

:::::::::::::
run.sh
:::::::::::::

#!/bin/bash

File Name:
run.sh

Purpose:
bash run file

Parameters:

Discussion:

Licensing:
This code is distributed under the GNU LGPL license.

Modified:
2018.12.03 Mon

Author:
Young Won Lim

bash -x run.sh

fname=quaternary_search

echo on

cd ~/Work/CORDIC/1.quaternary_tree_search

make quaternary_search N=10

cd ~/

./quaternary_search 3 |tee \$fname.log

enscript -o - \$fname.log | ps2pdf - \$fname.log.pdf

pdfunite quaternary_tree_*.pdf \$fname.log.pdf \$fname.out.pdf

for i in \$(seq 1 5); do
./quaternary_search 1 |tee quaternary_search_i_\$i.out
done

:::::::::::::
Makefile
:::::::::::::

File Name:
Makefile

Purpose:
makefile for quaternary_search

Parameters:

#

```
#
# Discussion:
#
#
# Licensing:
#
# This code is distributed under the GNU LGPL license.
#
# Modified:
#
# 2018.12.03 Mon
#
# Author:
#
# Young Won Lim
#
#-----
CC=gcc
CFLAGS=-Wall
MACROS=-DN=$(N)
LIBS=-lm

DEPS = quaternary1_search_defs.h
SRCS = quaternary2_search_defs.c \
      quaternary3_level.c \
      quaternary4_path.c \
      quaternary5_traverse.c \
      quaternary6_subtree.c \
      quaternary7_cordic.c \
      quaternary8_plot.c \
      quaternary9_main.c

OBJS = $(SRCS:.c=.o)

PRNS = run.sh Makefile $(DEPS) $(SRCS)

FNAME = ./print/quaternary_tree_search.c

.SUFFIXES : .o .c .cpp

.c.o : $(DEPS)
      $(CC) -c $(CFLAGS) $(MACROS) -o $@ $<

quaternary_search: $(OBJS)
      $(CC) $(CFLAGS) -o ~/quaternary_search $^ $(LIBS)
      rm -f *.o *~ core

print: run.sh Makefile $(DEPS) $(SRCS)
      /bin/more $(PRNS) > $(FNAME)
      enscript -o - --highlight=c $(FNAME) | ps2pdf - $(FNAME).pdf

clean:
      rm -f *.o *~ core

:~::~:
quaternary1_search_defs.h
:~::~:
//-----
// File Name:
// quaternary1_search_defs.h
//
// Purpose:
//
// Definitions and macros
//
```

```

// Parameters:
//
//
// Discussion:
//
//
// Licensing:
//
// This code is distributed under the GNU LGPL license.
//
// Modified:
//
// 2018.11.27 Tue
//
// Author:
//
// Young Won Lim
//
//-----
// #define N 8 // the number of a tree
#define R 4 // the number of expanding choices = R=4

//-----
// (R)-ary tree node
// 1st R choices -a(2*i)-a(2*i+1) at the step i // 0
// 2nd R choices -a(2*i)+a(2*i+1) at the step i // 1
// 3rd R choices +a(2*i)-a(2*i+1) at the step i // 2
// 4th R choices +a(2*i)+a(2*i+1) at the step i // 3
//-----
// for the file IO in an R script, arrange members
// that leaves no hole in memory
//-----
typedef struct node {
    double theta; // input angle to the i-th step
    int branch; // denotes which child of the parent
    int depth; // denotes the i-th step computation
    int id; // serial number for expand nodes

    int child[R]; // pointers to the 4 children
    int parent; // pointers to the parent
} nodetype;

//-----
// queue node type
// used for breadth first search traversal
//-----
typedef struct qnode {
    struct node * node; // angle tree node
    struct qnode * next; // queue node
} qnodetype;

//--- quaternary2.search_defs.c -----
nodetype * create_node();
qnodetype * create_qnode();

//--- quaternary3.level.c -----
void print_level_nodes(int depth);
nodetype find_level_min_node(int depth);
nodetype find_global_min_node();

//--- quaternary4.path.c -----
qnodetype* find_path(nodetype *p);
void print_path(qnodetype *q, char *str);

//--- quaternary5.traverse.c -----

```

```
void pr_node(nodetype *p);
void copy_node(nodetype *p, nodetype *q);
void expand_node(nodetype *p);
void tree_traverse(nodetype *p);
```

```
//--- quaternary6.leaves.c -----
void write_subtree_leaves(int depth_leaf, int depth_root);
void read_subtree_leaves(int depth_leaf, int depth_root);
void write_subtree_nodes(int depth_root, int class, int depth_leaf);
void read_subtree_nodes(int depth_root, int class, int depth_leaf);
```

```
//--- quaternary7.cordic.c -----
nodetype* cordic_expand(nodetype *p);
qnodetype* cordic_traverse(nodetype *p);
qnodetype *find_cordic_path(nodetype *p);
nodetype find_cordic_node(nodetype *p);
```

```
//--- binary8.plot.c -----
void plot_path(qnodetype *q, char *str);
```

```
//-----
// Global Variables
//-----
```

```
typedef struct param {
    int NN; // the depth/height of a binary tree
    int RR; // R=2 : binary tree
    double theta;
```

```
    char tstring[256];
```

```
} paramtype;
```

```
paramtype Param;
```

```
double a[2*N]; // because of quaternary search tree
```

```
:::::::::::::::
```

```
quaternary2_search_defs.c
```

```
:::::::::::::::
```

```
//-----
```

```
// File Name:
```

```
//     quaternary2_search_defs.c
```

```
//
```

```
// Purpose:
```

```
//
```

```
//     create node and qnode
```

```
//
```

```
// Parameters:
```

```
//
```

```
//
```

```
// Discussion:
```

```
//
```

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//
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```
// Licensing:
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//
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```
//     This code is distributed under the GNU LGPL license.
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// Modified:
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//     2018.11.27 Tue
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//
```

```
// Author:
```

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//
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```
//     Young Won Lim
```

```
//
```

```
//-----  
#include <stdio.h>  
#include <math.h>  
#include <stdlib.h>  
  
#include "quaternary1_search_defs.h"  
  
//-----  
// create a node for an angle tree  
//-----  
nodetype * create_node() {  
    nodetype * p = (nodetype *) malloc (sizeof(nodetype));  
  
    if (p == NULL) {  
        perror("node creation error \n");  
        exit(1);  
    }  
    else {  
        return p;  
    }  
}  
  
//-----  
// create a node for a queue  
//-----  
qnodetype * create_qnode() {  
  
    qnodetype * q = (qnodetype *) malloc (sizeof(qnodetype));  
  
    if (q == NULL) {  
        perror("qnode creation error \n");  
        exit(1);  
    }  
    else {  
        return q;  
    }  
}  
  
:~::~:  
quaternary3_level.c  
:~::~:  
//-----  
// File Name:  
//     quaternary3_level.c  
//  
// Purpose:  
//     find the minimum cost leaf node  
//  
// Parameters:  
//  
// Discussion:  
//  
// Licensing:  
//     This code is distributed under the GNU LGPL license.  
//  
// Modified:  
//     2018.11.27 Tue  
//  
// Author:  
//
```

```

//      Young Won Lim
//
//-----
#include <stdio.h>
#include <math.h>
#include <stdlib.h>

#include "quaternary1_search_defs.h"

//-----
// print all the nodes at the given level
//-----
void print_level_nodes(int depth) {
    FILE *fp;
    char fname[64];
    nodetype p;
    int i;

    printf("* print %d level node \n", depth);

    sprintf(fname, "ternary_tree_L%02d.dat", depth);

    fp = fopen(fname, "rb");

    while (fread(&p, sizeof(p), 1, fp) != 0) {
        printf(" %-5d %+f (Level %2d) ", p.id, p.theta, depth);
        printf("child: ");
        for (i=0; i<R; ++i) printf("%2d ", p.child[i]);
        printf("parent: %2d ", p.parent);
        printf("\n");
    }
    printf("-----\n");

    fclose(fp);
}

//-----
// find the node with the min residue angle at the given level
//-----
nodetype find_level_min_node(int depth) {
    static nodetype p, p_min;
    double minval = 1e100;
    double residue;

    FILE *fp;
    char fname[64];

    // printf("* find level %d min node : ", depth);

    sprintf(fname, "quaternary_tree_L%02d.dat", depth);

    fp = fopen(fname, "rb");

    while (fread(&p, sizeof(p), 1, fp) != 0) {
        // printf(" %d %f ", p.id, p.theta);
        residue = fabs(p.theta);
        if (minval > residue) {
            minval = residue;
            p_min = p;
        }
        // printf("residue=%10.6f minval=%10.6f \n", residue, minval);
        // pr_node(&p);
    }
}

```

```

printf("level min node : depth=%2d ", depth);
printf("theta=%10.6f ", p_min.theta);
printf("minval=%10.6f ", minval);
printf("id=%d \n", p_min.id);

fclose(fp);

return(p_min);
}

//-----
// find the node with the globally min residue angle
//-----
nodetype find_global_min_node() {
    nodetype p, p_min;
    double minval = 1e100;
    double residue;
    int i, i_min;

    // printf("* find global min node \n");

    for (i=0; i<N; ++i) {
        // printf("level %d\n", i);
        p = find_level_min_node(i);
        residue = fabs(p.theta);
        if (minval > residue) {
            minval = residue;
            p_min = p;
            i_min = i;
        }
    }

    printf("\nglobal min node : ");
    printf("depth=%2d ", i_min);
    printf("theta=%10.6f ", p_min.theta);
    printf("minval=%10.6f ", minval);
    printf("id=%d \n", p_min.id);

    return(p_min);
}

//-----
// sorting residue angles at the given level
//-----
// void sort_level_nodes(int depth) { T.B.D

:~::~:
quaternary4_path.c
:~::~:
//-----
// File Name:
//   quaternary4_path.c
//
// Purpose:
//   find and print the optimal path
//
// Parameters:
//
//
// Discussion:
//
//
// Licensing:
//

```

```
// This code is distributed under the GNU LGPL license.
//
// Modified:
//
// 2018.11.27 Tue
//
// Author:
//
// Young Won Lim
//
//-----
```

```
#include <stdio.h>
#include <math.h>
#include <stdlib.h>
#include <string.h>
```

```
#include "quaternary1_search_defs.h"
```

```
//-----
// find min path (min residue angles)
//-----
qnodetype *find_path(nodetype *p) {
    qnodetype *q, *path;
    int depth, pid;
    FILE *fp;
    char fname[64];

    // printf("* find a path from the root to the given node \n");

    path = NULL;

    depth = p->depth;

    while (depth >= 0) {

        // printf("* optimal path : depth= %d \n", depth);

        q = create_qnode();
        q->next = path;
        q->node = p;
        path = q;

        pid = p->parent;

        p = create_node();

        depth--;

        if (depth < 0) break;

        sprintf(fname, "quaternary_tree_L%02d.dat", depth);

        fp = fopen(fname, "rb");

        fread(p, sizeof(*p), 1, fp);

        if (p->id == pid) continue;

        fseek(fp, (pid - p->id - 1)*sizeof(*p), SEEK_CUR);
        fread(p, sizeof(*p), 1, fp);

        fclose(fp);

        // depth = p->depth;
    }

    // printf("* end of find optimal path \n");
}
```



```

    return(path);
}

//-----
// print nodes in a path from root to node
//-----
void print_path(qnodetype* q, char *str) {
    int u0, u1, i;

    // printf("* print the found path\n");

    printf("\npath type : %s \n", str);

    while (q) {
        printf("dp=%2d ", (q->node)->depth);
        // printf("th=%10.6f ", (q->node)->theta);
        printf("th=%-+15.6g ", (q->node)->theta);
        i = (q->node)->depth;

        q = q->next;

        if (q == NULL) {
            printf("\n");
            break;
        }
        printf("br=%2d ", (q->node)->branch);

        switch ((q->node)->branch) {
            case R-4 : u0=+1; u1=+1; break; // =0
            case R-3 : u0=+1; u1=-1; break; // =1
            case R-2 : u0=-1; u1=+1; break; // =2
            case R-1 : u0=-1; u1=-1; break; // =3
            default: u0=+1; u1=+1; break;
        }

        if (0) {
            printf("-u0=%+2d ", -u0);
            printf("a[%2d]=%10.6f ", 2*i, a[2*i]);
            printf("-u1=%+2d ", -u1);
            printf("a[%2d]=%10.6f ", 2*i+1, a[2*i+1]);
            printf("\n");
        } else {
            printf(" :");
            printf(" %10.6f", -a[2*i]-a[2*i+1]);
            printf(" %10.6f", -a[2*i]+a[2*i+1]);
            printf(" %10.6f", +a[2*i]-a[2*i+1]);
            printf(" %10.6f", +a[2*i]+a[2*i+1]);
            printf("\n");
        }
    }
}

```

```

:~::~:
quaternary5_traverse.c
:~::~:

```

```

//-----
// File Name:
//   quaternary5_traverse.c
//
// Purpose:
//

```

```
//      tree traverse and expanding a node
//
// Parameters:
//
//
// Discussion:
//
//
// Licensing:
//
//      This code is distributed under the GNU LGPL license.
//
// Modified:
//
//      2018.11.27 Tue
//
// Author:
//
//      Young Won Lim
//
//-----
#include <stdio.h>
#include <math.h>
#include <stdlib.h>

#include "quaternary1_search_defs.h"

FILE *fp_r; // read file pointer
FILE *fp_w; // write file pointer

//-----
// print node information
//-----
void pr_node(nodetype *p) {
    int i;

    printf("id=%d pa=%d ch=[", p->id, p->parent);
    for (i=0; i<R; ++i) printf("%d ", p->child[i]);
    printf("] th=%f br=%d dp=%d ", p->theta, p->branch, p->depth);
    printf("\n");
}

//-----
// copy a node structure
//-----
void copy_node(nodetype *p, nodetype *q) {
    int i;

    p->theta = q->theta;
    p->branch = q->branch;
    p->depth = q->depth;
    p->id = q->id;
    p->parent = q->parent;
    for (i=0; i<R; ++i)
        p->child[i] = q->child[i];
}

//-----
// create (R) children node to the current node pointed by p
//-----
void expand_node(nodetype *p) {
    nodetype c;
    int i, j, depth;
    double ntheta, theta;
    static int id = 1;

    // printf("* expanding a node... \n");
}
```

```

theta = p->theta;
depth = p->depth;

for (i=0; i<R; ++i) {
    switch (i) {
        case R-4 : ntheta = theta - a[depth*2] - a[depth*2+1]; break;
        case R-3 : ntheta = theta - a[depth*2] + a[depth*2+1]; break;
        case R-2 : ntheta = theta + a[depth*2] - a[depth*2+1]; break;
        case R-1 : ntheta = theta + a[depth*2] + a[depth*2+1]; break;
        default  : ntheta = theta + a[depth*2] + a[depth*2+1]; break;
    }

    // printf("%d %f =( %f %f) \n", i, ntheta, theta, a[i]);

    c.parent      = p->id;
    c.theta       = ntheta;
    c.depth       = p->depth + 1;
    c.branch      = i;
    c.id          = id++;
    for (j=0; j<R; ++j) c.child[j] = 0;

    p->child[i]   = c.id;

    fwrite(&c, sizeof(c), 1, fp_w);
}

// pr_node(p);

// printf("** -sizeof(*p)=%ld \n", -sizeof(*p));

fseek(fp_r, -sizeof(*p), SEEK_CUR);
fwrite(p, sizeof(*p), 1, fp_r);
// pr_node(p);

// printf("** end of expand\n");
}

//-----
// BFS Tree Traversal - level by level
//-----
void tree_traverse(nodetype *r) {
    nodetype p;
    int depth;

    char fname_r[64];
    char fname_w[64];

    //printf("** tree traversing ... \n");

    sprintf(fname_w, "quaternary_tree_L%02d.dat", 0);
    fp_w = fopen(fname_w, "w");
    fwrite(r, sizeof(*r), 1, fp_w);
    fclose(fp_w);

    for (depth=0; depth<N; ++depth) {

        // printf("** depth= %d \n", depth);

        sprintf(fname_r, "quaternary_tree_L%02d.dat", depth);
        sprintf(fname_w, "quaternary_tree_L%02d.dat", depth+1);

        fp_r = fopen(fname_r, "r+");
        fp_w = fopen(fname_w, "w");
    }
}

```

```

    while (fread(&p, sizeof(p), 1, fp_r) != 0) {
        expand_node(&p);
    }

    fclose(fp_r);
    fclose(fp_w);
}

// printf("* end of tree traversing ... \n");
}

::::::::::::::::::
quaternary6_subtree.c
::::::::::::::::::
//-----
// File Name:
//   quaternary6_subtree.c
//
// Purpose:
//
//   read / write subtrees and their leaf nodes
//
// Parameters:
//
//
// Discussion:
//
//
// Licensing:
//
//   This code is distributed under the GNU LGPL license.
//
// Modified:
//
//   2018.11.27 Tue
//
// Author:
//
//   Young Won Lim
//-----
#include <stdio.h>
#include <math.h>
#include <stdlib.h>

#include "quaternary1_search_defs.h"

//-----
// write all classified leaf nodes
//-----
void write_subtree_leaves(int depth_root, int depth_leaf) {
    nodetype p;
    int cnum; // the number of classes at depth_root
    int lnum; // the number of leaves per each class at depth_leaf
    int i, j, cnt;

    FILE *fp1; // read file pointer
    FILE *fp2; // write file pointer

    char fname1[64];
    char fname2[64];

    printf("* write subtree leaf nodes \n");

```

```

cnum = (int) pow(R, depth_root);           // no of classes
lnum = (int) pow(R, depth_leaf) / cnum;    // no of leaves per class

sprintf(fname1, "quaternary_tree_L%02d.dat", depth_leaf);
fp1 = fopen(fname1, "r");

for (i=0; i<cnum; i++) {
    sprintf(fname2, "quaternary_tree_L%02d.G%02d.dat", depth_leaf, i);
    fp2 = fopen(fname2, "w");

    for (j=0; j<lnum; j++) {
        cnt = fread(&p, sizeof(p), 1, fp1);
        if (cnt == 0) {
            perror("* error in reading file ...\n");
            exit(1);
        }
        fwrite(&p, sizeof(p), 1, fp2);
    }

    fclose(fp2);
}

fclose(fp1);
}

//-----
// read all classified leaf nodes
//-----
void read_subtree_leaves(int depth_root, int depth_leaf) {
    nodetype p;
    int cnum;    // the number of classes at depth_root
    int lnum;    // the number of leaves per each class at depth_leaf
    int i, j;

    FILE *fp2; // write file pointer

    char fname2[64];

    printf("* read subtree leaf nodes\n");

    cnum = (int) pow(R, depth_root);           // no of classes
    lnum = (int) pow(R, depth_leaf) / cnum;    // no of leaves per class

    for (i=0; i<cnum; i++) {
        sprintf(fname2, "quaternary_tree_L%02d.G%02d.dat", depth_leaf, i);
        fp2 = fopen(fname2, "r");

        for (j=0; j<lnum; j++) {
            fread(&p, sizeof(p), 1, fp2);
            printf(" %d", p.id);
        }
        printf(" * Group %02d\n", i);

        fclose(fp2);
    }
}

//-----
// write subtree nodes
//-----
void write_subtree_nodes(int depth_root, int class, int depth_leaf) {
    nodetype p;
    int cnum;    // the number of classes

```

```

int lnum; // the number of leaves per each class at depth_leaf
int i, j, cnt;

FILE *fp1; // read file pointer
FILE *fp2; // write file pointer

char fname1[64];
char fname2[64];

printf("* write subtree nodes \n");

for (i=depth_root; i<=depth_leaf; i++) {
    cnum = (int) pow(R, depth_root); // no of classes
    lnum = (int) pow(R, i) / cnum; // no of leaves per class

    sprintf(fname1, "quaternary_tree_L%02d.dat", i);
    fp1 = fopen(fname1, "r");

    sprintf(fname2, "quaternary_tree_L%02d.G%02d", i, class);
    sprintf(fname2, "%s.L%02d.dat", fname2, i - depth_root);
    fp2 = fopen(fname2, "w");

    fseek(fp1, class*lnum*sizeof(p), SEEK_CUR);
    for (j=0; j<lnum; j++) {
        cnt = fread(&p, sizeof(p), 1, fp1);
        if (cnt == 0) {
            perror("* error in reading file ... \n");
            exit(1);
        }
        fwrite(&p, sizeof(p), 1, fp2);
    }

    fclose(fp2);
    fclose(fp1);
}

}

//-----
// read subtree nodes
//-----
void read_subtree_nodes(int depth_root, int class, int depth_leaf) {
    nodetype p;
    int cnum; // the number of classes
    int lnum; // the number of leaves per each class at depth_leaf
    int i, j;

    FILE *fp2; // write file pointer

    char fname2[64];

    printf("* read subtree nodes \n");

    for (i=depth_root; i<=depth_leaf; i++) {
        cnum = (int) pow(R, depth_root); // no of classes
        lnum = (int) pow(R, i) / cnum; // no of leaves per class

        sprintf(fname2, "quaternary_tree_L%02d.G%02d", i, class);
        sprintf(fname2, "%s.L%02d.dat", fname2, i - depth_root);
        fp2 = fopen(fname2, "r");

        for (j=0; j<lnum; j++) {
            fread(&p, sizeof(p), 1, fp2);
            printf(" %d", p.id);
        }
        printf(" * Level %02d (%02d) \n", i, i-depth_root);

        fclose(fp2);
    }
}

```

```
}  
  
}  
  
:~::~  
quaternary7_cordic.c  
:~::~  
//-----  
// File Name:  
//   quaternary7_cordic.c  
//  
// Purpose:  
//  
//   finding the cordic path  
//  
// Parameters:  
//  
// Discussion:  
//  
//  
// Licensing:  
//  
//   This code is distributed under the GNU LGPL license.  
//  
// Modified:  
//  
//   2018.11.27 Tue  
//  
// Author:  
//  
//   Young Won Lim  
//-----  
#include <stdio.h>  
#include <math.h>  
#include <stdlib.h>  
  
#include "quaternary1_search_defs.h"  
  
//-----  
// node id is newly created  
//-----  
// nodetype* cordic_expand(nodetype *p);  
// qnodetype* cordic_traverse(nodetype *p);  
//-----  
// node id in the search tree is reused  
//-----  
// qnodetype *find_cordic_path(nodetype *p);  
// nodetype find_cordic_node(nodetype *p);  
//-----  
  
//-----  
// create (R) children node to the current node pointed by p  
//-----  
nodetype* cordic_expand(nodetype *p) {  
    nodetype *np;  
    int i, depth, mindex=0;  
    double ntheta[R], theta, minval=1E+10;  
    static int id = 1;  
  
    // printf("* cordic node... \n");  
  
    theta = p->theta;
```

```

depth = p->depth;

for (i=0; i<R; ++i) {
    switch (i) {
        case R-4 : ntheta[i] = theta - a[depth*2] - a[depth*2+1]; break;
        case R-3 : ntheta[i] = theta - a[depth*2] + a[depth*2+1]; break;
        case R-2 : ntheta[i] = theta + a[depth*2] - a[depth*2+1]; break;
        case R-1 : ntheta[i] = theta + a[depth*2] + a[depth*2+1]; break;
        default  : ntheta[i] = theta + a[depth*2] + a[depth*2+1]; break;
    }
}

for (i=0; i<R; ++i) {
    if (minval > fabs(ntheta[i])) {
        minval = fabs(ntheta[i]);
        mindex = i;
    }
}

// printf("%d %f =( %f %f) \n", mindex, ntheta[mindex], theta, a[depth]);

np = create_node ();
p->child[mindex] = id;
np->parent       = p->id;
np->theta       = ntheta[mindex];
np->depth       = p->depth +1;
np->branch      = mindex;
np->id          = id++;

return np;
}

//-----
// CORDIC Traversal
//-----
qnodetype* cordic_traverse(nodetype *p) {
    qnodetype *cordic_path=NULL; // CORDIC Queue Head
    qnodetype *cordic_tail=NULL; // CORDIC Queue Tail
    qnodetype *q, *nq;
    nodetype *np;
    int k =0;

    // printf("* cordic traversing ... \n");

    q = create_qnode();
    q->node = p;

    cordic_path = q;
    cordic_tail = q;

    while (cordic_tail != NULL) {
        // printf("* node %d to be expanded \n", k);

        k++;

        if ((q->node)->depth >= (N-1) ) {
            cordic_tail->next = NULL;

            printf("* find level %d cordic node : ", np->depth);
            printf("theta=%10.6f ", np->theta);
            printf("id=%d \n", np->id);

            break;
        }
    }
}

```



```

    if (q != NULL) np = cordic_expand(q->node);

    nq = create_qnode();
    nq->node = np;

    cordic_tail->next = nq;
    cordic_tail = nq;

    q = nq;
}

return (cordic_path);
}

//-----
// find a cordic path from any node p to a cordic leaf node
//-----
qnodetype *find_cordic_path(nodetype *p) {
    nodetype c[R];
    qnodetype *q;
    qnodetype *path=NULL;           // CORDIC Queue Head
    qnodetype *tail=NULL;          // CORDIC Queue Tail
    int depth, cid, i, mindex;
    double minval=1E+10;
    FILE *fp;
    char fname[64];

    // printf("* find a cordic node at the given depth \n");

    depth = p->depth;
    // pr_node(p);

    q = create_qnode();
    q->node = p;

    path = q;
    tail = q;

    while (depth < N-1) {

        // printf("* cordic path : depth= %d \n", depth);

        cid = p->child[0];
        // printf("cid=%d \n", cid);

        //.....
        sprintf(fname, "quaternary_tree_L%02d.dat", depth+1);

        fp = fopen(fname, "rb");

        fread(c, sizeof(*p), 1, fp);

        if (c[0].id != cid) {
            fseek(fp, (cid - c[0].id -1)*sizeof(*p), SEEK_CUR);
            fread(c, sizeof(*p), 1, fp);
        }

        for (i=1; i<R; ++i) {
            fread(c+i, sizeof(*p), 1, fp);
        }

        fclose(fp);
        //.....
    }
}

```

```

minval = 1E+10;
for (i=0; i<R; ++i) {
    if (minval > fabs(c[i].theta)) {
        minval = fabs(c[i].theta);
        mindex = i;
    }
}

p = create_node();

copy_node(p, &c[mindex]);

// pr_node(p);

depth = p->depth;

q = create_qnode();
q->node = p;
q->next = NULL;

tail->next = q;
tail = q;

}

printf("cordic min node : depth=%2d ", depth);
printf("theta=%10.6f ", p->theta);
printf("minval=%10.6f ", minval);
printf("id=%d \n", p->id);

// printf("* end of find a cordic path \n");
return(path);

}

//-----
// find a cordic leaf node only
//-----
nodetype find_cordic_node(nodetype *p) {
    nodetype c[R], *np;
    int depth, cid, i, mindex;
    double minval=1E+10;
    FILE *fp;
    char fname[64];

    // printf("* find a cordic node at the given depth \n");

    np = create_node();

    copy_node(np , p);

    depth = np->depth;
    // pr_node(np);

    while (depth < N-1) {

        // printf("* cordic path : depth= %d \n", depth);

        cid = np->child[0];
        // printf("cid=%d \n", cid);

        //.....
        sprintf(fname, "quaternary_tree_L%02d.dat", depth+1);

```

```

fp = fopen(fname, "rb");

fread(c, sizeof(*np), 1, fp);

if (c[0].id != cid) {
    fseek(fp, (cid - c[0].id - 1)*sizeof(*np), SEEK_CUR);
    fread(c, sizeof(*np), 1, fp);
}

for (i=1; i<R; ++i) {
    fread(c+i, sizeof(*np), 1, fp);
}

fclose(fp);
//.....

minval = 1E+10;
for (i=0; i<R; ++i) {
    if (minval > fabs(c[i].theta)) {
        minval = fabs(c[i].theta);
        mindex = i;
    }
}

copy_node(np, &c[mindex]);

// pr_node(np);

depth = np->depth;

}

printf("cordic min node : depth=%2d ", depth);
printf("theta=%10.6f ", p->theta);
printf("minval=%10.6f ", minval);
printf("id=%d \n", p->id);

// printf("* end of find a cordic path \n");
return(*np);

}

:::
quaternary8_plot.c
:::
//-----
// File Name:
//   quaternary8_plot.c
//
// Purpose:
//   find and print the optimal path
//
// Parameters:
//
//
// Discussion:
//
//
// Licensing:
//
//   This code is distributed under the GNU LGPL license.
//
// Modified:
//

```

```

// 2018.11.27 Tue
//
// Author:
//
// Young Won Lim
//
//-----
#include <stdio.h>
#include <math.h>
#include <stdlib.h>
#include <string.h>

#include "quaternary1_search_defs.h"

//-----
// latex plot a path from root to node
//-----
char *tree_construct(char * path);
void tree_string(FILE *fp, char * path);
void table_string(FILE *fp, char * path);
void create_tex_file(char *path, char *str);
void plot_path(qnodetype* q, char *str);

//-----
char *tree_construct(char * path) {
    char *t, *s, u[256], v[256];
    int br;
    static int i = 0;

    // printf("path=%s \n", path);

    s = malloc(256); // s must be a heap memory
    t = strtok(path, " ");

    if (t == NULL) {
        sprintf(s, "%d", i++);
        i = 0;
        // printf("s=%s \n", s);
        return(s);
    } else {
        br = atoi(t);
        sprintf(u, "%d", i++);
        sprintf(v, "%s", tree_construct(path+2));
        switch (br) {
            case R-4 : sprintf(s, "[%s %s x x x ] ", u, v); break;
            case R-3 : sprintf(s, "[%s x %s x x ] ", u, v); break;
            case R-2 : sprintf(s, "[%s x x %s x ] ", u, v); break;
            case R-1 : sprintf(s, "[%s x x x %s ] ", u, v); break;
        }
        // printf("s=%s \n", s);
        return(s);
    }
}

//-----
void tree_string(FILE *fp, char * path) {
    char p1[256]="";
    char p2[256]="";

    strcpy(p1, path); // strtok corrupts the input string
    strcpy(p2, tree_construct(p1));
    printf("tree=%s\n", p2);

    fprintf(fp, "\\Tree %s\n", p2);
}

```

```

//-----
void table_string(FILE *fp, char * path) {
    char *t, p[256];
    int br, u0, u1;
    double theta = Param.theta;
    int i = 0;

    strcpy(p, path); // strtok corrupts the input string
    // printf("path=%s \n", p);

    fprintf(fp, "\\hline\n");
    fprintf(fp, "$i$ & $br$ & $theta$ & $-u0$ & $a(2*i)$ & ");
    fprintf(fp, "$-u1$ & $a(2*i+1)$ & $theta'$ $ ");
    fprintf(fp, " \\ \\ \\ \\ \\hline\n");
    fprintf(fp, "\\hline\n");

    t = strtok(p, " ");

    // printf("t=%c \n", *t);

    while (t != NULL) {
        // printf("t=%c \n", *t);

        br = atoi(t);
        switch (br) {
            case R-4 : u0=+1; u1=+1; break; // =0
            case R-3 : u0=+1; u1=-1; break; // =1
            case R-2 : u0=-1; u1=+1; break; // =2
            case R-1 : u0=-1; u1=-1; break; // =3
        }

        fprintf(fp, "%d & %d & %f & ", i, br, theta);
        fprintf(fp, "%d & %f & %d & %f & ", -u0, a[2*i], -u1, a[2*i+1]);
        theta = theta - u0 * a[2*i] - u1 * a[2*i+1]; i++;
        fprintf(fp, "%f \\ \\ \\ \\ \\hline\n", theta);

        t = strtok(NULL, " ");
    }
}

//-----
void create_tex_file(char *path, char* str) {
    FILE *fp;
    char fname[256]="", bname[256]="", cmd[256]="";
    int cnt;

    if (!strcmp(str, "leafmin")) cnt = 0;
    else if (!strcmp(str, "globalmin")) cnt = 1;
    else if (!strcmp(str, "cordic")) cnt = 2;
    else cnt = 0;

    sprintf(bname, "quaternary_tree_%d_%s", cnt+1, str);
    sprintf(fname, "quaternary_tree_%d_%s.tex", cnt+1, str);

    fp = fopen(fname, "w");

    fprintf(fp, "\\documentclass{article}\n");
    fprintf(fp, "\\usepackage[margin=1in]{geometry}\n");
    fprintf(fp, "\\usepackage{graphicx}\n");
    fprintf(fp, "\\usepackage{tikz-qtrees}\n");
    fprintf(fp, "\\begin{document}\n");

    fprintf(fp, "\\setcounter{section}{%d}\n", cnt);
    fprintf(fp, "\\section{%s (%s) (N=%d R=%d theta=%f)}\n",
        Param.tstring, str, Param.NN, Param.RR, Param.theta);
}

```

```

fprintf(fp, "\\begin{tikzpicture}[scale=1]\n");
//.....
tree_string(fp, path);
//.....
fprintf(fp, "\\end{tikzpicture}\n");

fprintf(fp, "\\begin{center}\n");
fprintf(fp, "\\begin{tabular}{ |r|r|r|r|r|r|r|r| }\n");
//.....
table_string(fp, path);
//.....
fprintf(fp, "\\end{tabular}\n");
fprintf(fp, "\\end{center}\n");

fprintf(fp, "\\end{document}\n");

fclose(fp);

if (0) {
    sprintf(cmd, "latex %s.tex", bname);      printf("%s\n", cmd); system(cmd);
    sprintf(cmd, "dvi2pdf %s.dvi", bname);   printf("%s\n", cmd); system(cmd);
    sprintf(cmd, "xreader -w %s.pdf", bname); printf("%s\n", cmd); system(cmd);
} else {
    sprintf(cmd, "latex %s.tex > /dev/null", bname);
    printf("%s\n", cmd); system(cmd);
    sprintf(cmd, "dvi2pdf %s.dvi > /dev/null", bname);
    printf("%s\n", cmd); system(cmd);
    sprintf(cmd, "xreader -w %s.pdf > /dev/null", bname);
    printf("%s\n", cmd); system(cmd);
}
}

//-----
void plot_path(qnodetype* q, char *str) {
    char path[256]="", p[256]="";

    // printf("* plot a path \n");

    while (q) {
        q = q->next;

        if (q == NULL) {
            printf("\n");
            break;
        }
        sprintf(p, "%d ", (q->node)->branch);
        strcat(path, p);
    }

    printf("%s path=%s\n", str, path);

    create_tex_file(path, str);
}

:::
quaternary9_main.c
:::
//-----
// File Name:
//   quaternary8_main.c
//
// Purpose:
//
//   quaternary angle tree search main

```

```
//
// Parameters:
//
// Discussion:
//
// Licensing:
//
// This code is distributed under the GNU LGPL license.
//
// Modified:
//
// 2018.11.27 Tue
//
// Author:
//
// Young Won Lim
//-----
#include <stdio.h>
#include <math.h>
#include <stdlib.h>
#include <string.h>

#include "quaternary1_search_defs.h"

qnodetype *leafmin_path;
qnodetype *globalmin_path;
qnodetype *cordic_path;

//-----
// main - Ternary Angle Tree Search
//-----
int main(int argc, char *argv[]) {
    double theta; // = 4*atan(pow(2,-5));
    int i;

    nodetype p;
    nodetype min_leaf;
    nodetype min_global;
    nodetype cordic_node;

    if (argc != 2) {
        printf("quaternary_search i (theta=2^(-i)) \n");
        return 0;
    }

    i = atoi(argv[1]);
    theta = atan(pow(2, -1*i));

    printf("quaternary angle tree search (N=%d) \n", N);
    printf("theta= atan(pow(2,%d) = %10g \n", -1*i, theta);

    for (i=0; i<2*N; ++i) {
        a[i] = atan(1./pow(2, i));
    }

    Param.NN = N;
    Param.RR = R;
    Param.theta = theta;
    strcpy(Param.tstring, "quaternary angle tree");
}
```

```
p.theta = theta;
p.depth = 0;
p.id = 0;
p.branch = 0;
for (i=0; i<R; ++i) p.child[i]= i+1;

tree_traverse(&p);

printf("\n=====\n");
printf("* the optimal path to a leaf \n");
printf("=====\n");
min_leaf = find_level_min_node(N-1);
leafmin_path = find_path(&min_leaf);
print_path(leafmin_path, "leafmin");
plot_path(leafmin_path, "leafmin");

printf("\n=====\n");
printf("* the global optimal path to a node \n");
printf("=====\n");
min_global = find_global_min_node();
globalmin_path = find_path(&min_global);
print_path(globalmin_path, "globalmin");
plot_path(globalmin_path, "globalmin");

printf("\n=====\n");
printf("* the cordic path \n");
printf("=====\n");
// cordic_path = cordic_traverse(&p); // method 1
// cordic_path = find_cordic_path(&p); // method 2
cordic_node = find_cordic_node(&p); // method 3
cordic_path = find_path(&cordic_node);
print_path(cordic_path, "cordic");
plot_path(cordic_path, "cordic");

/*
printf("* classify leaf nodes \n");
write_subtree_leaves(2, N-1);
read_subtree_leaves(2, N-1);

printf("* subtree nodes \n");
write_subtree_nodes(2, 3, 5);
read_subtree_nodes(2, 3, 5);

printf("* print level nodes \n");
for (i=0; i<N; ++i) {
    print_level_nodes(i);
}
*/
}
```