Clamav funcation call flow(AC scan)

ac algorithm adding pattern explained

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The function cli_ac_addpatt

this function will adding signature into existing ac tire

Data structures

cli_ac_node // store info of each node in a ac tire

```
struct cli_ac_node {
    struct cli_ac_patt *list;
    struct cli_ac_node **trans, *fail;
};
```

list: a list of signature with same prefix, only node which is last letter of signature will have the list. e.g.: for sig “abcd”, “abce” and “ab”, both node “b” and “c” will have list, furthermore, for node “b”’s list, it’s pattern “ab”
trans: an array of 256 – the size of a ASCII table
fail: the fail node chain

cli_ac_patt // store data for each signature

```
struct cli_ac_patt {
    uint16_t *pattern, *prefix, length, prefix_length;
    uint32_t mindist, maxdist;
    uint32_t sigid;
    uint32_t lsigid[3];
    uint16_t ch[2];
    char *virname;
    void *customdata;
    uint16_t ch_mindist[2];
    uint16_t ch_maxdist[2];
    uint16_t parts, partno, special, special_pattern;
    struct cli_ac_special **special_table;
    struct cli_ac_patt *next, *next_same;
    uint16_t rtype, type;
    uint32_t offdata[4], offset_min, offset_max;
    uint32_t boundary;
    uint8_t depth;
};
```

mindist, maxdist: the slide between sub sigs
sigid: the mark the parent id of sub sig
parts: number of sub sigs in a signature
partno: current sub sig id in a signature
next: pattern list for signatures have same effective pattern but other signature information is not exactly the same
next_same: pattern list for signatures have same effective pattern and also other signature information is exactly the same
offset_min, offsetmax: the slide of signature matching start

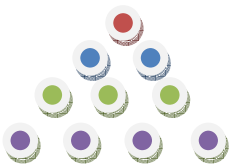
depth: at which level the node residents, corresponding to the char's position inside a signature

the root of a ac tire is cli_matcher->ac_root which is also a cli_ac_node type
and for each sig/subsig adding into ac tire, bellow code in cli_ac_addpatt will make sure the effective length of sig used in this algo should be either 2 or 3:

```
uint16_t len = MIN(root->ac_maxdepth, pattern->length);
if(len < root->ac_mindepth) return CL_EMALFDB;
```

here:
ac_maxdepth is inited as CLI_DEFAULT_AC_MAXDEPTH
ac_mindepth is inited as CLI_DEFAULT_AC_MINDEPTH

As the ac tire only have max 4 levels and min 3 levels with ac_root taken into account



level 0 – ac_root
level 1 – should not be leaf
level 2 – could be leaf
level 3 – could be leaf

So if first 2 or 3 characters of the signature are same, these sigs would be ending in the same leaf node linked via list like cli_ac_patt->next and cli_ac_patt->next_same

Test case

test.txt

NWSTARToooTESTkkkMYOtestTEST

ndb test
create ndb signature for test.txt
format
MalwareName:TargetType:Offset:HexSignature

File		
test1.ndb	test_ndb_sig1:0: 13,15:6f6f6f{1-2}6e6e6b6b6b	ooo{1-2}nnkkk
test2.ndb	test_ndb_sig2:0:0:6f6f6f{1-2}6d6d6b6b6b	ooo{1-2}mmkkk
test3.ndb	test_ndb_partsig:0:3,5:6f6f6e{1-2}6b6b6b	oon{1-2}kkk
test.ndb	test_ndb_partsig:0:3,5:6f6f6f{4-6}6b6b6b	ooo{4-6}kkk

Above is a regex(with range) signature with offset info, so it will be loaded into ac pattern structure and will be used in ac scan mode, the signature has a range information and the signature will be split into two sub-sigs.

with loading these signatures, will investigate how these sigs/sub-sigs are added into pattern list like:
cli_ac_node->list
cli_ac_patt->next
cli_ac_patt->next_same

the loading:

e.g.: this signature "test_ndb_regex:0:3,5:6f6f6f{4-6}6b6b6b" has regular expression with floating range involved, so should be loaded into AC scan structure and split into 2 sub signatures. These two sub sigs will be loaded in separately(has no direct connection in ac tire) and will be used in ac_scanbuff via offmetrix which will be bind together with parent sig id.

add signature(pre processing for regular expression) - AC

cli_ac_addsig

```
// get parent-sig id, number of parts, part index, mindist and maxdist
new->sigid = sigid;
new->parts = parts;
new->partno = partno;
new->mindist = mindist;
new->maxdist = maxdist;
new->ch[0] |= CLI_MATCH_IGNORE;
new->ch[1] |= CLI_MATCH_IGNORE;
// dealing case as "[]" – "HEXSIG[x-y]aa or aa[x-y]HEXSIG"
if(strchr(hexsig, '[')) // with "[" – no match for this case
if(strchr(hexsig, '(')) // with "(" –no match for this case

// dealing other case
new->pattern = cli_mpool_hex2ui(root->mempool, hex ? hex : hexsig);
// new->pattern is uint16_t
cli_mpool_hex2ui
    cli_realhex2ui // in this function, each byte of the pattern would be extended to uint16_t(low byte for the pattern byte and high byte for the matching type corresponding to the regular expression type)
```

```
#define CLI_MATCH_WILDCARD  0xff00
#define CLI_MATCH_CHAR      0x0000
#define CLI_MATCH_IGNORE    0x0100
#define CLI_MATCH_SPECIAL   0x0200
#define CLI_MATCH_NIBBLE_HIGH   0x0300
#define CLI_MATCH_NIBBLE_LOW    0x0400
```

```
            if(hex[i] == '?' && hex[i + 1] == '?')      val |= CLI_MATCH_IGNORE;
            if(hex[i + 1] == '?')     val |= CLI_MATCH_NIBBLE_HIGH;
            if(hex[i] == '?')     val |= CLI_MATCH_NIBBLE_LOW;
            if(hex[i] == '(')     val |= CLI_MATCH_SPECIAL;
    filter_add_acpatt //* prefiltering
    // check if there's regex in first letters
     if(new->pattern[i] & CLI_MATCH_WILDCARD)
     cli_caloff //"test_ndb_regex:0:3,5:6f6f6f{4-6}6b6b6b"
        if((pt = strchr(offcpy, ','))) offdata[2] = atoi(pt + 1); // which is 5
        offdata[0] = CLI_OFF_ABSOLUTE;
        *offset_min = offdata[1] = atoi(offcpy);    // which is 3
        *offset_max = *offset_min + offdata[2]; // which is 8
    // add the pattern into ac tire
     cli_ac_addpatt
```

add pattern to AC tire

========== the example ==========

signatures:

test1.ndb	test_ndb_sig1:0: 13,15:6f6f6f{1-2}6e6e6b6b6b	ooo{1-2}nnkkk
test2.ndb	test_ndb_sig2:0:0:6f6f6f{1-2}6d6d6b6b6b	ooo{1-2}mmkkk
test3.ndb	test_ndb_partsig:0:3,5:6f6f6e{1-2}6b6b6b	oon{1-2}kkk
test.ndb	test_ndb_partsig:0:3,5:6f6f6f{4-6}6b6b6b	ooo{4-6}kkk

loading sequence:

1. test_ndb_sig2
2. test_ndb_partsig
3. test_ndb_sig3
4. test_ndb_sig1

flow:

1. test_ndb_sig2
   a. for(i = 0; i < len; i++) // loop over effective pattern, length is 3
   b. while(ph) // false, ph = pt->list(null)
   c. if(ph_add_after) // false
   d. else // true
      a) pattern->next = pt->list; // pattern->next will be null
      b) pt->list = pattern;

2. test_ndb_partsig
   a. for(i = 0; i < len; i++) // loop over effective pattern, length is 3
   b. while(ph) // yes, ph = pt->list(has test_ndb_sig2)
      a) // !ph_add_after is true
         // ph->partno <= pattern->partno is true, both are 1
         // !ph->next is true
         if(!ph_add_after && ph->partno <= pattern->partno && (!ph->next || ph->next->partno > pattern->partno)) // true
            ph_add_after = ph;
      b) // ph->length == pattern->length is true, both are 3
         // ph->prefix_length == pattern->prefix_length is true, both is 0
         // no special char, so ch[0] and ch[1] are not changed after initialized
         if((ph->length == pattern->length) && (ph->prefix_length == pattern->prefix_length) && (ph->ch[0] == pattern->ch[0]) && (ph->ch[1] == pattern->ch[1])) // true
         i. if(!memcmp(ph->pattern, pattern->pattern, ph->length * sizeof(uint16_t)) && !memcmp(ph->prefix, pattern->prefix, ph->prefix_length * sizeof(uint16_t))) // true, double compare each char in effective pattern and prefix if there is

ii. // match=1 and do

iii. and since partno are same, so will do 'else' block in bellow code.

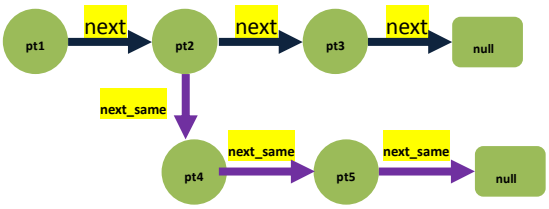
```
if(match) {
        if(pattern->partno < ph->partno) {
                pattern->next_same = ph;
                if(ph_prev)
                        ph_prev->next = ph->next;
                else
                        pt->list = ph->next;
                ph->next = NULL;
                break;
        } else {
                while(ph->next_same && ph->next_same->partno < pattern->partno)
                        ph = ph->next_same;
                pattern->next_same = ph->next_same;
                ph->next_same = pattern;
                return CL_SUCCESS;
        }
}
```

in 'else' block, insert according the partno with inc sequence
and return CL_SUCCESS means will not add into list
also
if match!=1 do:
ph_prev = ph; ph = ph->next; // try next pattern in list, ph_prev points to the pattern right before current pattern in list of in tire node

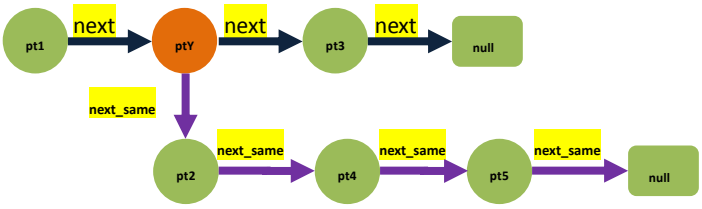
if match=1 but the partno is not current parrten's number of part sigs is less than current tire one's, current pattern of tire will be as current pattern's next_same and previous node's next pattern will be current pattern

the graph to illustrate:
for **nodeX**'s list:
current

pattern	partno
pt1	n/a
pt2	2
pt3	n/a
pt4	3
pt5	4



after inserting ptY
for **nodeX**'s list:
ptY: partno=1 and other info are same as pt2



c. if(ph_add_after) // will not go to here, returned at **return CL_SUCCESS**
   a) pattern->next = ph_add_after->next;
   b) ph_add_after->next = pattern;

3. test_ndb_sig3

node related to signature added before

4. test_ndb_sig1

a. for(i = 0; i < len; i++) // loop over effective pattern, length is 3
b. while(ph) // yes, ph = pt->list(has test_ndb_sig2->test_ndb_partsig)
   a) // !ph_add_after is true
      // ph->partno <= pattern->partno is true, both are 1
      // !ph->next is true
      if(!ph_add_after && ph->partno <= pattern->partno && (!ph->next || ph->next->partno > pattern->partno)) // true
         ph_add_after = ph;
   b) // ph->length == pattern->length is true, both are 3
      // ph->prefix_length == pattern->prefix_length is true, both is 0
      // no special char, so ch[0] and ch[1] are not changed after initialized
      if((ph->length == pattern->length) && (ph->prefix_length == pattern->prefix_length) && (ph->ch[0] == pattern->ch[0]) && (ph->ch[1] == pattern->ch[1])) // true
      i. if(!memcmp(ph->pattern, pattern->pattern, ph->length * sizeof(uint16_t)) && !memcmp(ph->prefix, pattern->prefix, ph->prefix_length * sizeof(uint16_t))) // true, double compare each char in effective pattern and prefix if there is
      ii. // match=1 and do
      iii. and since partno are same, so will do 'else' block in bellow code.

```
if(match) {
        if(pattern->partno < ph->partno) {
                pattern->next_same = ph;
                if(ph_prev)
                        ph_prev->next = ph->next;
                else
                        pt->list = ph->next;
                ph->next = NULL;
                break;
        } else {
                while(ph->next_same && ph->next_same->partno < pattern->partno)
                        ph = ph->next_same;
                pattern->next_same = ph->next_same;
                ph->next_same = pattern;
                return CL_SUCCESS;
        }
}
```

in ‘else’ block, insert according the partno with inc sequence
and return CL_SUCCESS means will not add into list

after the whole process, the ac tire for “OOO” is:

```
ac_root
|-> ‘o’
      |-> ‘o’

|->’o’->list(test_ndb_sig2)--next_same-->test_ndb_sig1--next_same-->test_ndb_partsig
                                                          NULL <--next_same--|
```

========== cli_ac_addpatt ==========

```
    uint16_t len = MIN(root->ac_maxdepth, pattern->length);
    // root->ac_maxdepth is set via CLI_DEFAULT_AC_MAXDEPTH
    if(len < root->ac_mindepth) return CL_EMALFDB;
    // root->ac_mindepth is set via CLI_DEFAULT_AC_MINDEPTH

    for(i = 0; i < len; i++)
      next = pt->trans[(unsigned char) (pattern->pattern[i] & 0xff)];
       if(!next) // this tran does not yet exist
         next = (struct cli_ac_node *) mpool_calloc(root->mempool, 1, sizeof(struct cli_ac_node)); // allocate
         newtable = mpool_realloc(root->mempool, root->ac_nodetable, root->ac_nodes * sizeof(struct cli_ac_node *));  // allocate a new node table to copy over the old ones and store the new one, copy over is done automatically via mpool_realloc
         root->ac_nodetable = (struct cli_ac_node **) newtable;
         root->ac_nodetable[root->ac_nodes - 1] = next;
         // put into the tire
         pt->trans[(unsigned char) (pattern->pattern[i] & 0xff)] = next;
      pt = next // pt will be pointed at the newly allocated/already exist node
    // create new pattern table and copy over
    newtable = mpool_realloc(root->mempool, root->ac_pattable, root->ac_patterns * sizeof(struct cli_ac_patt *));
    root->ac_pattable = (struct cli_ac_patt **) newtable;
    root->ac_pattable[root->ac_patterns - 1] = pattern;

    // pt now points at newly allocated/already exist ac node
    // ph points at pattern list for newly allocated/already exist ac node
    ph = pt->list; // the list only exists when this node is a leaf node(which stands for last char of an effective pattern) and patterns in the list share same leaf node(which also means same effective pattern(only 2 or 3 chars long))
```

```
    ph_add_after = ph_prev = NULL;

    while(ph) // if leaf is shared by other patterns(which is highly possible as only first 2 or 3 bytes of the signature is effectively used to build the ac tire), then try to insert it to the shared pattern list(pt->list), also if the pattern or sub-pattern are same, should add into a structure called pattern->next_same
    if(!ph_add_after && ph->partno <= pattern->partno && (!ph->next || ph->next->partno > pattern->partno))
        ph_add_after = ph;

    // same pattern length, same prefix length and same first two letters
    // ending in same leaf, need to further confirm if the two pattern are same or similar
    if((ph->length == pattern->length) && (ph->prefix_length == pattern->prefix_length) && (ph->ch[0] == pattern->ch[0]) && (ph->ch[1] == pattern->ch[1]))
        // if the characters part of the two pattern are exact the same, compare other info in the signature

        if(!memcmp(ph->pattern, pattern->pattern, ph->length * sizeof(uint16_t))
    && !memcmp(ph->prefix, pattern->prefix, ph->prefix_length * sizeof(uint16_t)))
            // if no other regex special case, the two sig are exact match
            if(!ph->special && !pattern->special) match = 1
            if(ph->special == pattern->special)
                //compare the special info
                a1 = ph->special_table[i];
                a2 = pattern->special_table[i];
            else match = 0;
            if(match) // sig info is the same
                // insert into next_same(same signature list) and sorting according to partno
                if(pattern->partno < ph->partno)
                    pattern->next_same = ph; // insert into same pattern list
                    if(ph_prev) ph_prev->next = ph->next; // remove ph from the leaf node's pattern list since it is added into same pattern list of current pattern
                    else pt->list = ph->next; // removing from current pattern's list
                else
                    while(ph->next_same && ph->next_same->partno < pattern->partno)
                        ph = ph->next_same;
                    pattern->next_same = ph->next_same;
                    ph->next_same = pattern;

        else
```

```
            // try next pattern in the list
            ph_prev = ph;
            ph = ph->next;

    if(ph_add_after) // insert
        pattern->next = ph_add_after->next;
        ph_add_after->next = pattern;
    else // append in head
        pattern->next = pt->list;
        pt->list = pattern;
```