Programming N-Ary trees
Quaternary trees
Applications to Image Compression

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Introduction

The aim of this project is to develop generic packages on n-ary and quaternary trees. These packages will be reused to implement another package allowing to achieve image compression and decompression.
1 Speciﬁcations of N-Ary generic package

A n-ary tree is a rooted tree in which each node has no more than n children.

1.1 Representation

It can be represented by:

• A value at the root of tree
• A father tree
• A children tree
• A brother tree

This structure will be implemented thanks to pointers.

1.2 Operations

Operations that one has to operate on n-ary tree are grouped into 3 categories: creation, consultation and modification. Here are the list of procedures to code.

1.2.1 Creation

• Nt_Create_Empty: create an empty n-ary tree.
• Nt_Create_Leaf: create a n-ary tree with a value, without brother or father.

1.2.2 Consultation

• Nt_Empty: check if tree is empty or not.
• Nt_Value: return value at the root of tree.
• Nt_Father: return father tree of tree.
• Nt_Child: return the n-th children tree of tree.
• Nt_Brother: return the n-th brother tree of tree.
• Nt_Display: display all content of tree.
• Nt_Search: search for a value into tree and return tree whose root value is found. If nothing is found return an empty tree.
• Nt_Number_Children: return the number of children tree at first level.
• Nt_Is_Leaf: check if tree is a leaf (no child).
• Nt_Is_Root: check if tree has no father.
1.2.3 Modification

- \texttt{Nt\_Change\_Value}: change value at the root of tree.
- \texttt{Nt\_Insert\_Child}: insert a tree without brother at position of first child. Old child becomes the first brother of inserted tree.
- \texttt{Nt\_Insert\_Brother}: insert a tree without brother at position of first brother.
- \texttt{Nt\_Delete\_Child}: delete the n-th child of tree.
- \texttt{Nt\_Delete\_Brother}: delete the n-th brother of tree.
- \texttt{Nt\_Change}: apply a function to each element of tree.
2.1 Structuration of data

A node is represented by a record type containing the value of the root, a pointer on the first child, a pointer on the brother and another one on the father tree. The tree\_nr type is set to private for hiding from user package the data structure chosen to represent the n-ary tree.

```pl
  type node;
  type tree\_nr is access node;
  type node is record
    val: T;
    first\_child: tree\_nr;
    brother: tree\_nr;
    father: tree\_nr;
  end record;
```

We chose to pass as generic parameters the type of value of the root, the procedure which displays element and the function that will be applied to each element.

```pl
  generic
    type T is private;
    with procedure write ( a: in T );
    with function main\_function ( a: in T ) return T;
```

2.2 Algorithmic refining

We describe now procedures and functions that we have coded.

2.2.1 function Nt\_Create\_Empty

```pl
  function Nt\_Create\_Empty return tree\_nr is
  begin
    return null;
  end Nt\_Create\_Empty;
```

2.2.2 function Nt\_Create\_Leaf

```pl
  function Nt\_Create\_Leaf ( value : in T ) return tree\_nr is
    a: tree\_nr;
  begin
    a:=new node;
    a.val:=value;
    a.first\_child:=null;
    a.brother:=null;
    a.father:=null;
    return a;
  ```
end Nt_Create_Leaf;

2.2.3 function Nt_Empty

function Nt_Empty ( a: in tree_nr ) return boolean is
begin
  return (a=null);
end Nt_Empty;

2.2.4 function Nt_Value

function Nt_Value ( a: in tree_nr ) return T is
begin
  return (a.val);
exception
  when constraint_error => raise tree_empty;
end Nt_Value;

We raise tree_empty exception if there is a constraint_error. We let it propagate up to test program where it is processed.

2.2.5 function Nt_Father

function Nt_Father ( a: in tree_nr ) return tree_nr is
begin
  if Nt_Empty(a) then
    raise tree_empty;
  else if a.father=null then
    raise relation_empty;
  else
    return a.father;
  end if;
end if;
end Nt_Father;

If tree has no father, we raise relation_empty exception.

2.2.6 function Nt_Child

function Nt_Child ( a: in tree_nr; n: in integer ) return tree_nr is
  tree_curr: tree_nr;
begin
  if Nt_Empty(a) then
    raise tree_empty;
  else
    tree_curr:=a.first_child;
    for i in 1..n-1 loop
      tree_curr:=tree_curr.brother;
    end loop;
    return tree_curr;
  end if;

exception
  when constraint_error => raise relation_empty;
end Nt_Child;
We raise relation_empty exception if there is a constraint error.

2.2.7 function Nt_Brother

```plaintext
function Nt_Brother ( a: in tree_nr; n: in integer ) return tree_nr is
    tree_curr: tree_nr;
    begin
        if Nt_Empty(a) then
            raise tree_empty;
        else
            tree_curr:=a;
            for i in 1..n loop
                tree_curr:=tree_curr.brother;
            end loop;
            return tree_curr;
        end if;
    exception
        when constraint_error -> raise relation_empty;
    end Nt_Brother;
```

2.2.8 procedure Nt_Display

For displaying the tree, we use a recursive auxiliary procedure which will allow to browse tree.

```plaintext
procedure Nt_Display( a: in tree_nr ) is
    begin
        if Nt_Empty(a) then
            raise tree_empty;
        else
            put(" ");
            Nt_Display_Aux(a," ");
        end if;
    end Nt_Display;
```

Auxiliary procedure is as follow:

```plaintext
procedure Nt_Display_Aux( a: in tree_nr ; str_shift: in string ) is
    str_inc: string(1..4);
    begin
        if a=null then
            null;
        else
            write(a.val);
            new_line;
            if (not Nt_Empty(a.first_child)) then
                put(str_shift&"|" );
                new_line;
                put(str_shift&"+- ");
                if (not Nt_Empty(a.brother)) then
                    str_inc:="|
                else
                    str_inc=" ";
                end if;
                -- we display child
                Nt_Display_Aux(a.first_child,str_shift&str_inc);
            end if;
```

if (not Nt_Empty(a.brother)) then
  put(str_shift);
  -- we display brothers
  Nt_Display_Aux(a.brother.str_shift);
end if;

end Nt_Display_Aux;

We browse firstly along the first children with a shift on display and along the brothers keeping the same shift for all brothers.

2.2.9 function Nt_Search

We use also here an auxiliary procedure that make browse the tree along two ways of recursivity: the children one and the brothers one.

function Nt_Search ( a: in tree_nr; e: in T ) return tree_nr is
  -- current tree
  tree_curr :tree_nr;
  -- boolean to keep on or not searching
  stop: boolean;
begin
  if Nt_Empty(a) then
    raise tree_empty;
    -- terminal case
  else if a.val=e then
    return a;
    -- general case: we use Nt_Search_Aux auxiliary procedure
    tree_curr is returned
  else
    stop:=false;
    tree_curr:=Nt_Create_Empty;
    Nt_Search_Aux(a.first_child.e.tree_curr.stop);
    return tree_curr;
  end if;
end if;

end Nt_Search;

The auxiliary procedure is as follow: we use a boolean, passed as data/results parameters, to finish the recursive calls if value is found. If it is found, tree_curr is set to a null pointer.

procedure Nt_Search_Aux ( tree:in tree_nr ; e: in T ; tree_curr: out tree_nr ; stop: in out boolean ) is
begin
  -- terminal case
  if tree=null then
    null;
  else if tree.val=e then
    stop:=true;
    tree_curr:=tree;
    -- we search firstly on child relation
    else if not stop then
      Nt_Search_Aux(tree.first_child.e.tree_curr.stop);
      else null;
    end if;
    -- then we search on brothers relation
    if not stop then
      Nt_Search_Aux (tree.brother.e.tree_curr.stop);
      else null;
    end if;
  end if;
end if;
2.2.10 function Nt_Number_Children

We count the number of children of a tree passed as parameter.

```pascal
function Nt_Number_Children( a: in tree_nr ) return integer is
n:integer;
tree_curr:tree_nr;
begin
if nt_Empty(a) then
  raise tree_empty;
else if a.first_child /= null then
  n:=1;
  tree_curr:=a.first_child;
  while tree_curr.brother /= null loop
    n:=n+1;
    tree_curr:=tree_curr.brother;
  end loop;
  return n;
else
  return 1;
end if;
end if;
end Nt_Number_Children;
```

2.2.11 function Nt_Is_Leaf

```pascal
function Nt_Is_Leaf( a: in tree_nr )return boolean is
begin
if a.first_child=null then
  return true;
else return false;
end if;
exception
  when constraint_error => raise tree_empty;
end Nt_Is_Leaf;
```

2.2.12 function Nt_Is_Root

```pascal
function Nt_Is_Root( a: in tree_nr )return boolean is
begin
if a.father=null then
  return true;
else return false;
end if;
exception
  when constraint_error => raise tree_empty;
end Nt_Is_Root;
```

2.2.13 procedure Nt_Change_Value
procedure Nt_Change_Value(a: in out tree_nr; e: in T) is
begin
  a.val := e;
exception
  when constraint_error => raise tree_empty;
end Nt_Change_Value;

2.2.14 procedure Nt_Insert_Child

procedure Nt_Insert_Child (tree: in out tree_nr ; tree_i: in out tree_nr ) is
begin
  if Nt_Empty(tree) then
    raise tree_empty;
  -- if tree to insert is empty, we do nothing
  else if tree_i=null then
    null;
    -- 2 possible cases: tree has a child or not
    else if tree.first_child=null then
      tree.first_child := tree_i;
    -- we insert tree_i at first child position and old child
    -- become the first brother
    else
      tree_i.brother := tree.first_child;
      tree_i.father := tree;
      tree.first_child := tree_i;
    end if;
  end if;
end if;
end Nt_Insert_Child;

2.2.15 procedure Nt_Insert_Brother

procedure Nt_Insert_Brother( tree: in out tree_nr ; tree_i: in out tree_nr ) is
begin
  if Nt_Empty(tree) then
    raise tree_empty;
  else if tree_i=null then
    null;
    else
      tree_i.father := tree.father;
      tree_i.brother := tree.brother;
      tree.brother := tree_i;
    end if;
  end if;
end Nt_Insert_Brother;

2.2.16 procedure Nt_Delete_Child

procedure Nt_Delete_Child ( a: in out tree_nr ; n: in integer ) is
  -- saved trees: previous and following the child
  a_prev: tree_nr;
  a_next: tree_nr;
begin
  if Nt_Empty(a) then
    raise tree_empty;
    -- if the n-th child does not exist, we do nothing
else if n>Nt_Number_Children(a) then
    null;
-- if n=1, deleting the first child
else if n=1 then
    a_next:=a.first_child;
a_next.father:=null;
a.first_child:=a_next.brother;
-- we save pointer on n-th child
-- ans pointer on child's brother to delete
else
    a_prev:=Nt_Child(a,n-1);
a_next:=a.prev.brother.brother;
a.prev.brother.brother:=null;
a.prev.brother.father:=null;
a.prev.brother:=a_next;
end if;
end if;
end Nt_Delete_Child;

2.2.17 procedure Nt_Delete_Brother

procedure Nt_Delete_Brother ( a :in out tree_nr ; n: in integer) is

-- saved trees: previous and following the child
a_prev: tree_nr;
a_next: tree_nr;

begin
if Nt_Empty(a) then
    raise tree_empty;
-- deleting the n-th brother
else
    -- previous tree before brother to delete
    -- if relation_empty is raised into Nt_Brother,
    -- it propagates
    a_prev:=Nt_Brother(a,n-1);
    -- next tree after brother to delete
    -- if a_prev or a_prev.brother is raised,
    -- constraint_error is raised, then it propagates
    a_next:=a.prev.brother.brother;
    -- case where a_prev or a_prev.brother is not null
    a.prev.brother.father:=null;
a.prev.brother.brother:=null;
a.prev.brother:=a_next;
end if;

exception

-- if a_prev or a_prev.brother is null, we do noting
when constraint_error => null;
end Nt_Delete_Brother;

2.2.18 procedure Nt_Change

The main function "main_function" is passed as generic parameter when tree_nary package is instanciated.

procedure Nt_Change( a: in out tree_nr ) is

begin
if Nt_Empty(a) then
    null;
else
    a.val:=main_function(a.val);
    Nt_Change(a.first_child);
    Nt_Change(a.brother);
end if;
end if;
end Nt_Change;
3 Specifications of Quaternary generic package

3.1 Representation

A quaternary tree is a tree with 0 or 4 children. These 4 children are called north-west, north-east, south-west and south-east child.

3.2 Operations

The following operations are the same as the implemented ones for tree_nary package:

\( \text{Qt
_Create
_Empty, Qt
_Create
_Leaf, Qt
_Empty, Qt
_Value, Qt
_Father, Qt
_Display, Qt
_Search, Qt
_Is
_Leaf, Qt
_Is
_Root, Qt
_Change
_Value, Qt
_Change. }\)

New functions to code are:

- \( \text{Qt
_Build: create quaternary tree from a value and 4 child trees. }\)
- \( \text{Qt
_North
_West: returns the north-west child of quaternary tree. }\)
- \( \text{Qt
_North
_East: returns the north-east child of quaternary tree. }\)
- \( \text{Qt
_South
_West: returns the south-west child of quaternary tree. }\)
- \( \text{Qt
_South
_East: returns the south-east child of quaternary tree. }\)
Conception of Quaternary tree
generic package

4.1 Structuration of data

Quaternary tree being a subcategory of n-ary tree, we declare a type "quaternary tree", which is a subtype of n-ary tree. The generic parameters are the same as those of n-ary tree package.

4.2 Algorithmic refining

We use "renames" ADA directive in specification part. This will allow to reuse all procedures and functions implemented into n-ary tree package. Example:

```
function Qt_Create_Empty return quat_tree renames Nt_Create_Empty;
```

We do the same thing for exceptions:

```
-- empty tree
treeq_empty: exception renames tree_empty;
-- no relation
relationq_empty: exception renames relation_empty;
```

We define a childq_empty exception for Qt_Build procedure.

4.2.1 procedure Qt_Build

```
---------------------------------------------------------------------
--- procedure Qt_Build: create quaternary tree from a value and
--- and 4 child trees
--- parameters: tree_res, built tree
--- val, father value
--- a_nw, a_ne, a_sw, a_se, respectively north-west,
--- north-east, south-west and south-east children
--- post-conditions: if one of child is empty, we raise
--- childq_empty exception
---------------------------------------------------------------------

procedure Qt_Build( value: in T; t_nw, t_ne, t_sw, t_se: in out tree_quat; tree_res: out tree_quat )
  is

begin

-- if one of child is empty, we raise childq_empty exception
if (Qt_Empty(t_nw) or Qt_Empty(t_ne) or Qt_Empty(t_sw) or Qt_Empty(t_se)) then
  raise childq_empty;
-- otherwise we build quaternary tree
else
  tree_res:=Qt_Create_Leaf(value);
  Nt_Insert_Child(tree_res,t_se);
  Nt_Insert_Child(tree_res,t_sw);
  Nt_Insert_Child(tree_res,t_ne);
  Nt_Insert_Child(tree_res,t_nw);
end if;
```
end Qt_Build;

4.2.2 function Qt_North_West
We use here Nt_Child function which returns the n-th child of a tree.

function Qt_North_West( a: in tree_quat ) return tree_quat is
begin
  return Nt_Child(a,1);
end Qt_North_West;

We do the same thing for Qt_North_East (return Nt_Child(a,2)), Qt_South_West (return Nt_Child(a,3)), Qt_South_East (return Nt_Child(a,4)).
Chapter 5

Specifications of pimage package with compression

The aim is to achieve compression and decompression on an image using a quaternary tree. The images that we use are squares and their dimension is a power of 2. A color is defined from the 3 primary colors (red, green, blue) and is integer coded.

The recursive compression algorithm of a image with dimension n is as follows: if image is homogeneous, then we create a leaf whose root value is the color of image. If image is not homogeneous, we split it into 4 sub-images of dimension n/2, and we create a quaternary tree whose the four children are the 4 encoded sub-images.

Browsing all the quaternary tree, we get a set of values representing the compressed image.
It is specified that pimage package allows to:

- create a test image from a dimension and a matrix.
- load an image from a file.
- save an image into a file.
- display an image.
- load an encoded image from a file.
- save an encoded image into a file.
- achieve an operation on an image.
Conception of pimage package

6.1 Structuration of data

We choose to define a color by a 32 bits value (pixel). Image is a matrix of pixels. We use dynamic arrays.

```plaintext
-- subtype tree_im
subtype tree_im is tree_quat;
-- definition of primary color
subtype color_prim is integer range 0..255;
-- definition of pixel: value coded on 32 bits
type pixel is mod 2**32;
-- image array
type image is array (integer range <> , integer range <> ) of pixel;
```

6.2 Algorithmic refining

6.2.1 procedure im_to_tree

This procedure is building a tree from an image. We follow the encoding algorithm:

```plaintext
procedure im_to_tree( im: in image; n: in integer; a: out tree_im; tol: in intensity) is
im_nw,im_ne,im_sw,im_se: image(1..n/2,1..n/2);
a_nw,a_ne,a_sw,a_se: tree_im;

begin
-- case where dimension equals 1
if n=1 then
    a:=Qt_Create_Leaf(integer(im(1,1)));
-- if it is homogeneous, we create a leaf with average color
else if is_homogeneous(im,n,tol) then
    a:=Qt_Create_Leaf(integer(col_aver(im,n)));
else -- we build the tree dividing dimensions by two
    for i in 1..n/2 loop
        for j in 1..n/2 loop
            im_nw(i,j):=im(i,j);
            im_ne(i,j):=im(i,j+n/2);
            im_sw(i,j):=im(i+n/2,j);
            im_se(i,j):=im(i+n/2,j+n/2);
        end loop;
    end loop;

    im_to_tree(im_nw,n/2,a_nw,tol);
    im_to_tree(im_ne,n/2,a_ne,tol);
    im_to_tree(im_sw,n/2,a_sw,tol);
    im_to_tree(im_se,n/2,a_se,tol);
    Qt_Build(-1,a_nw,a_ne,a_sw,a_se,a);
end if;
end if;
```
6.2.2 function is_homogeneous

We explain here how is_homogeneous function deals with 3 possibilities cases: tolerance is minimal (0), maximal (100), or between these two values. If it is maximal, then we return a boolean set to true and a leaf is created with the average value of the image (see procedure im_to_tree). If it is minimal, we check that all pixels have the same value. Finally for the middle case, we test the inequality abs(average - average) <= tolerance on each pixel.

```plaintext
function is_homogeneous( im: in image; n: in integer; tol: in intensity ) return boolean is
begin
  result := true;
  case tol is
    -- maximal tolerance allowed, image is considered homogeneous
    when intensity'tmax => return true;
    -- minimal tolerance, we compare first point with all others
    when intensity'tfirst =>
      val := integer(im(1,1));
      i := 1;
      while i <= n and result loop
        j := 1;
        while j <= n and result loop
          result := (im(i,j) = pixel(val));
          j := j + 1;
        end loop;
        i := i + 1;
      end loop;
      return result;
    -- general case: we compute the average color and we extract the
    -- 3 average primary colors that we compare to image pixels with
    -- condition : abs(average primary color) <= tolerance
    when others =>
      c_aver := integer(col_aver(im,n));
      i := 1;
      while i <= n and result loop
        j := 1;
        while j <= n and result loop
          result := (abs(get_blue(im(i,j)) - get_blue(pixel(c_aver))) <= tol) and
                    (abs(get_green(im(i,j)) - get_green(pixel(c_aver))) <= tol) and
                    (abs(get_red(im(i,j)) - get_red(pixel(c_aver))) <= tol);
          j := j + 1;
        end loop;
        i := i + 1;
      end loop;
      return result;
  end case;
end is_homogeneous;
```
6.2.3  procedure save_imagec

-----------------------------------------------------------------------------------------------

--- procedure save_imagec: save a compressed image into file from
--- a tree
--- parameters: a built tree, n the dimension of image
-----------------------------------------------------------------------------------------------

procedure save_imagec( a: in tree_im ; n: in pixel ) is

filename: string(1..4);
f: pack_pixel.file_type;

begin

put("Enter a filename(4 characters): ");
get(filename);
skip_line;
create(f,out_file, filename);
write(f,n);
tree_to_imc(a,f);
close(f);

end save_imagec;

We call the recursive procedure tree_to_imc which browses all the tree.

6.2.4  procedure tree_to_imc

-----------------------------------------------------------------------------------------------

--- procedure tree_to_imc: allow to convert tree to compressed
--- sequence
--- parameters: a the built tree, f the logic name of file
-----------------------------------------------------------------------------------------------

procedure tree_to_imc( a: in tree_im; f: in pack_pixel.file_type ) is

begin

if Qt.Empty(a) then
  null;
else
  if Qt.Value(a)=-1 then
    write(f,2**24);
  else
    write(f,pixel(Qt.Value(a)));
  end if;
tree_to_imc(Qt.Child(a,1),f);
tree_to_imc(Qt.Brother(a,1),f);
end if;

end tree_to_imc;

6.3  Algorithmic refining for decompression

Firstly, we must build a tree from encoded sequence (procedure load_im_encod and imc_to___tree) and
then rebuild image from this tree (procedure tree_to_im).

6.3.1  procedure load_im_encod

-----------------------------------------------------------------------------------------------

--- procedure load_im_encod: build a tree from compressed
--- sequence
--- parameters: a the rebuilt tree, n the dimension of original
--- image
-----------------------------------------------------------------------------------------------
procedure load_im_encod( a: out tree_im ; n: out pixel ) is

filename: string(1..4);
f: pack_pixel.file_type;
-- dimension of original image
dim:pixel;

begin

put("Enter a filename(4 characters): ");
get(filename);
skip_line;
open(f,in_file,filename);
-- we read dimension
read(f,dim);
n:=dim;
a:=imc_to_tree(f);
close(f);
end load_im_encod;

Here we use auxiliary function imc_to_tree.

6.3.2 function imc_to_tree

This function allows to build a tree from encoded sequence of a compressed image.

-------------------------------------------------------------------------------------------------

--- function imc_to_tree: return a tree from of a compressed image
--- parameters: f the logic name of compressed file
-------------------------------------------------------------------------------------------------

function imc_to_tree( f: in pack_pixel.file_type ) return tree_im is

--children of quaternary tree
a,a_nw,a_ne,a_sw,a_se: tree_im;
v: pixel;

begin

read(f,v);
-- if value equals -1 (coded by 2**24), we create a leaf
if v /= 2**24 then
  a:=Qt_Create_Leaf(integer(v));
else
  a_nw:=imc_to_tree(f);
  a_ne:=imc_to_tree(f);
  a_sw:=imc_to_tree(f);
  a_se:=imc_to_tree(f);
  Qt_Build(-1,a_nw,a_ne,a_sw,a_se,a);
end if;
return a;
end imc_to_tree;

6.3.3 procedure tree_to_im

Image can be rebuilt from tree. Tree is tree_im and output image is im. We use i_b, i_f, j_b, j_f to get the shift between recursive calls.

-------------------------------------------------------------------------------------------------

--- procedure tree_to_im: allow to reconstruct original image from compressed image
--- parameters: a the rebuilt tree, im image to build
--- i_b,i_f,j_b,j_f the indexed (begin and final)
--- n the dimension of original image
-------------------------------------------------------------------------------------------------
procedure tree_to_im ( a: in tree_im ; im: out image ; i_b,i_f,j_b,j_f: in integer ) is

begin

-- terminal case
if Qt_Empty(a) then
  null; -- general case
else if Qt_Value(a) /= -1 then
  for i in i_b..i_f loop
    for j in j_b..j_f loop
      im(i,j):=pixel(Qt_Value(a));
    end loop;
  end loop;
else -- we browse the children
  tree_to_im(Qt_North_West(a),im,i_b,i_f-(i_f-i_b+1)/2,j_b,j_f-(j_f-j_b+1)/2);
  tree_to_im(Qt_North_East(a),im,i_b,i_f-(i_f-i_b+1)/2,j_f-(j_f-j_b+1)/2+1,j_f);
  tree_to_im(Qt_South_West(a),im,i_f-(i_f-i_b+1)/2+1,i_b,j_f-(j_f-j_b+1)/2);
  tree_to_im(Qt_South_East(a),im,i_f-(i_f-i_b+1)/2+1,i_f,j_f-(j_f-j_b+1)/2+1,j_f);
end if;
end tree_to_im;

6.3.4 procedure thresh_im

For an example of operation, we choose to do a binary threshold.

procedure thresh_im( im: in out image ; n: in integer ; threshold: in integer ) is

begin

for i in 1..n loop
  for j in 1..n loop
    if (integer(im(i,j))<= threshold) then
      im(i,j):=0;
    else
      im(i,j):=1;
    end if;
  end loop;
end loop;
end thresh_im;
end pimage;
7. Validation of packages

7.1 n-ary and quaternary packages

Test program main_tree_nary.adb and main_tree_quater.adb use respectively tree_nary.adb and tree_quater.adb package. It is possible to make a tree for checking the good operating of all main above procedures and functions.

7.2 pimage package

Tests program main_pimage.adb allows to create an image and validate compression and decompression. An example of image is displayed as:

<table>
<thead>
<tr>
<th>10</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>255</th>
<th>30</th>
<th>30</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
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<td>255</td>
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<td>255</td>
<td>255</td>
<td>255</td>
</tr>
</tbody>
</table>

Figure 7.1: Content of test image 8×8

Its size equals to 260 bytes (64×4+4) because we save also the dimension. We take into account a tolerance to see if image is homogeneous. The tree built with a minimal tolerance (0) is represented on the following figure:

Figure 7.2: Content of tree for compression with minimal tolerance

Image compressed size equals to 104 bytes (25×4+4) with 4 bytes for dimension which was expected. With a maximal tolerance (100), we get a leaf with the average color of image (161) because this one is considered
as homogeneous from criterion into homogeneous function.

with a tolerance equal to 80, we get this tree:

![Tree diagram](image)

Figure 7.3: *Content of tree for compression with tolerance equal to 80*

We can notice that there will be a loss of information regards to test image with compression. Indeed, the north-west part of image is seen as homogeneous with this tolerance. This is illustrated on this figure:

![Decompressed image](image)

Figure 7.4: *Content of decompressed image 8x8 a tolerance equal to 80*

For each case, we save compressed image and check decompression.
Conclusion

This project has enabled us to create a package to make compression and decompression of images. The operations implemented for quaternary trees were reused and validated for encoding algorithm.

Sources of this project can be downloaded here: