Quantum Computer Outreach Project

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Contents

Chapter 1

Todo List

Global absolute (Complex x)

Check that the complex part is small

Global check_op ()

this is a temp fix to avoid getting stuck waiting for a user input.

Global controlled_qubit_op (const Complex op[2][2], int ctrl, int targ, Complex state[])

This expression can probably be simplified or broken over lines. The condition for the if statement is that root+step and root + step + root_max contain 1 in the ctrl-th bit.

Global display_average (Complex state[])

Bring all constants out of the loops. Don't use pow.

Rewrite pow for Q15

rename to display_average

Global led_cycle_test (void)

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

Global main (void)

fix this menu system

add a button for switching between display average and cycle modes

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

Is static enough? Or should we declare outside the function?

Should we use for loops? Or is it better not to..?

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 mat_mul_old (const Complex M[2][2], Complex V[], int i, int j)

Should these be outside the function?

Global op_routine (int select_op, Complex state[])

not sure if the breaks are needed here, I don't think they are.

need a check for zero button

File quantum.c

split into a complex math and operator files

Global read_external_buttons (void)

read buttons

How long should this be?

button remappings...

Global read_qubit_btn (int btn)

should return a qubit number which has been selected

Global repetition_code (int q0, Complex state[])

this

```
///       a  b     c     d  e  f
/// |q2> ----X--|-----|-----X--o--
///          |  |     |     |  |
/// |q1> -X--|--|  U  |--X--|--o--
///       |  |  |     |  |  |  |
/// |q0> -o--o--|-----|--o--o--X-- |q0>
///
```

generalise this, we should either have pseudo-random errors or the user should be able to choose which gates to do here

Global reset_cycle (void)

do it

Global setup_external_leds (void)

CURRENTLY CYCLING IS OFF

Global setup_timer ()

distinguish between the two different timers here...

Global single_qubit_op (const Complex op[2][2], int qubit, Complex state[])

Should we inline mat_mul here?

Global single_qubit_op (const Complex op[2][2], int qubit, Complex state[])

Should we inline mat_mul here?

Global sort_states (Complex state[], int num_qubits)

this function...

this

Global square_magnitude (Complex x)

Maybe we should inline this

Maybe we should inline this

Global TLC591x_mode_switch (int mode)

mode switcher for LED Driver

Global toffoli_gate (int q1, int q2, int q3, Complex state[])

Fancy non-blocking Interrupt routine { if(no button) return;

Global while (1)

we need button debouncing here

Global write_display_driver (void)

How long should this be?

Chapter 2

Bug List

Global btn_func [NUM_BTNS-NUM_QUBITS]

this.

Global check_op ()

same as above^

Global check_qubit ()

this probably shouldn't be an infinite loop. the counter lets the loop exit after some time to check if the 'reset' button is pressed

problem with sampling, will cause the program to hang while waiting for qubit input

Global controlled_qubit_op (const Complex op[2][2], int ctrl, int targ, Complex state[])

this needs to be a long int for $>$16 qubits

Global display_average (Complex state[])

there is a phase bug when cycling the gates Loop over all qubits k = 0, 1, 2, ... N-1

The problem is with the sign function, which will not distinguish between (e.g.) 1 and i. I think all the problems stem from that kind of error. c = sign(state[root + step]) - sign(state[root + root_max + step]);

Chapter 3

Data Structure Index

3.1 Data Structures

Here are the data structures with brief descriptions:

Chapter 4

File Index

4.1 File List

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

Chapter 5

Data Structure Documentation

5.1 BTN Struct Reference

pin mappings

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

Data Fields

- int **chip**
- int line

    [chip number]

5.1.1 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 = J11:25
//
```

button mapping type

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

- /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/io.h

5.2 cycle_node Struct Reference

The basis for a linked list of states to cycle.

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

Collaboration diagram for cycle_node:

Data Fields

- RGB ∗ rgb

    Array of corresponding RGB values.
- int size

    The size of the above arrays.
- struct cycle_node ∗ next

    Pointer to the next item.
- struct cycle_node ∗ previous

    Pointer to the previous item.

5.2.1 Detailed Description

The basis for a linked list of states to cycle.

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

- /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/io.h

5.3 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.

5.3.1 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:

- /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/io.h

5.4 LED_GLOBAL Struct Reference

Global LED strobing state parameter.

`#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)

5.4.1 Detailed Description

Global LED strobing state parameter.

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

- /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/io.h

5.5 RGB Struct Reference

A type for holding red, green, blue values.

`#include <io.h>`

Data Fields

- unsigned _Fract **R**
- unsigned _Fract **G**
- unsigned _Fract **B**

5.5.1 Detailed Description

A type for holding red, green, blue values.

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

- /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/io.h

Chapter 6

File Documentation

6.1 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/algo.c File Reference

Contains quantum algorithms to be run.

```
#include "algo.h"
```

Include dependency graph for algo.c:

Functions

- int op_routine (int select_op, Complex state[])

  gate routine
- int check_qubit ()

  function returns the integer for the label of which qubit is selected
- while (1)
- int check_op ()

  End of qubit select.
- int reset_button ()

  reset button, triggered by sw3 returns 1 if the reset button is pressed, 0 if not
- void gate (const Complex op[2][2], int qubit, Complex state[])

  single qubit gate
- void gate_display (const Complex op[2][2], int qubit, Complex state[])

  single qubit gate with display
- void two_gate (const Complex op[2][2], int ctrl, int targ, Complex state[])

  two-qubit gate
- void two_gate_display (const Complex op[2][2], int ctrl, int targ, Complex state[])

  two-qubit gate with display
- void swap (int q1, int q2, Complex state[])

  does the swap operation between two qubits and displays the state
- void swap_test (Complex state[])

  from tests.c
- void toffoli_gate (int q1, int q2, int q3, Complex state[])

  QFT.
- void **toffoli_test** (Complex state[])
- void repetition_code (int q0, Complex state[])

  repetition code

Variables

- int **release** = 0
- return **select_qubit**
- return **select_op**

6.1.1 Detailed Description

Contains quantum algorithms to be run.

Authors

J Scott, O Thomas

Date

Nov 2018

6.1.2 Function Documentation

6.1.2.1 int check_op ( )

End of qubit select.

function returns integer label used in switch statement in main

Todo this is a temp fix to avoid getting stuck waiting for a user input.

Check for the reset button, returns 1 for pressed, 0 for not

-2 means reset

6.1.2.2 int check_qubit ( )

function returns the integer for the label of which qubit is selected

Returns

int select_qubit (-1 if no qubit is selected)

Bug problem with sampling, will cause the program to hang while waiting for qubit input

Bug this probably shouldn't be an infinite loop. the counter lets the loop exit after some time to check if the 'reset' button is pressed

Check for the reset button Check for the reset button, returns 1 for pressed, 0 for not

-2 means reset

6.1.2.3 void gate (const **Complex** *op[2][2]*, int *qubit*, **Complex** *state[ ]*)

single qubit gate

perform single qubit gate does 2x2 operator on state vector

6.1.2.4 void gate_display (const Complex *op[2][2]*, int *qubit*, Complex *state[]*)

single qubit gate with display

Display gates!!! does 2x2 operator on state vector displays the average state of the qubit by tracing over all waits to let the user see the state (LEDs)

delay();

6.1.2.5 int op_routine (int *select_op*, Complex *state[]*)

gate routine

functions for performing gate routines, takes qubit & button ints

Todo not sure if the breaks are needed here, I don't think they are.

X

Z

H

SWAP

Todo need a check for zero button

Do nothing

End of switch

6.1.2.6 void repetition_code (int *q0*, Complex *state[]*)

repetition code

added repetition_code for bit flip errors, currently only shows a fixed error which is a failed X on one of the ancillas.

Todo this

```
///         a  b      c      d  e  f
/// |q2> ----X--|-----|-----X--o--
///            |  |      |      |  |
/// |q1> -X--|--|   U   |--X--|--o--
///        |  |  |      |  |  |  |
/// |q0> -o--o--|-----|--o--o--X--  |q0>
///
```

check position of 'q0' in the state, if the first qubit then q1, q2 are the next 2. e.g. q0=0 -> q1=1, q2=2

check if q0 is the last qubit then wrap so q1 is (q0-1) q2 is (q0-2)

else have q0 in the middle of q1 & q0

do the gates, without displaying the intermediate steps?

step a

step b

now up to U step c as a test I have hardcoded in only 2 X's corresponding to an error on q2

Todo generalise this, we should either have pseudo-random errors or the user should be able to choose which gates to do here decoding steps d-f

step d

step e

step f

done!

6.1.2.7 int reset_button ( )

reset button, triggered by sw3 returns 1 if the reset button is pressed, 0 if not

function returns 1 if the sw3 is pressed or 0 if not. Turn LED on to signify reset

Turn LED off and return

6.1.2.8 void swap (int *q1*, int *q2*, Complex *state[]*)

does the swap operation between two qubits and displays the state

swap using 3 cNots

6.1.2.9 void swap_test (Complex *state[]*)

from tests.c

swap for ever!

6.1.2.10 void toffoli_gate (int *q1*, int *q2*, int *q3*, Complex *state[]*)

QFT.

Toffoli gate.

```
/// H Rz Rz --------
/// ---o--|---H Rz---
/// ------o------o-H-
///
```

Todo Fancy non-blocking Interrupt routine { if(no button) return;

pause and do display cycling();

Make this a low priority interrupt so that everything else can interrupt it.

Do stuff for a while

return when you're done.

}Toffoli gate

```
/// -o--    ------o-----o--o-----
/// -|--    ------|-----|--|-----
/// -o-- = ---o--X--o--X--|-----
/// -|--    ---|-----|-----|-----
/// -X--    --rX----rX*---rX-----
///           a   b  c  d  e
///
```

q1 ctrl 1 q2 ctrl 2 q3 target $<$ a

$<$ b

< c

< d

< e

6.1.2.11 void two_gate (const Complex *op[2][2],* int *ctrl,* int *targ,* Complex *state[ ]*)

two-qubit gate

perform controlled single qubit gate does controlled 2x2 operator

6.1.2.12 void two_gate_display (const Complex *op[2][2],* int *ctrl,* int *targ,* Complex *state[ ]*)

two-qubit gate with display

does controlled 2x2 operator displays the state waits to let the user see the state

6.1.2.13 while (1)

Todo we need button debouncing here

6.2 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/algo.h File Reference

header file for algorithms

```
#include "quantum.h"
#include "display.h"
```

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

Functions

- int op_routine (int select_op, Complex state[ ])

    functions for performing gate routines, takes qubit & button ints
- int check_qubit ()

    function returns the integer for the label of which qubit is selected
- int check_op ()

    function returns integer label used in switch statement in main
- int reset_button ()

    function returns 1 if the sw3 is pressed or 0 if not.
- void gate (const Complex op[2][2], int qubit, Complex state[ ])

    perform single qubit gate
- void two_gate (const Complex op[2][2], int ctrl, int targ, Complex state[ ])

    perform controlled single qubit gate
- void gate_display (const Complex op[2][2], int qubit, Complex state[ ])

    Display gates!!!
- void two_gate_display (const Complex op[2][2], int ctrl, int targ, Complex state[ ])

    two-qubit gate with display
- void swap (int q1, int q2, Complex state[ ])

    swap using 3 cNots
- void swap_test (Complex state[ ])

from tests.c
- void toffoli_gate (int q1, int q2, int q3, Complex state[])

  Toffoli gate.
- void **toffoli_test** (Complex state[])
- void repetition_code (int q0, Complex state[])

  added repetition_code for bit flip errors, currently only shows a fixed error which is a failed X on one of the ancillas.

6.2.1 Detailed Description

header file for algorithms

Authors

J Scott, O Thomas

Date

Nov 2018

6.2.2 Function Documentation

6.2.2.1 int check_op ( )

function returns integer label used in switch statement in main

Bug same as above^

function returns integer label used in switch statement in main

Todo this is a temp fix to avoid getting stuck waiting for a user input.

Check for the reset button, returns 1 for pressed, 0 for not

-2 means reset

6.2.2.2 int check_qubit ( )

function returns the integer for the label of which qubit is selected

Returns

int select_qubit (-1 if no qubit is selected)

Bug problem with sampling, will cause the program to hang while waiting for qubit input

Bug this probably shouldn't be an infinite loop. the counter lets the loop exit after some time to check if the 'reset' button is pressed

Check for the reset button Check for the reset button, returns 1 for pressed, 0 for not

-2 means reset

6.2.2.3 void gate (const **Complex** *op[2][2],* int *qubit,* **Complex** *state[]*)

perform single qubit gate

perform single qubit gate does 2x2 operator on state vector

6.2.2.4 void gate_display (const Complex *op[2][2]*, int *qubit*, Complex *state[ ]*)

Display gates!!!

Display gates!!! does 2x2 operator on state vector displays the average state of the qubit by tracing over all waits to let the user see the state (LEDs)

delay();

6.2.2.5 int op_routine (int *select_op*, Complex *state[ ]*)

functions for performing gate routines, takes qubit & button ints

functions for performing gate routines, takes qubit & button ints

Todo not sure if the breaks are needed here, I don't think they are.

X

Z

H

SWAP

Todo need a check for zero button

Do nothing

End of switch

6.2.2.6 void repetition_code (int *q0*, Complex *state[ ]*)

added repetition_code for bit flip errors, currently only shows a fixed error which is a failed X on one of the ancillas.

todo.

added repetition_code for bit flip errors, currently only shows a fixed error which is a failed X on one of the ancillas.

Todo this

```
///        a  b      c      d  e  f
/// |q2> ----X--|-----|-----X--o--
///          |  |     |     |  |
/// |q1> -X--|--|  U  |--X--|--o--
///       |  |  |     |  |  |  |
/// |q0> -o--o--|-----|--o--o--X--  |q0>
///
```

check position of 'q0' in the state, if the first qubit then q1, q2 are the next 2. e.g. q0=0 -> q1=1, q2=2

check if q0 is the last qubit then wrap so q1 is (q0-1) q2 is (q0-2)

else have q0 in the middle of q1 & q0

do the gates, without displaying the intermediate steps?

step a

step b

now up to U step c as a test I have hardcoded in only 2 X's corresponding to an error on q2

Todo generalise this, we should either have pseudo-random errors or the user should be able to choose which gates to do here decoding steps d-f

step d

step e

step f

done!

6.2.2.7 int reset_button ( )

function returns 1 if the sw3 is pressed or 0 if not.

function returns 1 if the sw3 is pressed or 0 if not. Turn LED on to signify reset

Turn LED off and return

6.2.2.8 void swap (int *q1*, int *q2*, Complex *state[]*)

swap using 3 cNots

swap using 3 cNots

6.2.2.9 void swap_test (Complex *state[]*)

from tests.c

swap for ever!

6.2.2.10 void toffoli_gate (int *q1*, int *q2*, int *q3*, Complex *state[]*)

Toffoli gate.

Toffoli gate.

```
/// H Rz Rz --------
/// ---o--|---H Rz---
/// ------o------o-H-
///
```

Todo Fancy non-blocking Interrupt routine { if(no button) return;

pause and do display cycling();

Make this a low priority interrupt so that everything else can interrupt it.

Do stuff for a while

return when you're done.

}Toffoli gate

```
/// -o--    ------o-----o--o-----
/// -|--    ------|-----|--|-----
/// -o-- = ---o--X--o--X--|-----
/// -|--    ---|-----|-----|-----
/// -X--    --rX----rX*---rX-----
///           a   b  c  d  e
///
```

q1 ctrl 1 q2 ctrl 2 q3 target < a

< b

< c

< d

< e

6.2.2.11 void two_gate (const **Complex** *op[2][2],* int *ctrl,* int *targ,* **Complex** *state[ ]*)

perform controlled single qubit gate

perform controlled single qubit gate does controlled 2x2 operator

6.2.2.12 void two_gate_display (const **Complex** *op[2][2],* int *ctrl,* int *targ,* **Complex** *state[ ]*)

two-qubit gate with display

does controlled 2x2 operator displays the state waits to let the user see the state

6.3 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/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:

6.3.1 Detailed Description

General config settings #pragma for microcontroller.

Authors

J Scott, O Thomas

Date

Nov 2018

Description: Include this once at the top of main

6.4 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/consts.c File Reference

contains all (global) constants)

`#include "consts.h"`

Include dependency graph for consts.c:

Variables

- const Complex rX [2][2]
- const Complex rXT [2][2]
- const Complex X [2][2]
- const Complex Y [2][2]
- const Complex Z [2][2]
- const Complex H [2][2]

6.4.1 Detailed Description

contains all (global) constants)

Authors

J Scott, O Thomas

Date

Nov 2018

6.4.2 Variable Documentation

6.4.2.1 const Complex H[2][2]

Initial value:

```
= {{{0.7071067812, 0.0}, {0.7071067812, 0.0}},
                         {{0.7071067812, 0.0}, {-0.7071067812, 0.0}}}
```

Parameters

H	Hadamard gate

6.4.2.2 const Complex rX[2][2]

Initial value:

```
= {{{0.5, 0.5},{0.5, -0.5}},
                          {{0.5, -0.5},{0.5, 0.5}}}
```

Parameters

rX	sqrt X gate (0.5+0.5i 0.5-0.5i) (0.5-0.5i 0.5+0.5i)

6.4.2.3 const Complex rXT[2][2]

Initial value:

```
= {{{0.5, -0.5},{0.5, 0.5}},
                          {{0.5, 0.5},{0.5, -0.5}}}
```

Parameters

rXT	Adjoint of rX

6.4.2.4 const Complex X[2][2]

Initial value:

```
= {{{0.0, 0.0},{ONE_Q15, 0.0}},
                         {{ONE_Q15, 0.0},{0.0, 0.0}}}
```

Parameters

X	pauli X gate

6.4.2.5 const Complex Y[2][2]

Initial value:

```
= {{{0.0, 0.0}, {0.0, -1.0}},
                              {{0.0, ONE_Q15}, {0.0, 0.0}}}
```

Parameters

Y	Pauli y gate

6.4.2.6 const Complex Z[2][2]

Initial value:

```
= {{{ONE_Q15, 0.0}, {0.0, 0.0}},
                              {{0.0, 0.0}, {-1.0, 0.0}}}
```

Parameters

Z	Pauli z gate

6.5 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/consts.h File Reference

header file for (global) constants

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

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

Macros

- #define **NUM_QUBITS** 4
- #define **STATE_LENGTH** 16
- #define **FULL_PHASE** 0.124996185
- #define **HALF_PHASE** 0.062498093
- #define LED_NUM 4

  The number of external LEDs.
- #define NUM_BTNS 9

  number of total buttons
- #define **ONE_Q15** 0.9999694824
- #define **BTN_CHIP_NUM** 2

Typedefs

- typedef signed _Fract Q15

  Basic fractional time.
- typedef Q15 Complex [2]

  Complex type.

Variables

- const Complex rX [2][2]
- const Complex rXT [2][2]
- const Complex X [2][2]
- const Complex Y [2][2]
- const Complex Z [2][2]
- const Complex H [2][2]

6.5.1 Detailed Description

header file for (global) constants

Authors

J Scott, O Thomas

Date

Nov 2018

6.5.2 Variable Documentation

6.5.2.1 const Complex H[2][2]

Parameters

H	Hadamard gate

6.5.2.2 const Complex rX[2][2]

Parameters

rX	is square root of X
rX	sqrt X gate (0.5+0.5i 0.5-0.5i) (0.5-0.5i 0.5+0.5i)

6.5.2.3 const Complex rXT[2][2]

Parameters

rXT	Adjoint of rX

6.5.2.4 const Complex X[2][2]

Parameters

X	pauli X gate

6.5.2.5 const Complex Y[2][2]

Parameters

Y	Pauli y gate

6.5.2.6 const Complex Z[2][2]

Parameters

Z	Pauli z gate

6.6 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/display.c File Reference

for all the state display functions

`#include "display.h"`

Include dependency graph for display.c:

Macros

- #define NUM_MAX_AMPS 4

Functions

- void display_average (Complex state[ ])

    Display the state amplitudes on LEDs.
- void display_cycle (Complex state[ ])

    cycles through the non-zero amplitude states
- int sort_states (Complex state[ ], int num_qubits)
- int remove_zero_amp_states (Complex state[ ], int disp_state[ ])

    takes state vector, number of qubits and vector to write the nonzero elements of the statevector to.

6.6.1 Detailed Description

for all the state display functions

6.6.2 Macro Definition Documentation

6.6.2.1 #define NUM_MAX_AMPS 4

Parameters

state	The state vector
num_qubits	The number of qubits in the state vector

Returns

This function finds the amplitude of the state vector with the largest magnitude.

6.6.3 Function Documentation

6.6.3.1 void display_average (**Complex** *state[]*)

Display the state amplitudes on LEDs.

Parameters

state	Pass in the state vector

Note

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

Todo Bring all constants out of the loops. Don't use pow.

Bug there is a phase bug when cycling the gates Loop over all qubits k = 0, 1, 2, ... N-1

Compute powers of 2

ROOT loop: starts at 0, increases in steps of 1

STEP loop: starts at 0, increases in steps of 2^(k+1)

Bug The problem is with the sign function, which will not distinguish between (e.g.) 1 and i. I think all the problems stem from that kind of error. c = sign(state[root + step]) - sign(state[root + root_max + step]);

Compute two temporary variables to check real and imaj signs

Set c = 1 if there is a phase difference in either r or i

if(c==1 || c==3 || c==2)

Zeros are at the index root + step

Todo Rewrite pow for Q15

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

write phase update leds for each qubits average zero and one amps

6.6.3.2 void display_cycle (**Complex** *state[]*)

cycles through the non-zero amplitude states

Parameters

state	The state to display
N	The length of the state vector

Filter the state

Allocate RGB array

Decode

Look at the jth bit

Reset the cycle

Each iteration of this loop writes

Loop here to add stuff

6.6.3.3 int remove_zero_amp_states (Complex *state[ ]*, int *disp_state[ ]*)

takes state vector, number of qubits and vector to write the nonzero elements of the statevector to.

updates disp_state where the first 'return value of the function'elements are the nonzero elements of the state vector 'state'

the disp_state elements are the nonzero elements of the state

```
/// e.g. state =  (00) = (1/r2) (Bell state)
///               (01)    ( 0  )
///               (10)    ( 0  )
///               (11)    (1/r2)
/// Then displ_state would have 2 elements
/// disp_state = (0) standing for (00)
///              (3)              (11)
///
```

Note

we have to allocate disp_state to be the size of state, the function returns count which tells us the first 'count' elements of disp_state to use. In the Bell state example there are 2 values in disp_state, 0 & 3, count is returned as 3 which means take the first count-1 elements (in this case 2) of disp_state which is 0,1 which is the correct elements

6.6.3.4 int sort_states (Complex *state[ ]*, int *num_qubits*)

Todo this

Todo this function...

6.7 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/display.h File Reference

Description: Header file containing all the functions for displaying the qubits state vector.

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

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

Functions

- void display_average (Complex state[ ])

  Display the state amplitudes on LEDs.
- void display_cycle (Complex state[ ])

  cycles through the non-zero amplitude states
- int remove_zero_amp_states (Complex state[ ], int disp_state[ ])

  updates disp_state where the first 'return value of the function'elements are the nonzero elements of the state vector 'state'
- int sort_states (Complex state[ ], int num_qubits)

6.7.1 Detailed Description

Description: Header file containing all the functions for displaying the qubits state vector.

Authors

J Scott, O Thomas

Date

Nov 2018

6.7.2 Function Documentation

6.7.2.1 void display_average (Complex *state[ ]*)

Display the state amplitudes on LEDs.

Parameters

state	Pass in the state vector

Note

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

Todo rename to display_average

Parameters

state	Pass in the state vector

Note

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

Todo Bring all constants out of the loops. Don't use pow.

Bug there is a phase bug when cycling the gates Loop over all qubits k = 0, 1, 2, ... N-1

Compute powers of 2

ROOT loop: starts at 0, increases in steps of 1

STEP loop: starts at 0, increases in steps of 2^(k+1)

Bug The problem is with the sign function, which will not distinguish between (e.g.) 1 and i. I think all the problems stem from that kind of error. c = sign(state[root + step]) - sign(state[root + root_max + step]);

Compute two temporary variables to check real and imaj signs

Set c = 1 if there is a phase difference in either r or i

if(c==1 || c==3 || c==2)

Zeros are at the index root + step

Todo Rewrite pow for Q15

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

write phase update leds for each qubits average zero and one amps

6.7.2.2 void display_cycle (Complex *state[ ]*)

cycles through the non-zero amplitude states

Parameters

state	The state to display
N	The length of the state vector

Filter the state

Allocate RGB array

Decode

Look at the jth bit

Reset the cycle

Each iteration of this loop writes

Loop here to add stuff

6.7.2.3 int remove_zero_amp_states (Complex *state[ ]*, int *disp_state[ ]*)

updates disp_state where the first 'return value of the function'elements are the nonzero elements of the state vector 'state'

Parameters

state	complex state vector in
disp_state	complex inout vector where the first n entries are the nonzero elements of 'state'

Returns

returns the number of elements to look at in disp_state.

updates disp_state where the first 'return value of the function'elements are the nonzero elements of the state vector 'state'

the disp_state elements are the nonzero elements of the state

```
/// e.g. state =  (00) = (1/r2) (Bell state)
///               (01)   ( 0  )
///               (10)   ( 0  )
///               (11)   (1/r2)
/// Then displ_state would have 2 elements
/// disp_state = (0) standing for (00)
///              (3)              (11)
///
```

Note

we have to allocate disp_state to be the size of state, the function returns count which tells us the first 'count' elements of disp_state to use. In the Bell state example there are 2 values in disp_state, 0 & 3, count is returned as 3 which means take the first count-1 elements (in this case 2) of disp_state which is 0,1 which is the correct elements

6.7.2.4 int sort_states (Complex *state[ ]*, int *num_qubits*)

Todo this

Todo this function...

6.8 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/io.c File Reference

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

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

Include dependency graph for io.c:

Macros

- #define **DISPLAY_CHIP_NUM** 2
- #define **MAX_CYCLE_LENGTH** 16
- #define **PERIOD** 500000

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_buttons (void)

  <— Global in this file
- int read_qubit_btn (int btn)

  Read the state of a qubit button.
- int read_func_btn (int btn)

  Read the state of a qubit button.
- void setup_external_leds (void)

  Set external variable RGB LEDs.
- int add_to_cycle (RGB colors[ ], int size)

  Add an item to the list of states to cycle.
- int reset_cycle (void)

  Reset the LED display cycle _∗.
- 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)

    Read external buttons.
- 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 [BTN_CHIP_NUM]

    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.
- RGB **cycle_colors** [MAX_CYCLE_LENGTH][NUM_QUBITS]
- int **last_row** = 0
- int **cycle_counter** = 0
- BTN btn_qubit [NUM_QUBITS]

    button mapping 1st byte 00000100 btn A26-28 -> logical 0 00000010 btn A7-9 -> logical 6 00000001 btn A4-6 -> logical 7 00001000 btn A1-3 -> logical 8
- BTN btn_func [NUM_BTNS-NUM_QUBITS]

    <— Global in this file

6.8.1 Detailed Description

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

Authors

J Scott, O Thomas

Date

Nov 2018

6.8.2 Function Documentation

6.8.2.1 void __attribute__ ((__interrupt__, no_auto_psv))

The max value for isr_counter.

Timer 6 and 7 for cycling superposition states.

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

Write a row to the leds

6.8.2.2 int add_to_cycle (RGB *colors[ ]*, int *size*)

Add an item to the list of states to cycle.

Add an element to the states to be cycled.

Parameters

leds	An array of LED indices
colors	Corresponding RGB values for each LED
size	The size of both the above arrays

This function is used to add a set of LED states (RGB values) into the list of states being cycled.

Repeatedly calling this function adds a new state to the end of the list of displayed states. LED states are shown in the order this function is called.

The implementation uses the linked list type cycle_node. Each call of this function adds a new element to the end of cycle node Add the new colors to top of array

6.8.2.3 void flash_all (int *number*)

Flash all the LEDs a number of times.

Parameters

number	

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

Flash LED a number of times.

Flash one LED a number of times.

6.8.2.5 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

6.8.2.6 int led_cycle_test (void)

Loop to cycle through LEDs 0 - 15.

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

6.8.2.7 int read_btn (int *btn*)

Read the state of a push button.

Parameters

btn	

Note

How well do you know C

6.8.2.8 int read_external_buttons (void)

Read external buttons.

Update the buttons array (see declaration above)

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

SH pin

Todo How long should this be?

Todo button remappings...

6.8.2.9 int read_func_btn (int *btn*)

Read the state of a qubit button.

Parameters

btn	The index of the button to read

Returns

the state of the button – 1 if pressed, 0 if not

The button state is in the buttons array Each element of that array is a byte Get the relevant byte

Retrieve the value of the right bit

Return the button state

6.8.2.10 int read_qubit_btn (int *btn*)

Read the state of a qubit button.

Parameters

btn	The index of the button to read

Returns

the state of the button – 1 if pressed, 0 if not

Todo should return a qubit number which has been selected

The button state is in the buttons array Each element of that array is a byte Get the relevant byte

Retrieve the value of the right bit

Return the button state

6.8.2.11 int reset_cycle (void)

Reset the LED display cycle _∗.

Reset the display cycle. Called before adding anything.

Todo do it

6.8.2.12 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.

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

Turn a particular LED on or off.

Parameters

color	
state	

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

Set an LED strobing.

Parameters

color	
state	

6.8.2.15 void setup_external_buttons (void)

<— Global in this file

All the setup for external buttons.

All the setup for external buttons For the qubits

logical 0

logical 1

logical 2

logical 3

For the function buttons

logical 4

logical 5

logical 6

logical 7

logical 8

6.8.2.16 void setup_external_leds (void)

Set external variable RGB LEDs.

Initialise LED lines

Initialise parameters to zero

Initialise display buffer to zero

Set flashing period

Turn timer 6 on

Todo CURRENTLY CYCLING IS OFF

6.8.2.17 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

6.8.2.18 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

6.8.2.19 void toggle_strobe (int *color*)

Toggle LED strobe.

Parameters

color	

6.8.2.20 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

6.8.2.21 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?

6.8.3 Variable Documentation

6.8.3.1 BTN btn_func[NUM_BTNS-NUM_QUBITS]

<— Global in this file

Bug this.

6.8.3.2 BTN btn_qubit[NUM_QUBITS]

button mapping 1st byte 00000100 btn A26-28 -> logical 0 00000010 btn A7-9 -> logical 6 00000001 btn A4-6 -> logical 7 00001000 btn A1-3 -> logical 8

2nd byte 10000000 btn A23-25 -> logical 1 00000010 btn A20-22 -> logical 2 00000100 btn A17-19 -> logical 3 00000001 btn A13-15 -> logical 4 00001000 btn A10-12 -> logical 5

6.8.3.3 int buttons[BTN_CHIP_NUM]

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

6.8.3.4 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).

6.8.3.5 LED_GLOBAL led_global = {0}

Parameters

led_global	Global LED strobing state parameter

6.9 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/io.h File Reference

Description: Header file for input output functions.

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

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

Data Structures

- struct BTN

    pin mappings
- struct LED_GLOBAL

    Global LED strobing state parameter.
- struct LED

    Each LED has the following type.
- struct RGB

    A type for holding red, green, blue values.
- struct cycle_node

    The basis for a linked list of states to cycle.

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

Typedefs

- typedef struct cycle_node cycle_node_t

  The basis for a linked list of states to cycle.

Functions

- int setup_io (void)

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

  All the setup for external buttons.
- int read_qubit_btn (int btn)

  Read the state of a qubit button.
- int read_func_btn (int btn)

  Read the state of a qubit button.
- 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)
- int add_to_cycle (RGB colors[], int size)

  Add an element to the states to be cycled.
- int reset_cycle (void)

  Reset the display cycle. Called before adding anything.

6.9.1 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.

Authors

J Scott, O Thomas

Date

Nov 2018

6.9.2 Function Documentation

6.9.2.1 int add_to_cycle (RGB *colors[ ]*, int *size*)

Add an element to the states to be cycled.

Add an element to the states to be cycled.

Parameters

leds	An array of LED indices
colors	Corresponding RGB values for each LED
size	The size of both the above arrays

This function is used to add a set of LED states (RGB values) into the list of states being cycled.

Repeatedly calling this function adds a new state to the end of the list of displayed states. LED states are shown in the order this function is called.

The implementation uses the linked list type cycle_node. Each call of this function adds a new element to the end of cycle node Add the new colors to top of array

6.9.2.2 void flash_all (int *number*)

Flash all the LEDs a number of times.

Parameters

number	

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

Flash one LED a number of times.

Parameters

color	
number	

Flash one LED a number of times.

6.9.2.4 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

6.9.2.5 int led_cycle_test (void)

Loop to cycle through LEDs 0 - 15.

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

6.9.2.6 int read_btn (int *btn*)

Read the state of a push button.

Parameters

btn	

Note

How well do you know C

6.9.2.7 int read_external_buttons (void)

Update the buttons array (see declaration above)

Update the buttons array (see declaration above)

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

SH pin

Todo How long should this be?

Todo button remappings...

6.9.2.8 int read_func_btn (int *btn*)

Read the state of a qubit button.

Parameters

btn	The index of the button to read

Returns

the state of the button – 1 if pressed, 0 if not

The button state is in the buttons array Each element of that array is a byte Get the relevant byte

Retrieve the value of the right bit

Return the button state

6.9.2.9 int read_qubit_btn (int *btn*)

Read the state of a qubit button.

Parameters

btn	The index of the button to read

Returns

the state of the button – 1 if pressed, 0 if not

Parameters

btn	The index of the button to read

Returns

the state of the button – 1 if pressed, 0 if not

Todo should return a qubit number which has been selected

The button state is in the buttons array Each element of that array is a byte Get the relevant byte

Retrieve the value of the right bit

Return the button state

6.9.2.10 int reset_cycle (void)

Reset the display cycle. Called before adding anything.

Reset the display cycle. Called before adding anything.

Todo do it

6.9.2.11 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.

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

Turn a particular LED on or off.

Parameters

color	
state	

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

Set an LED strobing.

Parameters

color	
state	

6.9.2.14 void setup_external_buttons (void)

All the setup for external buttons.

All the setup for external buttons.

All the setup for external buttons For the qubits

logical 0

logical 1

logical 2

logical 3

For the function buttons

logical 4

logical 5

logical 6

logical 7

logical 8

6.9.2.15 void setup_external_leds (void)

Set external variable RGB LEDs.

Initialise LED lines

Initialise parameters to zero

Initialise display buffer to zero

Set flashing period

Turn timer 6 on

Todo CURRENTLY CYCLING IS OFF

6.9.2.16 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

6.9.2.17 void toggle_strobe (int *color*)

Toggle LED strobe.

Parameters

color	

6.9.2.18 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

6.9.2.19 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?

6.10 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/main.c File Reference

The main function.

```
#include "config.h"
#include "time.h"
#include "algo.h"
#include "display.h"
```

Include dependency graph for main.c:

Functions

- int main (void)

6.10.1 Detailed Description

The main function.

Authors

J Scott, O Thomas

Date

Nov 2018

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`

6.10.2 Function Documentation

6.10.2.1 int main (void)

Test single qubit gates

Todo fix this menu system

Todo add a button for switching between display average and cycle modes

In this test the qubit buttons (0 - 3) will be used to select a qubit and the function buttons (4 - 6) will be used to perform an operation on the selected qubit (X, Z or H).

The loop is made of two parts. The first waits for a qubit to be selected and the second chooses a single qubit operation for that qubit. Once the gate has been pressed the operation is immediately executed and the loop repeats.

Wait for a qubit operation to be selected

Perform operation

$<$

Note

Really important!

6.11 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/quantum.c File Reference

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

`#include "quantum.h"`
Include dependency graph for quantum.c:

Functions

- int pow2 (int k)

  A simple function to compute integer powers of 2.
- int sign (Complex a)

  returns phase quadrant
- void **cadd** (const Complex a, const Complex b, Complex result)
- void **cmul** (const Complex a, const Complex b, Complex result)
- Q15 absolute (Complex x)

  abs function
- Q15 square_magnitude (Complex x)

  Compute the magnitude squared of a complex number.
- void zero_state (Complex state[ ])

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

  This is an old version of the mat_mul function.
- void mat_mul (const Complex M[2][2], Complex V[ ], int i, int j)

  This version uses inlined cadd and cmul.
- void single_qubit_op (const Complex op[2][2], int k, Complex state[ ])

  apply operator
- void single_qubit_op_new (const Complex op[2][2], int k, Complex state[ ])

  New function to perform single qubit gates.
- void controlled_qubit_op_new (const Complex op[2][2], int ctrl, int targ, Complex state[ ])

  Efficient controlled qubit operation.
- void controlled_qubit_op (const Complex op[2][2], int ctrl, int targ, Complex state[ ])

  Old controlled qubit operations.

6.11.1 Detailed Description

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

Authors

J Scott, O Thomas

Date

Nov 2018

Todo split into a complex math and operator files

6.11.2 Function Documentation

6.11.2.1 Q15 absolute (Complex *x*)

abs function

Parameters

x	A complex number to find the absolute value of

Returns

The absolute value

Todo Check that the complex part is small

6.11.2.2 void controlled_qubit_op (const Complex *op[2][2],* int *ctrl,* int *targ,* Complex *state[ ]*)

Old controlled qubit operations.

apply controlled 2x2 op

Bug this needs to be a long int for >16 qubits

ROOT loop: starts at 0, increases in steps of 1

STEP loop: starts at 0, increases in steps of 2^(k+1)

First index is ZERO, second index is ONE

Note

for 2 qubit case check if the index in the ctrl qubit is a 1 then apply the 2x2 unitary else do nothing
sorry. this checks for the first element of the state vector i.e. the target qubits |0> and checks that the state vector element is one which the control qubit has a |1> state -> (root + step)

The second element of the state vector to take is then the first +2^(target qubit number). This also needs to be checked that the control qubit is in the |1>.

Todo This expression can probably be simplified or broken over lines. The condition for the if statement is that root+step and root + step + root_max contain 1 in the ctrl-th bit.

6.11.2.3 void controlled_qubit_op_new (const Complex *op[2][2],* int *ctrl,* int *targ,* Complex *state[ ]*)

Efficient controlled qubit operation.

Parameters

op	the operation (ctrl-op is performed)
ctrl	the index of the ctrl qubit
targ	the index of the targ qubit
state	the state vector

This function is implemented similarly to the single qubit case above. Now there are three ranges of indices to increment through, separated by the two qubit indices.

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

This version uses inlined cadd and cmul.

2x2 complex matrix multiplication

Parameters

M	A 2x2 complex matrix
V	A Nx1 complex vector
i	The first index to pick from the vector V
j	The second index to pick from the vector V

Todo Is static enough? Or should we declare outside the function?

Todo Should we use for loops? Or is it better not to..?

This is necessary because the previous computations use V

6.11.2.5 void mat_mul_old (const Complex *M[2][2]*, Complex *V[ ]*, int *i*, int *j*)

This is an old version of the mat_mul function.

Parameters

M	A 2x2 complex matrix
V	A Nx1 complex vector
i	The first index to pick from the vector V
j	The second index to pick from the vector V

The function uses cadd and cmul

Todo Should these be outside the function?

6.11.2.6 int pow2 (int *k*)

A simple function to compute integer powers of 2.

Parameters

k	The exponent of 2 to compute

Returns

2^k

6.11.2.7 int sign (Complex *a*)

returns phase quadrant

```
///         Im
//           |
//      1    |    0
//           |
//   ----------------- Re
//           |
//      2    |    3
//           |
///
```

6.11.2.8 void single_qubit_op (const Complex *op[2][2]*, int *k*, Complex *state[ ]*)

apply operator

Parameters

state	state vector containing amplitudes
qubit	qubit number to apply 2x2 matrix to
N	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.	Consider the three qubit case, with amplitudes shown in the table below:

```
*     index     binary   amplitude
*      ----------------------------
*        0        0 0 0       a0
*        1        0 0 1       a1
*        2        0 1 0       a2
*        3        0 1 1       a3
*        4        1 0 0       a4
*        5        1 0 1       a5
*        6        1 1 0       a6
*        7        1 1 1       a7
*      ----------------------------
*      Qubit:     2 1 0
*
```

If a single qubit operation is applied to qubit 2, then the 2x2 matrix must be applied to all pairs of (0,1) in the first column, with the numbers in the other columns fixed. In other words, the following indices are paired:

```
(0+0)  (1+0)  (2+0)  (3+0)
(4+0)  (5+0)  (6+0)  (7+0)
```

where the top line corresponds to the ZERO amplitude and the bottom row corresponds to the ONE amplitude.

Similarly, for qubit 1 the pairings are:

```
(0+0)  (0+4)  (1+0)  (1+4)
(2+0)  (2+4)  (3+0)  (3+4)
```

And for qubit 0 the pairings are:

```
(0+0)  (0+2)  (0+4)  (0+6)
(1+0)  (1+2)  (1+4)  (1+6)
```

These numbers are exactly the same as the previous function, which means the same nested loops can be used to perform operation. Now the index

```
root + step
```

refers to the ZERO amplitude (the first element in the column vector to be multiplied by the 2x2 matrix), and the index Complex state[], int N root + 2^k + step

corresponds to the ONE entry. ROOT loop: starts at 0, increases in steps of 1

STEP loop: starts at 0, increases in steps of 2^(k+1)

First index is ZERO, second index is ONE

Todo Should we inline mat_mul here?

6.11.2.9 void single_qubit_op_new (const Complex *op[2][2],* int *k,* Complex *state[ ]*)

New function to perform single qubit gates.

Parameters

op	the unitary to perform
k	the index of the qubit to modify
state	the state vector

The function computes a single qubit operation acting on

Parameters

state.	It sets the bit position associated with the qubit to zero, and then generates all possible indices in the other bit positions. These correspond to the ZERO states. The ONE states are obtained by changing the kth bit from zero to one.

6.11.2.10 Q15 square_magnitude (Complex *x*)

Compute the magnitude squared of a complex number.

Parameters

x	The input complex number x

Returns

The value of |x|^2

Todo Maybe we should inline this

6.11.2.11 void zero_state (Complex *state[]*)

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!

6.12 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/quantum.h File Reference

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

```
#include <math.h>
#include "consts.h"
```

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

Enumerations

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

  Basis states.

Functions

- void zero_state (Complex state[])

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

  returns phase quadrant
- void mat_mul (const Complex M[2][2], Complex V[], int i, int j)

  2x2 complex matrix multiplication
- void single_qubit_op (const Complex op[2][2], int qubit, Complex state[])

  apply operator
- void controlled_qubit_op (const Complex op[2][2], int ctrl, int targ, Complex state[])

  apply controlled 2x2 op
- Q15 absolute (Complex x)

  abs function
- int pow2 (int k)

  A simple function to compute integer powers of 2.
- Q15 square_magnitude (Complex x)

  Compute the magnitude squared of a complex number.

6.12.1 Detailed Description

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

Authors

J Scott, O Thomas

Date

Nov 2018

6.12.2 Function Documentation

6.12.2.1 Q15 absolute (Complex *x*)

abs function

Parameters

x	A complex number to find the absolute value of

Returns

The absolute value

Todo Check that the complex part is small

6.12.2.2 void controlled_qubit_op (const Complex *op[2][2]*, int *ctrl*, int *targ*, Complex *state[]*)

apply controlled 2x2 op

Parameters

op	single qubit unitary 2x2
ctrl	control qubit number (0,1,..,n-1)
targ	target qubit number (0,1,...,n-1)
state	complex state vector

apply controlled 2x2 op

Bug this needs to be a long int for >16 qubits

ROOT loop: starts at 0, increases in steps of 1

STEP loop: starts at 0, increases in steps of 2^(k+1)

First index is ZERO, second index is ONE

Note

for 2 qubit case check if the index in the ctrl qubit is a 1 then apply the 2x2 unitary else do nothing sorry. this checks for the first element of the state vector i.e. the target qubits |0> and checks that the state vector element is one which the control qubit has a |1> state -> (root + step)

The second element of the state vector to take is then the first +2^(target qubit number). This also needs to be checked that the control qubit is in the |1>.

Todo This expression can probably be simplified or broken over lines. The condition for the if statement is that root+step and root + step + root_max contain 1 in the ctrl-th bit.

6.12.2.3 void mat_mul (const 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.

2x2 complex matrix multiplication

Parameters

M	A 2x2 complex matrix
V	A Nx1 complex vector
i	The first index to pick from the vector V
j	The second index to pick from the vector V

Todo Is static enough? Or should we declare outside the function?

Todo Should we use for loops? Or is it better not to..?

This is necessary because the previous computations use V

6.12.2.4 int pow2 (int *k*)

A simple function to compute integer powers of 2.

Parameters

k	The exponent of 2 to compute

Returns

2^k

6.12.2.5 int sign (Complex *a*)

returns phase quadrant

```
///         Im
//           |
//      1    |   0
//           |
//  ----------------- Re
//           |
//      2    |   3
//           |
///
```

6.12.2.6 void single_qubit_op (const Complex *op[2][2]*, int *k*, Complex *state[ ]*)

apply operator

Parameters

state	state vector containing amplitudes
qubit	qubit number to apply 2x2 matrix to
op	2x2 operator to be applied
state	state vector containing amplitudes
qubit	qubit number to apply 2x2 matrix to
N	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.	Consider the three qubit case, with amplitudes shown in the table below:

```
*     index     binary   amplitude
*      -----------------------------
*        0       0 0 0       a0
*        1       0 0 1       a1
*        2       0 1 0       a2
*        3       0 1 1       a3
*        4       1 0 0       a4
*        5       1 0 1       a5
*        6       1 1 0       a6
*        7       1 1 1       a7
*      -----------------------------
*      Qubit:    2 1 0
*
```

If a single qubit operation is applied to qubit 2, then the 2x2 matrix must be applied to all pairs of (0,1) in the first column, with the numbers in the other columns fixed. In other words, the following indices are paired:

```
(0+0) (1+0) (2+0) (3+0)
(4+0) (5+0) (6+0) (7+0)
```

where the top line corresponds to the ZERO amplitude and the bottom row corresponds to the ONE amplitude.

Similarly, for qubit 1 the pairings are:

```
(0+0) (0+4) (1+0) (1+4)
(2+0) (2+4) (3+0) (3+4)
```

And for qubit 0 the pairings are:

```
(0+0) (0+2) (0+4) (0+6)
(1+0) (1+2) (1+4) (1+6)
```

These numbers are exactly the same as the previous function, which means the same nested loops can be used to perform operation. Now the index

```
root + step
```

refers to the ZERO amplitude (the first element in the column vector to be multiplied by the 2x2 matrix), and the index Complex state[], int N root + 2^k + step

corresponds to the ONE entry. ROOT loop: starts at 0, increases in steps of 1

STEP loop: starts at 0, increases in steps of 2^(k+1)

First index is ZERO, second index is ONE

Todo Should we inline mat_mul here?

6.12.2.7 Q15 square_magnitude (Complex *x*)

Compute the magnitude squared of a complex number.

Parameters

x	The input complex number x

Returns

The value of |x|^2

Todo Maybe we should inline this

Parameters

x	The input complex number x

Returns

The value of |x|^2

Todo Maybe we should inline this

6.12.2.8 void zero_state (Complex *state[]*)

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

2^(number of qubits)

Parameters

state	complex state vector

2^(number of qubits)

Note

oh the clarity!

6.13 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/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.

6.13.1 Detailed Description

Description: Functions for communicating with serial devices.

Authors

J Scott, O Thomas

Date

Nov 2018

6.13.2 Function Documentation

6.13.2.1 int send_byte_spi_1 (int *data*)

Send a byte to the SPI1 peripheral.

Parameters

data	byte to be sent to SPI1

6.13.2.2 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.

6.14 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/spi.h File Reference

Description: SPI communication functions.

```
#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.

6.14.1 Detailed Description

Description: SPI communication functions.

Authors

J Scott, O Thomas

Date

Nov 2018

6.14.2 Function Documentation

6.14.2.1 int send_byte_spi_1 (int *data*)

Send a byte to the SPI1 peripheral.

Parameters

data	byte to be sent to SPI1

6.14.2.2 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.

6.15 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/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** ()
- void delay ()

    Delay function!

6.15.1 Detailed Description

Description: Functions to control the on chip timers.

Authors

J Scott, O Thomas

Date

Nov 2018

6.15.2 Function Documentation

6.15.2.1 void setup_timer ( )

Todo distinguish between the two different timers here...

6.16 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/time.h File Reference

Description: Header file containing all the timing functions.

`#include "spi.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** ()
- void delay ()

  Delay function!

6.16.1 Detailed Description

Description: Header file containing all the timing functions.

Authors

J Scott, O Thomas

Date

Nov 2018

6.16.2 Function Documentation

6.16.2.1 void setup_timer ( )

Todo distinguish between the two different timers here...

6.17 /home/jrs/Documentos/work/git-projects/qcomp-design/quantum/dspic33e/qcomp-sim-c.X/trap.c File Reference

Description: Catch all the hardware traps and exceptions.

`#include "xc.h"`

Include dependency graph for trap.c:

Functions

- void **trap_enable** (void)
- void **__attribute__** ((__interrupt__, no_auto_psv))

6.17.1 Detailed Description

Description: Catch all the hardware traps and exceptions.

Authors

J Scott, O Thomas

Date

Dec 2018