.4 void single_qubit_op (Complex *op[2][2],* int *qubit,* Complex *state[ ],* int *Qnum*)

apply operator

Parameters

state	state vector containing amplitudes
qubit	qubit number to apply 2x2 matrix to
Qnum	total number of qubits in the state
op	2x2 operator to be applied

This routine applies a single qubit gate to the state vector

Parameters

state.	<pre>index binary amplitude
	----------------------------- 	
	  0 0 0 0 a_0
	  1 0 0 1 a_1
	  2 0 1 0 a_2
	  3 0 1 1 a_3
	  4 1 0 0 a_4
	  5 1 0 1 a_5
	  6 1 1 0 a_6
	  7 1 1 1 a_7
	----------------------------- 	
	Qubit: 2 1 0</pre>

Consider qubit 2. The value of the ZERO state is formed by adding up all the amplitudes corresponding to its ZERO state. That is, indices 0, 1, 2 and 3. The ONE state is obtained by adding up the other indices: 4, 5, 6 and

1.

2^(total qbits -1 - current)

Loop here for each contribution to the zero and one amplitude

loop over j

n + j ∗ 2^(k+1)

5.7.2.5 void zero_state (**Complex** *state[ ],* int *Qnum*)

Initialise state to the vacuum (zero apart from the first position) Specify the dimension – of the matrix, i.e.

2^(number of qubits)

Note

oh the clarity!

5.8 dspic33e/qcomp-sim-c.X/quantum.h File Reference

Description: Header file containing all the matrix arithmetic for simulating a single qubit.

```
#include "p33EP512MU810.h"
#include "xc.h"
#include <math.h>
```

Include dependency graph for quantum.h: This graph shows which files directly or indirectly include this file:

Macros

- #define **ONE_Q15** 0.9999694824

Typedefs

- typedef signed _Fract Q15

  Basic fractional time.
- typedef Q15 Complex [2]

  Complex type.

Enumerations

- enum State {
ZERO, **ONE**, **PLUS**, **MINUS**,
iPLUS, **iMINUS** }
Basis states.

Functions

- void make_ops (Complex X[2][2], Complex Y[2][2], Complex Z[2][2], Complex H[2][2])
Create complex X, Y, Z and H.
- void zero_state (Complex state[ ], int Qnum)
Initialise state to the vacuum (zero apart from the first position) Specify the dimension – of the matrix, i.e.
- void mat_mul (Complex M[2][2], Complex V[ ], int i, int j)
2x2 complex matrix multiplication
- void single_qubit_op (Complex op[2][2], int qubit, Complex state[ ], int Qnum)
apply operator
- void qubit_display (Complex state[ ], int Qnum)
Display the state amplitudes on LEDs.

5.8.1 Detailed Description

Description: Header file containing all the matrix arithmetic for simulating a single qubit.

5.8.2 Function Documentation

5.8.2.1 void make_ops (**Complex** *X[2][2],* **Complex** *Y[2][2],* **Complex** *Z[2][2],* **Complex** *H[2][2]*)

Create complex X, Y, Z and H.

Parameters

X	Pauli X c-Matrix
Z	Pauli Z c-matrix
H	Hadamard c-matrix
Y	Pauli Y c-matrix

5.8.2.2 void mat_mul (**Complex** *M[2][2],* **Complex** *V[ ],* int *i,* int *j*)

2x2 complex matrix multiplication

Parameters

M	complex matrix
V	complex vector
i	integer first element of state vector
j	integer second element of state vector

Todo Because of the way the array types work (you can't pass a multidimensional array of unknown size) we will also need a function for 4x4 matrix multiplication.

5.8.2.3 void qubit_display (**Complex** *state[ ],* int *N*)

Display the state amplitudes on LEDs.

Parameters

state	Pass in the state vector
Qnum	The total number of qubits

Note

Currently the function only displays superpositions using the red and blue colors.

Parameters

state	Pass in the state vector
N	The total number of qubits

Note

Currently the function only displays superpositions using the red and blue colors.

The routine works by adding up the squares of the amplitudes corresponding to each state of a given qubit. Suppose there are three qubits. Then the state vector is given by

```
index     binary   amplitude
----------------------------
  0       0 0 0       a_0
  1       0 0 1       a_1
  2       0 1 0       a_2
  3       0 1 1       a_3
  4       1 0 0       a_4
  5       1 0 1       a_5
  6       1 1 0       a_6
  7       1 1 1       a_7
----------------------------
Qubit:    2 1 0
```

Consider qubit 2. The value of the ZERO state is formed by adding up all the amplitudes corresponding to its ZERO state. That is, indices 0, 1, 2 and 3. The ONE state is obtained by adding up the other indices: 4, 5, 6 and 7.

So the amplitudes for qubit 2 are

ZERO: (a_0)^2 + (a_1)^2 + (a_2)^2 + (a_3)^2 ONE: (a_4)^2 + (a_5)^2 + (a_6)^2 + (a_7)^2

Corresponding to the following indices:

ZERO: 0+0, 1+0, 2+0, 3+0 ONE: 4+0, 5+0, 6+0, 7+0

For qubit 1 the indices are:

ZERO: 0+0, 0+4, 1+0, 1+4 ONE: 2+0, 2+4, 3+0, 3+4

And for qubit 0 the indices are:

ZERO: 0+0, 0+2, 0+4, 0+6 ONE: 1+0, 1+2, 1+4, 1+6

The examples above are supposed to show the general pattern. For N qubits, qubit number k, the ZERO and ONE states are given by summing all the square amplitudes corresponding to the following indices:

ZERO: n + (2^(k+1) ∗ j), where n = 0, 1, ..., 2^k - 1 and j = 0, 1, ..., 2^(N-k-2)

ONE: n + (2^(k+1) ∗ j), where n = 2^k, 2^k + 1, ..., 2^(k+1) - 1 and j = 0, 1, ..., 2^(N-k-2)

The amplitudes are obtained by summing over both n and j. Notice that there is an edge condition when k = N-1. There, j apparently ranges from 0 to -1. In this case, the only value of j is 0. The condition arises because of the way that 2^(N-k-2) is obtained (i.e. such that multiplying it by 2^(k+1) gives 2^(N-1).) However, if k = N-1, then 2^(k+1) = 2^N already, so it must be multiplied by 2^(-1). The key point is that the second term should not ever equal 2^N, so j should stop at 0.

The above indices can be expressed as the sum of a ROOT and a STEP as follows:

index = ROOT + STEP

where ROOT ranges from 0 to 2^k-1. This corresponds to the n values that give rise to ZERO. The indices for ONE can be obtained by adding 2^k to root. The STEP = j is a multiple of 2^(k+1) starting from zero that does not equal or exceed 2^N. ROOT can be realised using the following for loop:

for(int root = 0; root < 2^k; root ++) { ... // ZERO index root; // ONE index root + 2^k; }

Then the STEP component can be realised as

for(int step = 0; step < 2^N; step += 2^(k+1)) { // Add the following to root... step; } Loop over all qubits k = 0, 1, 2, ... N-1

ROOT loop

STEP loop

Zeros are at the index root + step

Ones are at the index root + 2^k + step

update leds for each qubits average zero and one amps

5.8.2.4 void single_qubit_op (Complex *op[2][2],* int *qubit,* Complex *state[ ],* int *Qnum*)

apply operator

Parameters

state	state vector containing amplitudes
qubit	qubit number to apply 2x2 matrix to
Qnum	total number of qubits in the state
op	2x2 operator to be applied
state	state vector containing amplitudes
qubit	qubit number to apply 2x2 matrix to
Qnum	total number of qubits in the state
op	2x2 operator to be applied

This routine applies a single qubit gate to the state vector

Parameters

state.

```
index     binary   amplitude
----------------------------
  0       0 0 0       a_0
  1       0 0 1       a_1
  2       0 1 0       a_2
  3       0 1 1       a_3
  4       1 0 0       a_4
  5       1 0 1       a_5
  6       1 1 0       a_6
  7       1 1 1       a_7
----------------------------
Qubit:    2 1 0
```

Consider qubit 2. The value of the ZERO state is formed by adding up all the amplitudes corresponding to its ZERO state. That is, indices 0, 1, 2 and 3. The ONE state is obtained by adding up the other indices: 4, 5, 6 and

1.

2^(total qbits -1 - current)

Loop here for each contribution to the zero and one amplitude

loop over j

n + j ∗ 2^(k+1)

5.8.2.5 void zero_state (Complex state[], int Qnum)

Initialise state to the vacuum (zero apart from the first position) Specify the dimension – of the matrix, i.e. 2^(number of qubits)

Note

oh the clarity!

5.9 dspic33e/qcomp-sim-c.X/spi.c File Reference

Description: Functions for communicating with serial devices.

```
#include "spi.h"
```

Include dependency graph for spi.c:

Functions

- int setup_spi (void)
  Set up serial peripheral interface.
- int send_byte_spi_1 (int data)
  Send a byte to the SPI1 peripheral.
- int read_byte_spi_3 ()
  Recieve a byte from the SPI3 peripheral.

5.9.1 Detailed Description

Description: Functions for communicating with serial devices.

5.9.2 Function Documentation

5.9.2.1 int send_byte_spi_1 (int data)

Send a byte to the SPI1 peripheral.

Parameters

data	byte to be sent to SPI1

5.9.2.2 int setup_spi (void)

Set up serial peripheral interface.

Pin mappings — Pin mappings and codes — J10:41 = J1:91 = uC:70 = RPI74 (PPS code: 0100 1010) J10:44 = J1:93 = uC:9 = RPI52 (PPS code: 0011 0100) J10:47 = J1:101 = uC:34 = RPI42 (PPS code: 0010 1010) J10:43 = J1:95 = uC:72 = RP64 (PPS reg: RPOR0_L; code: 0100 0000) J10:46 = J1:97 = uC:69 = RPI73 (PPS code: 0100 1001) J10:7 = J1:13 = uC:3 = RP85 (PPS reg: RPOR6_L; code: 0101 0101) J10:5 = J1:7 = uC:5 = RP87 (PPS reg: RPOR6_H) J10:55 = J1:117 = uC:10 = RP118 (PPS reg: RPOR13_H)

— Pin mappings for SPI 1 module — SPI 1 Clock Out (SCK1) PPS code: 000110 (0x06) SPI 1 Data Out (SDO1) PPS code: 000101 (0x05) SPI 1 Slave Select PPS code: 000111

— Pin mappings for SPI 3 module — SPI 3 Clock Out (SCK3) PPS code: 100000 (0x20) SPI 3 Data Out (SDO3) PPS code: 011111 (0x1F) SPI 3 Slave Select PPS code: 100001

Configure the SPI 1 pins

< Put SCK1 on J10:43

< Put SDO1 on J10:55

The clock pin also needs to be configured as an input

< Set SCK1 on J10:43 as input

Configure the SPI 3 output pins

< Put SCK3 on J10:7

< Put SDO3 on J10:5

< Put SDI3 on J10:44

< Set SCK3 on J10:7 as input

```
@note
```

SPI 1 clock configuration

SCK1 = F_CY / (Primary Prescaler ∗ Secondary Prescaler)

Assuming that F_CY = 50MHz, and the prescalers are 4 and 1, the SPI clock frequency will be 12.5MHz.

5.10 dspic33e/qcomp-sim-c.X/spi.h File Reference

Description: SPI communication functions.

```
#include "p33EP512MU810.h"
#include "xc.h"
```

Include dependency graph for spi.h: This graph shows which files directly or indirectly include this file:

Functions

- int setup_spi (void)

  Set up serial peripheral interface.
- int send_byte_spi_1 (int data)

  Send a byte to the SPI1 peripheral.
- int read_byte_spi_3 ()

  Recieve a byte from the SPI3 peripheral.

5.10.1 Detailed Description

Description: SPI communication functions.

5.10.2 Function Documentation

5.10.2.1 int send_byte_spi_1 (int *data*)

Send a byte to the SPI1 peripheral.

Parameters

data	byte to be sent to SPI1

5.10.2.2 int setup_spi (void)

Set up serial peripheral interface.

Pin mappings — Pin mappings and codes — J10:41 = J1:91 = uC:70 = RPI74 (PPS code: 0100 1010) J10:44 = J1:93 = uC:9 = RPI52 (PPS code: 0011 0100) J10:47 = J1:101 = uC:34 = RPI42 (PPS code: 0010 1010) J10:43 = J1:95 = uC:72 = RP64 (PPS reg: RPOR0_L; code: 0100 0000) J10:46 = J1:97 = uC:69 = RPI73 (PPS code: 0100 1001) J10:7 = J1:13 = uC:3 = RP85 (PPS reg: RPOR6_L; code: 0101 0101) J10:5 = J1:7 = uC:5 = RP87 (PPS reg: RPOR6_H) J10:55 = J1:117 = uC:10 = RP118 (PPS reg: RPOR13_H)

— Pin mappings for SPI 1 module — SPI 1 Clock Out (SCK1) PPS code: 000110 (0x06) SPI 1 Data Out (SDO1) PPS code: 000101 (0x05) SPI 1 Slave Select PPS code: 000111

— Pin mappings for SPI 3 module — SPI 3 Clock Out (SCK3) PPS code: 100000 (0x20) SPI 3 Data Out (SDO3) PPS code: 011111 (0x1F) SPI 3 Slave Select PPS code: 100001

Configure the SPI 1 pins

$<$ Put SCK1 on J10:43

$<$ Put SDO1 on J10:55

The clock pin also needs to be configured as an input

$<$ Set SCK1 on J10:43 as input

Configure the SPI 3 output pins

$<$ Put SCK3 on J10:7

$<$ Put SDO3 on J10:5

$<$ Put SDI3 on J10:44

$<$ Set SCK3 on J10:7 as input

```
@note
```

SPI 1 clock configuration

SCK1 = F_CY / (Primary Prescaler $*$ Secondary Prescaler)

Assuming that F_CY = 50MHz, and the prescalers are 4 and 1, the SPI clock frequency will be 12.5MHz.

5.11 dspic33e/qcomp-sim-c.X/tests.c File Reference

Description: Contains all the tests we have performed on the micro- controller.

```
#include "tests.h"
#include "io.h"
#include "quantum.h"
#include "time.h"
```

Include dependency graph for tests.c:

Functions

- void dim_leds ()

  Testing the speed of 2$^\wedge$ 15 2x2 real matrix multiplications void mat_mul_test() {.

5.11.1 Detailed Description

Description: Contains all the tests we have performed on the micro- controller.

5.11.2 Function Documentation

5.11.2.1 void dim_leds ( )

Testing the speed of 2^15 2x2 real matrix multiplications void mat_mul_test() {.

Define state vector |0> = (1,0) |1> = (0,1) Vector V; init_state(V, ZERO);

Matrix2 X = {{0}}, Z = {{0}}, H = {{0}}; make_ops(X, Z, H);

Start the timer start_timer();

Do a matrix multiplication test unsigned int n = 0; while (n < 32768) { mat_mul(X, V); n++; }

Read the timer unsigned long int time = read_timer();

Show that the test is finished set_led(red, on);

wait (add a breakpoint here) while(1 == 1);

}

5.12 dspic33e/qcomp-sim-c.X/tests.h File Reference

Description: Header file containing all the tests we performed.

```
#include "p33EP512MU810.h"
#include "xc.h"
```

Include dependency graph for tests.h: This graph shows which files directly or indirectly include this file:

Functions

- void **mat_mul_test** ()
- void **mat_mul_test_cmplx** ()
- void **one_qubit** ()
- void **one_qubit_cmplx** ()
- void dim_leds ()

  Testing the speed of 2^15 2x2 real matrix multiplications void mat_mul_test() {.
- void **multi_led_strobe** ()

5.12.1 Detailed Description

Description: Header file containing all the tests we performed.

5.12.2 Function Documentation

5.12.2.1 void dim_leds ( )

Testing the speed of 2^15 2x2 real matrix multiplications void mat_mul_test() {.

Define state vector |0> = (1,0) |1> = (0,1) Vector V; init_state(V, ZERO);

Matrix2 X = {{0}}, Z = {{0}}, H = {{0}}; make_ops(X, Z, H);

Start the timer start_timer();

Do a matrix multiplication test unsigned int n = 0; while (n < 32768) { mat_mul(X, V); n++; }

Read the timer unsigned long int time = read_timer();

Show that the test is finished set_led(red, on);

wait (add a breakpoint here) while(1 == 1);

}

5.13 dspic33e/qcomp-sim-c.X/time.c File Reference

Description: Functions to control the on chip timers.

```
#include "time.h"
```

Include dependency graph for time.c:

Functions

- void **setup_clock** ()
- void setup_timer ()
- void **reset_timer** ()
- void **start_timer** ()
- void **stop_timer** ()
- unsigned long int **read_timer** ()

5.13.1 Detailed Description

Description: Functions to control the on chip timers.

5.13.2 Function Documentation

5.13.2.1 void setup_timer ( )

Todo distinguish between the two different timers here...

5.14 dspic33e/qcomp-sim-c.X/time.h File Reference

Description: Header file containing all the timing functions.

```
#include "p33EP512MU810.h"
#include "xc.h"
```

Include dependency graph for time.h: This graph shows which files directly or indirectly include this file:

Functions

- void **setup_clock** ()
- void setup_timer ()
- void **reset_timer** ()
- void **start_timer** ()
- void **stop_timer** ()
- unsigned long int **read_timer** ()

5.14.1 Detailed Description

Description: Header file containing all the timing functions.

5.14.2 Function Documentation

5.14.2.1 void setup_timer ( )

Todo distinguish between the two different timers here...