Lua源码粗浅解析(5.4.7)

A、常见数据结构

1、TString

- TString

```
/*
** Header for a string value.
*/
typedef struct TString {
  CommonHeader;
  lu_byte extra;  /* reserved words for short strings; "has hash" for longs */  //关键字，0为非关键字，关键字从不参与GC
  ls_byte shrlen;  /* length for short strings, negative for long strings */    //字符串长度，如果是长字符串（大于40，长字符串不会放到string hash table中）该字段值为LSTRREG（-1）
  unsigned int hash;                                                            //hash值
  union {
    size_t lnglen;  /* length for long strings */                              //长字符串的长度
    struct TString *hnext;  /* linked list for hash table */                   //短字符串
  } u;
  char *contents;  /* pointer to content in long strings */                    //指向具体字符串内容的指针
  lua_Alloc falloc;  /* deallocation function for external strings */          //
  void *ud;  /* user data for external strings */                             //外部参数
} TString;
```

- luaS_newlstr

```
/*
** new string (with explicit length)
*/
TString *luaS_newlstr (lua_State *L, const char *str, size_t l) {
  if (l <= LUAI_MAXSHORTLEN)  /* short string? */    //小于40属于short string会放在global_State的stringtable中
    return internshrstr(L, str, l);
  else {                                             //大于40的每次都会创建新对象
    TString *ts;
    if (l_unlikely(l * sizeof(char) >= (MAX_SIZE - sizeof(TString))))
      luaM_toobig(L);
    //创建TString
    ts = luaS_createlngstrobj(L, l);
    //赋值
    memcpy(getlngstr(ts), str, l * sizeof(char));
    return ts;
  }
}
```

PS:过长的字符串（长度大于40）每次都会创建一个新对象，大概是是为了性能考虑，如果全放在 global_State 中的strt 中(strt的数据类型为stringtable)，长度过长时性能较差（计算hash 值时会遍历整个字符串）。stringtable缩小扩容都是2倍。

- internshrstr

```c
/*
** Checks whether short string exists and reuses it or creates a new one.
*/
static TString *internshrstr (lua_State *L, const char *str, size_t l) {
  TString *ts;
  global_State *g = G(L);
  stringtable *tb = &g->strt;
  unsigned int h = luaS_hash(str, l, g->seed);
  TString **list = &tb->hash[lmod(h, tb->size)];
  lua_assert(str != NULL);  /* otherwise 'memcmp'/'memcpy' are undefined */
  for (ts = *list; ts != NULL; ts = ts->u.hnext) {
    if (l == cast_uint(ts->shrlen) &&
        (memcmp(str, getshrstr(ts), l * sizeof(char)) == 0)) {
      /* found! */
      if (isdead(g, ts))  /* dead (but not collected yet)? */
        changewhite(ts);  /* resurrect it */
      return ts;
    }
  }
  /* else must create a new string */
  if (tb->nuse >= tb->size) {  /* need to grow string table? */
    growstrtab(L, tb);
    list = &tb->hash[lmod(h, tb->size)];  /* rehash with new size */
  }
  ts = createstrobj(L, sizestrshr(l), LUA_VSHRSTR, h);
  ts->shrlen = cast(ls_byte, l);
  getshrstr(ts)[l] = '\0';  /* ending 0 */
  memcpy(getshrstr(ts), str, l * sizeof(char));
  ts->u.hnext = *list;
  *list = ts;
  tb->nuse++;
  return ts;
}
```

- stringtable

```c
typedef struct stringtable {
  TString **hash;  /* array of buckets (linked lists of strings) */    //二维数组
  int nuse;  /* number of elements */                                  //元素个数
  int size;  /* number of buckets */                                   //桶的大小
} stringtable;
```

2、Table

- Table

```c
typedef struct Table {
  CommonHeader;
  lu_byte flags;  /* 1<<p means tagmethod(p) is not present */  //原表标记
  lu_byte lsizenode;  /* log2 of size of 'node' array */        //hash表大小
  unsigned int alimit;  /* "limit" of 'array' array */          //数组大小
  Value *array;  /* array part */                               //数组
  Node *node;                                                   //元素列表
  struct Table *metatable;                                      //原表
  GCObject *gclist;                                             //gc相关，指向所处gc列表中的位置
} Table;
```

- table相关操作指令：

- OP_NEWTABLE：

```c
vmcase(OP_NEWTABLE) {
  StkId ra = RA(i);
  unsigned b = cast_uint(GETARG_vB(i));  /* log2(hash size) + 1 */
  unsigned c = cast_uint(GETARG_vC(i));  /* array size */
  Table *t;
  if (b > 0)
    b = 1u << (b - 1);  /* hash size is 2^(b - 1) */
  if (TESTARG_k(i)) {  /* non-zero extra argument? */
    lua_assert(GETARG_Ax(*pc) != 0);
    /* add it to array size */
    c += cast_uint(GETARG_Ax(*pc)) * (MAXARG_vC + 1);
  }
  pc++;  /* skip extra argument */
  L->top.p = ra + 1;  /* correct top in case of emergency GC */
  t = luaH_new(L);  /* memory allocation */
  sethvalue2s(L, ra, t);
  if (b != 0 || c != 0)
    luaH_resize(L, t, c, b);  /* idem *///设置大小
  checkGC(L, ra + 1);
  vmbreak;
}
```

- OP_SETLIST：

```c
//设置table数组部分元素
vmcase(OP_SETLIST) {
  StkId ra = RA(i);
  unsigned n = cast_uint(GETARG_vB(i));
  unsigned int last = cast_uint(GETARG_vC(i));
  Table *h = hvalue(s2v(ra));
  if (n == 0)
    n = cast_uint(L->top.p - ra) - 1;  /* get up to the top */
  else
    L->top.p = ci->top.p;  /* correct top in case of emergency GC */
  last += n;
  if (TESTARG_k(i)) {
    last += cast_uint(GETARG_Ax(*pc)) * (MAXARG_vC + 1);
    pc++;
  }
  /* when 'n' is known, table should have proper size */
  if (last > luaH_realasize(h)) {  /* needs more space? */
    /* fixed-size sets should have space preallocated */
    lua_assert(GETARG_vB(i) == 0);
    luaH_resizearray(L, h, last);  /* preallocate it at once */
  }
  for (; n > 0; n--) {
    TValue *val = s2v(ra + n);
    obj2arr(h, last - 1, val);
    last--;
    luaC_barrierback(L, obj2gco(h), val);
  }
  vmbreak;
}
```

○ OP_SETI：

```
//设置key为int类型的元素，可能放在数组部分也可能放到hash部分
//具体逻辑在luaV_fastseti
vmcase(OP_SETI) {
  StkId ra = RA(i);
  int hres;
  int b = GETARG_B(i);
  TValue *rc = RKC(i);
  luaV_fastseti(s2v(ra), b, rc, hres);
  if (hres == HOK)
    luaV_finishfastset(L, s2v(ra), rc);
  else {
    TValue key;
    setivalue(&key, b);
    Protect(luaV_finishset(L, s2v(ra), &key, rc, hres));
  }
  vmbreak;
}
```

○ OP_SETFIELD：

```
//设置key为short string类型的元素
vmcase(OP_SETFIELD) {
  StkId ra = RA(i);
  int hres;
  TValue *rb = KB(i);
  TValue *rc = RKC(i);
  TString *key = tsvalue(rb);  /* key must be a short string */
  char* content = key->contents;
  luaV_fastset(s2v(ra), key, rc, hres, luaH_psetshortstr);
  if (hres == HOK)
    luaV_finishfastset(L, s2v(ra), rc);
  else
    Protect(luaV_finishset(L, s2v(ra), rb, rc, hres));
  vmbreak;
}
```

○ OP_SETTABLE：

```
//设置单个元素
vmcase(OP_SETTABLE) {
  StkId ra = RA(i);
  int hres;
  TValue *rb = vRB(i);  /* key (table is in 'ra') */
  TValue *rc = RKC(i);  /* value */
  //判断key是否为int类型
  if (ttisinteger(rb)) {  /* fast track for integers? */
    luaV_fastseti(s2v(ra), ivalue(rb), rc, hres);
  }
  else {
    //非int类型，hres可能在数组部分也可能在hash部分
    luaV_fastset(s2v(ra), rb, rc, hres, luaH_pset);
  }
  if (hres == HOK)
    luaV_finishfastset(L, s2v(ra), rc);
  else
    Protect(luaV_finishset(L, s2v(ra), rb, rc, hres));
  vmbreak;
}
```

○ local tbl = {1,["test1"] = 4,2,["test2"] = 5,3,["test3"] = 6};该代码的指令调用：首先调用OP_NEWTABLE，并且b(hash size)、c(array size)不为0，再调用OP_SETFIELD，一个个设置hash部分数据以及OP_SETLIST一次性设置array部分数据。

local tbl = {}; tbl[1] = 1; tbl["test1"] = 4; tbl[2] = 2; 该代码的指令调用：首先

调用OP_NEWTABLE，并且b(hash size)、c(array size)为0，再按顺序调用OP_SETI或者OP_SETFIELD，赋值过程中会调整table的数组和hash大小。
OP_SETTABLE在5.4.7貌似没用了。被拆分为OP_SETI和OP_SETFIELD。

- luaV_fastseti（OP_SETI查找位置）：

```c
#define luaV_fastseti(t,k,val,hres) \
if (!ttistable(t)) hres = HNOTABLE; \
else { luaH_fastseti(hvalue(t), k, val, hres); }

#define luaH_fastseti(t,k,val,hres) \
{ Table *h = t; lua_Unsigned u = l_castS2U(k) - 1u; \
  //未超过数组大小，此时该下标为空则直接赋值
  //否则则替换
  if ((u < h->alimit)) { \
  lu_byte *tag = getArrTag(h, u); \
  if (tagisempty(*tag)) hres = ~cast_int(u); \
    else { fval2arr(h, u, tag, val); hres = HOK; }} \
  //超过数组大小，则会放到hash表，对hash表长度取模
  else { hres = luaH_psetint(h, k, val); }}
```

- luaV_finishset，如果luaV_fastseti和luaV_fastset没有找到位置，则调用luaV_finishset：

```c
void luaV_finishset (lua_State *L, const TValue *t, TValue *key, TValue *val, int hres) {
  int loop;  /* counter to avoid infinite loops */
  for (loop = 0; loop < MAXTAGLOOP; loop++) {
    const TValue *tm;  /* '__newindex' metamethod */
    if (hres != HNOTABLE) {  /* is 't' a table? */
      Table *h = hvalue(t);  /* save 't' table */
      tm = fasttm(L, h->metatable, TM_NEWINDEX);  /* get metamethod */
      //没有newindex的元方法
      if (tm == NULL) {  /* no metamethod? */
        luaH_finishset(L, h, key, val, hres);  /* set new value */
        invalidateTMcache(h);
        luaC_barrierback(L, obj2gco(h), val);
        return;
      }
      /* else will try the metamethod */
    }
    else {  /* not a table; check metamethod */
      tm = luaT_gettmbyobj(L, t, TM_NEWINDEX);
      if (l_unlikely(notm(tm)))
        luaG_typeerror(L, t, "index");
    }
    /* try the metamethod */
    //元方法是个函数则调用对应的函数
    if (ttisfunction(tm)) {
      luaT_callTM(L, tm, t, key, val);
      return;
    }
```

```
    //元方法不是函数则把元方法当作一个table继续
    t = tm;  /* else repeat assignment over 'tm' */
    luaV_fastset(t, key, val, hres, luaH_pset);
    if (hres == HOK)
      return;  /* done */
    /* else 'return luaV_finishset(L, t, key, val, slot)' (loop) */
  }
  luaG_runerror(L, "'__newindex' chain too long; possible loop");
}

void luaH_finishset (lua_State *L, Table *t, const TValue *key, TValue
*value, int hres) {
  lua_assert(hres != HOK);
  if (hres == HNOTFOUND) {
    luaH_newkey(L, t, key, value);
  }
  else if (hres > 0) {  /* regular Node? */
    setobj2t(L, gval(gnode(t, hres - HFIRSTNODE)), value);
  }
  else {  /* array entry */
    hres = ~hres;  /* real index */
    obj2arr(t, hres, value);
  }
}
```

- luaH_newkey：

```
//如果key是int类型，且在数组大小限制内，则在这之前赋值已经完成，到这一步则是因
为
//key为非int类型或者key为int类型但超过数组限制从而被分配到hash部分。
static void luaH_newkey (lua_State *L, Table *t, const TValue
*key,TValue *value)
{
  Node *mp;
  TValue aux;
  if (l_unlikely(ttisnil(key)))
    luaG_runerror(L, "table index is nil");
  else if (ttisfloat(key))
  {
    //key为浮点数，首先尝试转成int类型
    lua_Number f = fltvalue(key);
    lua_Integer k;
    if (luaV_flttointeger(f, &k, F2Ieq)) {  /* does key fit in an
integer? */
      setivalue(&aux, k);
      key = &aux;  /* insert it as an integer */
    }
    else if (l_unlikely(luai_numisnan(f)))
      luaG_runerror(L, "table index is NaN");
  }
  if (ttisnil(value))
    return;  /* do not insert nil values */
```

```
//获取key对应的node
mp = mainpositionTV(t, key);
if (!isempty(gval(mp)) || isdummy(t)) {  /* main position is taken?
*/
  Node *othern;
  Node *f = getfreepos(t);  /* get a free place */
  if (f == NULL) {  /* cannot find a free place? */
    rehash(L, t, key);  /* grow table */
    /* whatever called 'newkey' takes care of TM cache */
    luaH_set(L, t, key, value);  /* insert key into grown table */
    return;
  }
  lua_assert(!isdummy(t));
  //获取当前位置的node的key本该所在的位置
  othern = mainpositionfromnode(t, mp);
  //如果不相等那就是其他key之前就已经发生过碰撞被分配到这里
  if (othern != mp) {  /* is colliding node out of its main position?
*/
    /* yes; move colliding node into free position */
    //将原来的挪到空闲位置,并将传入的key放入所对应的node里面
    while (othern + gnext(othern) != mp)  /* find previous */
      othern += gnext(othern);
    gnext(othern) = cast_int(f - othern);  /* rechain to point to 'f'
*/
    *f = *mp;  /* copy colliding node into free pos. (mp->next also
goes) */
    if (gnext(mp) != 0) {
      gnext(f) += cast_int(mp - f);  /* correct 'next' */
      gnext(mp) = 0;  /* now 'mp' is free */
    }
    setempty(gval(mp));
  }
  else {  /* colliding node is in its own main position */
    /* new node will go into free position */
    //赋值到找到的空闲位置并且将空闲位置连接起来
    if (gnext(mp) != 0)
      gnext(f) = cast_int((mp + gnext(mp)) - f);  /* chain new
position */
    else lua_assert(gnext(f) == 0);
    gnext(mp) = cast_int(f - mp);
    mp = f;
  }
}
//没有发生冲突且table的lsizenode不为0,则找到对应位置直接赋值
setnodekey(L, mp, key);
luaC_barrierback(L, obj2gco(t), key);
lua_assert(isempty(gval(mp)));
setobj2t(L, gval(mp), value);
}
```

- rehash：

```c
static void rehash (lua_State *L, Table *t, const TValue *ek)
{
  unsigned int asize;  /* optimal size for array part */
  unsigned int na;  /* number of keys in the array part */
  //nums[i]记录的值是key的大小在2^(i - 1)到2^i的数量
  unsigned int nums[MAXABITS + 1];
  int i;
  unsigned totaluse;
  for (i = 0; i <= MAXABITS; i++) nums[i] = 0;  /* reset counts */
  setlimittosize(t);
  //计算数组部分数据分布
  na = numusearray(t, nums);  /* count keys in array part */
  totaluse = na;  /* all those keys are integer keys */
  //计算hash部分数据分布
  totaluse += numusehash(t, nums, &na);  /* count keys in hash part */
  /* count extra key */
  if (ttisinteger(ek))
    na += countint(ivalue(ek), nums);
  totaluse++;
  /* compute new size for array part */
  //计算新的数组部分大小
  asize = computesizes(nums, &na);
  /* resize the table to new computed sizes */
  //重新分配数组以及hash表的大小
  luaH_resize(L, t, asize, totaluse - na);
}

//计算数组部分大小，规则是找到最大且数量超过一半的
static unsigned computesizes (unsigned nums[], unsigned *pna)
{
  int i;
  unsigned int twotoi;  /* 2^i (candidate for optimal size) */
  unsigned int a = 0;  /* number of elements smaller than 2^i */
  unsigned int na = 0;  /* number of elements to go to array part */
  unsigned int optimal = 0;  /* optimal size for array part */
  /* loop while keys can fill more than half of total size */
  for (i = 0, twotoi = 1;
       twotoi > 0 && *pna > twotoi / 2;
       i++, twotoi *= 2) {
    a += nums[i];
    if (a > twotoi/2) {  /* more than half elements present? */
      optimal = twotoi;  /* optimal size (till now) */
      na = a;  /* all elements up to 'optimal' will go to array part */
    }
  }
  lua_assert((optimal == 0 || optimal / 2 < na) && na <= optimal);
  *pna = na;
  return optimal;
}
```

- 因此定义一个table时最好是定义即初始化，否则一个个添加元素会导致多次rehash。或者用 table.create(数组大小，hash大小)api来创建table。table.create如下所示：

```
static int tcreate (lua_State *L)
{
  lua_Unsigned sizeseq = (lua_Unsigned)luaL_checkinteger(L, 1);
  lua_Unsigned sizerest = (lua_Unsigned)luaL_optinteger(L, 2, 0);
  luaL_argcheck(L, sizeseq <= UINT_MAX, 1, "out of range");
  luaL_argcheck(L, sizerest <= UINT_MAX, 2, "out of range");
  lua_createtable(L, (unsigned)sizeseq, (unsigned)sizerest);
  return 1;
}

LUA_API void lua_createtable (lua_State *L, unsigned narray, unsigned nrec)
{
  Table *t;
  lua_lock(L);
  t = luaH_new(L);
  sethvalue2s(L, L->top.p, t);
  api_incr_top(L);
  if (narray > 0 || nrec > 0)
    luaH_resize(L, t, narray, nrec);
  luaC_checkGC(L);
  lua_unlock(L);
}
```

- table其他相关API：
  - ipairs和pairs：
    - ipairs源码如下所示：

```
static int luaB_ipairs (lua_State *L)
{
  luaL_checkany(L, 1);
  lua_pushcfunction(L, ipairsaux);  /* iteration function */
  lua_pushvalue(L, 1);  /* state */
  lua_pushinteger(L, 0);  /* initial value */
  return 3;
}

static int ipairsaux (lua_State *L)
{
  lua_Integer i = luaL_checkinteger(L, 2);
  //累加index
  i = luaL_intop(+, i, 1);
  lua_pushinteger(L, i);
  return (lua_geti(L, 1, i) == LUA_TNIL) ? 1 : 2;
}

LUA_API int lua_geti (lua_State *L, int idx, lua_Integer n)
{
  TValue *t;
  lu_byte tag;
  lua_lock(L);
```

```
    t = index2value(L, idx);
    //查找key为int类型的元素·这一步需要说明的是·该key不一定会在数组中。
hash表也会找·只要key满足条件。
    luaV_fastgeti(t, n, s2v(L->top.p), tag);
    //当原表中该key为空时·会调用luaV_finishget·该函数会调用元表的index
元方法·
    //如果元表的index元方法是个表则重复该操作·如果是个函数则调用该函数
    if (tagisempty(tag)) {
      TValue key;
      setivalue(&key, n);
      tag = luaV_finishget(L, t, &key, L->top.p, tag);
    }
    api_incr_top(L);
    lua_unlock(L);
    return novariant(tag);
}
```

ipairs遍历table时是从下标1开始查找·并且原表没有会去元表中查找。当value为nil时退出。

- pairs源码如下所示：

```
int luaH_next (lua_State *L, Table *t, StkId key)
{
  unsigned int asize = luaH_realasize(t);
  unsigned int i = findindex(L, t, s2v(key), asize);   /* find
original key */
  //遍历数组部分
  for (; i < asize; i++) {   /* try first array part */
    lu_byte tag = *getArrTag(t, i);
    if (!tagisempty(tag)) {   /* a non-empty entry? */
      setivalue(s2v(key), cast_int(i) + 1);
      farr2val(t, i, tag, s2v(key + 1));
      return 1;
    }
  }
  for (i -= asize; i < sizenode(t); i++) {   /* hash part */
    //#define gnode(t,i)     (&(t)->node[i])
    //遍历table的hash部分,gnode是直接将i当成下标·而不是key
    if (!isempty(gval(gnode(t, i)))) {   /* a non-empty entry? */
      Node *n = gnode(t, i);
      getnodekey(L, s2v(key), n);
      setobj2s(L, key + 1, gval(n));
      return 1;
    }
  }
  return 0;   /* no more elements */
}
```

pairs会遍历数组和hash。

- 几个特殊的table：

- registry表，key为LUA_REGISTRYINDEX，返回的是global_State的l_registry字段。
- global表，key为LUA_RIDX_GLOBALS（2），保存在l_registry表，字面意思全局变量会放在这个表里。
- loaded表，key为LUA_LOADED_TABLE（loaded），保存在package表(保存在l_registry表，key为package)，调用require加载解析过的lua文件或代码会保存在这个表里。调用load加载代码不会保存在该表中。require和load都会调用lua_load来解析代码。

```c
LUA_API int lua_load (lua_State *L, lua_Reader reader, void *data,
const char *chunkname, const char *mode)
{
  ZIO z;
  int status;
  lua_lock(L);
  if (!chunkname) chunkname = "?";
  luaZ_init(L, &z, reader, data);
  status = luaD_protectedparser(L, &z, chunkname, mode);
  if (status == LUA_OK) {  /* no errors? */
    LClosure *f = clLvalue(s2v(L->top.p - 1));  /* get new function */
    //load什么样的代码upvalue size会小于1？
    //require("return 1")这样的代码，upvalue size都是1
    if (f->nupvalues >= 1) {  /* does it have an upvalue? */
      /* get global table from registry */
      TValue gt;
      getGlobalTable(L, &gt);
      /* set global table as 1st upvalue of 'f' (may be LUA_ENV) */
      setobj(L, f->upvals[0]->v.p, &gt);
      luaC_barrier(L, f->upvals[0], &gt);
    }
  }
  lua_unlock(L);
  return status;
}
```

从上面代码可以看出，会将解析生成的LClosure的第一个upvalue指向global表，而当定义非local变量的时候，会调用OP_SETTABUP，给第一个upvalue赋值，此时第一个upvalue指向的是global表。这也就是说全局变量会放在global表。

3、CClosure和LClosure

```c
#define ClosureHeader \
CommonHeader; lu_byte nupvalues; GCObject *gclist

typedef struct CClosure {
  ClosureHeader;
  lua_CFunction f;      //函数指针
  TValue upvalue[1];  /* list of upvalues */
} CClosure;

typedef struct LClosure {
```

```
  ClosureHeader;      //nupvalues upvalue的数量、gclist gc相关
  struct Proto *p;
  UpVal *upvals[1];  /* list of upvalues */
} LClosure;
```

UpVal结构体的定义如下：

```
typedef struct UpVal {
  CommonHeader;
  union {
    TValue *p;  /* points to stack or to its own value */
    ptrdiff_t offset;  /* used while the stack is being reallocated */
  } v;
  union {
    struct {  /* (when open) */
      struct UpVal *next;  /* linked list */
      struct UpVal **previous;
    } open;
    TValue value;  /* the value (when closed) */
  } u;
} UpVal;
```

LClosure的upvalue分为open和close两种状态，当v.p不是指向u.value的时候就是open，当v.p指向u.value就是
close的。下面通过一个实例来解释。

```
function test()
  local a = 1
  return function()
      a = a + 1
  end
end

local testfunc = test()
testfunc()
testfunc()
```

当调用函数test生成一个LClosure时（pushclosure），此时a的作用域还未结束，此时这个upvalue就是open
的，v.p指向的是a在lua栈上的地址，当函数test执行结束时，a的作用域结束，lua栈回收，此时upvalue会变成
close（luaF_closeupval），会将原来的值赋值给u.value，并且v.p也会指向u.value。当upvalue是open的时候，
会记录在lua_State的openupval字段。当变成close的时候，会从openupvalue双向列表里删除。

B、协程

1、创建协程luaB_cocreate

```c
static int luaB_cocreate (lua_State *L) {
  lua_State *NL;
  //此时栈顶必须是一个函数。如果执行local co = coroutine.create(counter),
  //首先会执行OP_CLOSURE,创建一个LClosure对象放在栈顶
  luaL_checktype(L, 1, LUA_TFUNCTION);
  //创建一个新的lua_State对象放在栈顶
  NL = lua_newthread(L);
  //将LClosure对象再次压入栈顶
  lua_pushvalue(L, 1);  /* move function to top */
  //将栈顶的1个数据(也就是LClosure对象)复制到NL的栈顶,并且L的栈顶收缩
  lua_xmove(L, NL, 1);  /* move function from L to NL */
  return 1;
}
```

2、唤起协程luaB_coresume

```c
static int luaB_coresume (lua_State *L) {
  //此时需要切换的协程处于栈顶
  lua_State *co = getco(L);
  int r;
  //lua_gettop(L) - 1的作用是获取参数个数
  r = auxresume(L, co, lua_gettop(L) - 1);
  if (l_unlikely(r < 0)) {
    lua_pushboolean(L, 0);
    lua_insert(L, -2);
    return 2;  /* return false + error message */
  }
  else {
    lua_pushboolean(L, 1);
    lua_insert(L, -(r + 1));
    return r + 1;  /* return true + 'resume' returns */
  }
}

static int auxresume (lua_State *L, lua_State *co, int narg) {
  int status, nres;
  if (l_unlikely(!lua_checkstack(co, narg))) {
    lua_pushliteral(L, "too many arguments to resume");
    return -1;  /* error flag */
  }
  //将参数复制到协程co
  lua_xmove(L, co, narg);
  //就不再进一步展开了。在这一步中会调用setjmp,将当前的执行环境(包括寄存器、堆栈指针等)
  //保存到协程co的errorJmp字段上,然后执行协程co的指令
  status = lua_resume(co, L, narg, &nres);
  if (l_likely(status == LUA_OK || status == LUA_YIELD)) {
    if (l_unlikely(!lua_checkstack(L, nres + 1))) {
      lua_pop(co, nres);  /* remove results anyway */
      lua_pushliteral(L, "too many results to resume");
```

```
      return -1;  /* error flag */
    }
    //将返回值复制到L的栈上
    lua_xmove(co, L, nres);  /* move yielded values */
    return nres;
  }
  else {
    lua_xmove(co, L, 1);  /* move error message */
    return -1;  /* error flag */
  }
}
```

3、挂起协程luaB_yield

```
static int luaB_yield (lua_State *L) {
  return lua_yield(L, lua_gettop(L));
}

LUA_API int lua_yieldk (lua_State *L, int nresults, lua_KContext ctx,
lua_KFunction k) {
  CallInfo *ci;
  luai_userstateyield(L, nresults);
  lua_lock(L);
  ci = L->ci;
  api_checkpop(L, nresults);
  if (l_unlikely(!yieldable(L))) {
    if (L != G(L)->mainthread)
      luaG_runerror(L, "attempt to yield across a C-call boundary");
    else
      luaG_runerror(L, "attempt to yield from outside a coroutine");
  }
  //此时的L是之前调用resume唤起的协程
  //将状态设为挂起，记录返回值个数
  L->status = LUA_YIELD;
  ci->u2.nyield = nresults;  /* save number of results */
  if (isLua(ci)) {  /* inside a hook? */
    lua_assert(!isLuacode(ci));
    api_check(L, nresults == 0, "hooks cannot yield values");
    api_check(L, k == NULL, "hooks cannot continue after yielding");
  }
  else {
    if ((ci->u.c.k = k) != NULL)  /* is there a continuation? */
      ci->u.c.ctx = ctx;  /* save context */
    //调用longjmp，跳转到之前resume保存的地方
    luaD_throw(L, LUA_YIELD);
  }
  lua_assert(ci->callstatus & CIST_HOOKED);  /* must be inside a hook */
  lua_unlock(L);
  return 0;  /* return to 'luaD_hook' */
}
```

C、GC

```
#define luaC_condGC(L, pre, pos) \
    { if (G(L)->GCdebt <= 0) { pre: luaC_step(L): pos;}: \
    | condchangemem(L, pre, pos): }
```

只有当GCdebt小于等于0时，才会触发GC，这个GCdebt的单位是对象的个数而不是实际的内存大小。当申请一个新的需要GC的对象时，该变量做-1操作。totalbytes字段才是保存当前lua虚拟机申请过的内存字节数。需要注意的是并不是每次new一个GC对象都会去check gc。

1、增量式GC

```c
static void incstep (lua_State *L, global_State *g) {
  //STEPSIZE默认值为250
  l_obj stepsize = applygcparam(g, STEPSIZE, 100);
  //work2do 为STEPSIZE的两倍
  l_obj work2do = applygcparam(g, STEPMUL, stepsize);
  int fast = 0;
  if (work2do == 0) {  /* special case: do a full collection */
    work2do = MAX_LOBJ;  /* do unlimited work */
    fast = 1;
  }
  do {  /* repeat until pause or enough work */
    l_obj work = singlestep(L, fast);  /* perform one single step */
    if (g->gckind == KGC_GENMINOR)  /* returned to minor collections? */
      return;  /* nothing else to be done here */
    work2do -= work;
  } while (work2do > 0 && g->gcstate != GCSpause);
  if (g->gcstate == GCSpause)
    setpause(g);  /* pause until next cycle */
  else
    luaE_setdebt(g, stepsize);
}
```

GCSpause

```c
//清理灰色链表并且标记根节点（单步）
static void restartcollection (global_State *g) {
  cleargraylists(g);
  g->marked = NFIXED;
  markobject(g, g->mainthread);
  markvalue(g, &g->l_registry);
  markmt(g);
  markbeingfnz(g);  /* mark any finalizing object left from previous cycle */
}
```

GCSpropagate

```
static void propagatemark (global_State *g) {
  GCObject *o = g->gray;
  //设置为黑色，这里要跟luaC_barrierback对应看，假如在GCSpropagate阶段，global表已经被
  扫描过了，global表被标记为黑色。
  //此时又定义一个全局变量，那么在luaC_barrierback里会将global表又塞回gray列表。
  nw2black(o);
  //从灰色链表里删除
  g->gray = *getgclist(o);  /* remove from 'gray' list */
  switch (o->tt) {
    case LUA_VTABLE: traversetable(g, gco2t(o)); break;
    case LUA_VUSERDATA: traverseudata(g, gco2u(o)); break;
    case LUA_VLCL: traverseLclosure(g, gco2lcl(o)); break;
    case LUA_VCCL: traverseCclosure(g, gco2ccl(o)); break;
    case LUA_VPROTO: traverseproto(g, gco2p(o)); break;
    case LUA_VTHREAD: traversethread(g, gco2th(o)); break;
    default: lua_assert(0);
  }
}
```

luaC_barrierback和luaC_barrier，关于这两个网上解释一大堆，但没有我特别信服的文章。在这里写下此时的思考，之后如果发现理解不对再改。

luaC_barrierback(L,父节点，子节点) 如果父节点是黑色并且子节点是白色，则将父节点改为灰色，放入 **grayagain**列表。**luaC_barrier(L,父节点，子节点)**，当**GC**步骤小于等于**GCSenteratomic**时，如果父节点是黑色并且子节点是白色，直接将子节点改为黑色。否则，将子节点设置为新的白色，等待下次**GC**。按我的理解，这两种其实可以互相替换，或者只保留一个。这两种的主要分别是作用的对象类型上，**table**的赋值用 **luaC_barrierback**，这是因为**table**赋值是经常性的操作，用**luaC_barrierback**放到**grayagain**列表，在之后一次性做标记。而**upvalue**的改变用**luaC_barrier**是因为**upvalue**的变动不是经常性的，这样能减少遍历的对象，提升性能。

GCSenteratomic

这个阶段是也是单步的，需要在这一步明确所有对象的颜色（此时如果main thread、register表等是白色则加入 gray表），并且在最后将global_State的currentwhite设置为新白色。

GCSswpallgc、GCSswpfinobj、GCSswptobefnz

```
case GCSswpallgc: {  /* sweep "regular" objects */
  sweepstep(L, g, GCSswpfinobj, &g->finobj, fast);
  work = GCSWEEPMAX;
  break;
}
case GCSswpfinobj: {  /* sweep objects with finalizers */
  sweepstep(L, g, GCSswptobefnz, &g->tobefnz, fast);
  work = GCSWEEPMAX;
  break;
}
case GCSswptobefnz: {  /* sweep objects to be finalized */
  sweepstep(L, g, GCSswpend, NULL, fast);
  work = GCSWEEPMAX;
```

```
      break;
    }
  }
```

这三个阶段做的是相同的工作，只是对应的列表不一样而已（GCSswpallgc阶段遍历的是global_State的allgc列表、GCSswpfinobj阶段遍历的是global_State的finobj列表、GCSswptobefnz遍历的是global_State的tobefnz列表），各自检查对应的列表，如果需要回收就回收，不需要则改变对象marked字段，设置为新的白色。每次最多检查GCSWEEPMAX（20）个对象。 如果对象的类型是table或者userdata，当设置元表并且有"__gc"元方法时，会将该对象从allgc列表中移除，并放入finobj列表。 在GCSenteratomic阶段，会调用separatetobefnz函数，这个函数会将finobj列表里白色的移动到tobefnz列表。所以在GCSswpfinobj阶段处理finobj列表时，finobj列表里的元素全是不需要回收的，所以这阶段的作用是将finobj列表里的元素的颜色改成当前白色。

GCSswpend

在非紧急状态下，如果常驻的string table太空闲，则会回收global_State的strt字段。 如果string table的size太大或者申请内存时第一次失败后或者lua脚本调用collectgarbage("collect")，会设为紧急状态，并做一次完整步骤的GC，并再次申请内存。

```
static void checkSizes (lua_State *L, global_State *g) {
  if (!g->gcemergency) {
    if (g->strt.nuse < g->strt.size / 4)  /* string table too big? */
      luaS_resize(L, g->strt.size / 2);
  }
}

//首次内存申请失败，则会执行这个函数
static void *tryagain (lua_State *L, void *block, size_t osize, size_t nsize) {
  global_State *g = G(L);
  if (cantryagain(g)) {
    luaC_fullgc(L, 1);  /* try to free some memory... */
    return callfrealloc(g, block, osize, nsize);  /* try again */
  }
  else return NULL;  /* cannot run an emergency collection */
}

static void growstrtab (lua_State *L, stringtable *tb) {
  //global的strt太大
  if (l_unlikely(tb->nuse == INT_MAX)) {  /* too many strings? */
    luaC_fullgc(L, 1);  /* try to free some... */
    if (tb->nuse == INT_MAX)  /* still too many? */
      luaM_error(L);  /* cannot even create a message... */
  }
  if (tb->size <= MAXSTRTB / 2)  /* can grow string table? */
    luaS_resize(L, tb->size * 2);
}

void luaC_fullgc (lua_State *L, int isemergency) {
  global_State *g = G(L);
  lua_assert(!g->gcemergency);
  //设为紧急状态
  g->gcemergency = cast_byte(isemergency);  /* set flag */
```

```
      //阻塞执行一次完整步骤的GC，遍历所有的对象
      switch (g->gckind) {
        case KGC_GENMINOR: fullgen(L, g); break;
        case KGC_INC: fullinc(L, g); break;
        case KGC_GENMAJOR:
          g->gckind = KGC_INC;
          fullinc(L, g);
          g->gckind = KGC_GENMAJOR;
          break;
      }
      g->gcemergency = 0;
    }

    //执行完整的GC，遍历所有对象做标记或回收，最后将gcstate设为GCSpause阶段。
    static void fullinc (lua_State *L, global_State *g) {
      if (keepinvariant(g))  /* black objects? */
        entersweep(L); /* sweep everything to turn them back to white */
      /* finish any pending sweep phase to start a new cycle */
      luaC_runtilstate(L, GCSpause, 1);
      luaC_runtilstate(L, GCScallfin, 1);  /* run up to finalizers */
      /* 'marked' must be correct after a full GC cycle */
      lua_assert(g->marked == gettotalobjs(g));
      luaC_runtilstate(L, GCSpause, 1);  /* finish collection */
      setpause(g);
    }
```

GCScallfin

每次从tobefnz列表中取出一个对象，并调用对象的"__gc"方法。

2、分代式GC

- G_NEW 0 //新创建的对象
- G_SURVIVAL 1 //G_NEW对象存活一次GC变成G_SURVIVAL
- G_OLD0 2 //luaC_barrier时对象变成G_OLD0
- G_OLD1 3 //G_SURVIVAL和G_OLD0状态的对象存活一次GC变成G_OLD
- G_OLD 4 //G_OLD1或者G_TOUCHED2对象存活过一次GC变成G_OLD
- G_TOUCHED1 5 //luaC_barrierback时对象变成G_TOUCHED1
- G_TOUCHED2 6 //G_TOUCHED1对象存活一次GC变成G_TOUCHED2

```
    tbl = {1,2,3}
```

上述代码minor gc步骤介绍：
1、新建tbl对象时，tbl的mark字段为(白色|G_NEW)，因为tbl是全局变量，那么会放在global表，会调用
luaC_barrierback，如果global表此时是黑色的，那global表会变成（灰色|G_TOUCHED1）并且放入grayagain列
表。
2、第一次执行minor gc：在youngcollection函数中调用atomic(L)时，当清空grayagain列表时，（此时假设
grayagain只有一个global表一个元素），首先将global表改成（黑色|G_TOUCHED1），由于此时是

G_TOUCHED1，那么又会改成（灰色|G_TOUCHED1）重新加到grayagain列表中。而属于global表的tbl对象，由于也是一个table，在处理global表时会把tbl加入gray列表，并且最终会被设置为（黑色|G_NEW）并从gray列表里删除。

调用sweepgen时，会将tbl对象设置为（白色|G_SURVIVAL）。G_NEW到G_SURVIVAL会重新设置为白色。

对于global表还在grayagain列表，执行finishgencycle时，会将global表设置为（黑色|G_TOUCHED2）并且保留在grayagain列表。

3、第二次执行minor gc：在youngcollection函数中调用atomic(L)时，当清空grayagain列表时，（此时假设grayagain只有一个global表一个元素），由于此时是G_TOUCHED2，会将global表改成（黑色|G_OLD）。而属于global表的tbl对象改成（黑色|G_SURVIVAL）。调用sweepgen时，会将tbl对象设置为（黑色|G_OLD1）。4、第三次执行minor gc：调用sweepgen时，会将tbl对象设置为（黑色|G_OLD）。

```lua
local function create_closure()
    local upvalue = {1,2,3}
    return function(new_value)
        upvalue = new_value
    end
end
local closure = create_closure()
local new_table = {4,5,6}
closure(new_table)
```

操作码为OP_SETUPVAL 上述代码minor gc步骤介绍：

1、首先会调用luaC_barrier，由于new_object数据类型为table，new_object会变为（灰色|G_OLD0），并且加入gray列表。

2、第一次执行minor gc：调用atomic时，该元素会被设置为黑色|G_OLD0，调用sweepgen时，该元素会被设置为黑色|G_OLD1。

3、第二次执行minor gc：调用sweepgen时，该元素会被设置为黑色|G_OLD。

Minor Collection

```c
static void youngcollection (lua_State *L, global_State *g) {
  l_obj addedold1 = 0;
  l_obj marked = g->marked;  /* preserve 'g->marked' */
  GCObject **psurvival;  /* to point to first non-dead survival object */
  GCObject *dummy;  /* dummy out parameter to 'sweepgen' */
  lua_assert(g->gcstate == GCSpropagate);
  if (g->firstold1) {  /* are there regular OLD1 objects? */
    markold(g, g->firstold1, g->reallyold);  /* mark them */
    g->firstold1 = NULL;  /* no more OLD1 objects (for now) */
  }
  markold(g, g->finobj, g->finobjrold);
  markold(g, g->tobefnz, NULL);

  atomic(L);  /* will lose 'g->marked' */

  /* sweep nursery and get a pointer to its last live element */
  g->gcstate = GCSswpallgc;
  psurvival = sweepgen(L, g, &g->allgc, g->survival, &g->firstold1, &addedold1);
```

```c
  /* sweep 'survival' */
  sweepgen(L, g, psurvival, g->old1, &g->firstold1, &addedold1);
  g->reallyold = g->old1;
  g->old1 = *psurvival;  /* 'survival' survivals are old now */
  g->survival = g->allgc;  /* all news are survivals */

  /* repeat for 'finobj' lists */
  dummy = NULL;  /* no 'firstold1' optimization for 'finobj' lists */
  psurvival = sweepgen(L, g, &g->finobj, g->finobjsur, &dummy, &addedold1);
  /* sweep 'survival' */
  sweepgen(L, g, psurvival, g->finobjold1, &dummy, &addedold1);
  g->finobjrold = g->finobjold1;
  g->finobjold1 = *psurvival;  /* 'survival' survivals are old now */
  g->finobjsur = g->finobj;  /* all news are survivals */

  sweepgen(L, g, &g->tobefnz, NULL, &dummy, &addedold1);

  /* keep total number of added old1 objects */
  g->marked = marked + addedold1;

  /* decide whether to shift to major mode */
  if (checkminormajor(g, addedold1)) {
    //切换到major gc
    minor2inc(L, g, KGC_GENMAJOR);  /* go to major mode */
    g->marked = 0;  /* avoid pause in first major cycle */
  }
  else
    finishgencycle(L, g);  /* still in minor mode; finish it */
}
```

- g->marked参数：
  如果是分代式GC的minor gc，该参数表示累计变为G_OLD1的元素个数。minor gc和major gc相互切换时会将该参数置为0。这个精度并不准确。
  否则该参数表示标记到的参数个数。
  分代式GC处于minor gc时的global_State的marked字段的精度并不准确是因为某个元素调用luaC_objbarrier时，marked字段会加1，并且该元素被设置为G_OLD0，而G_OLD0变为G_OLD1是，marked字段又会加1，一个元素变为G_OLD1，而marked字段被累加了两次。

- g->GCmajorminor参数：
  上一次minor gc累计变为G_OLD1的元素个数。

- checkminormajor(g, addedold1)
  1、如果本次变为G_OLD1的元素数量，比g->GCmajorminor的LUA_GCPMINORMUL(百分比，默认值为25)的一半还要多 2、或者g->marked，比g->GCmajorminor还要多。
  则会切换为major gc。

Major Collection

```c
void luaC_step (lua_State *L) {
  global_State *g = G(L);
```

```
        lua_assert(!g->gcemergency);
        if (!gcrunning(g))  /* not running? */
          luaE_setdebt(g, 2000);
        else {
          switch (g->gckind) {
            case KGC_INC:
            case KGC_GENMAJOR:
              incstep(L, g);
              break;
            case KGC_GENMINOR:
              youngcollection(L, g);
              setminordebt(g);
              break;
          }
        }
      }
```

- minor gc切换到major gc的时候执行minor2inc源码如下所示：

```
    static void minor2inc (lua_State *L, global_State *g, lu_byte kind) {
      //GCmajorminor设置为本次minor gc变为G_OLD1的元素累计个数
      g->GCmajorminor = g->marked;  /* number of live objects */
      g->gckind = kind;
      g->reallyold = g->old1 = g->survival = NULL;
      g->finobjrold = g->finobjold1 = g->finobjsur = NULL;
      //将gcstate设置为GCSswpallgc
      entersweep(L);  /* continue as an incremental cycle */
      /* set a debt equal to the step size */
      //设置debt，100的LUA_GCPSTEPSIZE（百分比，默认值为250%），即debt=250
      luaE_setdebt(g, applygcparam(g, STEPSIZE, 100));
    }
```

major gc跟增量式GC代码一样，只是major gc从GCSswpallgc开始，当执行完GCSenteratomic后，会调用checkmajorminor检查是否再次切换到minor gc，代码如下所示：

```
    ...
    case GCSenteratomic: {
      work = atomic(L);
      if (checkmajorminor(L, g))
        entersweep(L);
      break;
    }
    ...

    static int checkmajorminor (lua_State *L, global_State *g) {
      if (g->gckind == KGC_GENMAJOR) {  /* generational mode? */
        //当前元素总数
        l_obj numobjs = gettotalobjs(g);
        //相较于上次minor gc增加的元素个数
```

```
        l_obj addedobjs = numobjs - g->GCmajorminor;
        //新增元素的LUAI_MAJORMINOR（百分比，默认值为50%）
        l_obj limit = applygcparam(g, MAJORMINOR, addedobjs);
        //会被GC的元素个数
        l_obj tobecollected = numobjs - g->marked;
        if (tobecollected > limit) {
          //切换到minor gc
          //如果是白色则直接释放，否则直接设置为G_OLD。
          atomic2gen(L, g);  /* return to generational mode */
          setminordebt(g);
          return 0;  /* exit incremental collection */
        }
      }
      g->GCmajorminor = g->marked;  /* prepare for next collection */
      return 1;  /* stay doing incremental collections */
    }
```

3、lua脚本调用

在lua中调用collectgarbage("collect")，执行的是上面所记录的luaC_fullgc函数，会阻塞执行完所有步骤，直到gcstate再次处于GCSpause阶段。

D、热更

- 跟热更相关的表：
  loaded表，l_registry表的key为LUA_LOADED_TABLE（_LOADED）。
  searchers表，l_registry表的key为searchers。

- require相关伪代码如下所示：

```
static int ll_require (lua_State *L) {
  //获取传入的文件名
  const char *name = luaL_checkstring(L, 1);
  lua_settop(L, 1);  /* LOADED table will be at index 2 */
  //查找_LOADED表里是否已经加载过对应模块
  lua_getfield(L, LUA_REGISTRYINDEX, LUA_LOADED_TABLE);
  lua_getfield(L, 2, name);  /* LOADED[name] */
  if (lua_toboolean(L, -1))  /* is it there? */
    return 1;  /* package is already loaded */

  ...

  findloader(L, name);

  ...

  //执行findloader生成的对象
  lua_call(L, 2, 1);  /* run loader to load module */

  ...
```

```
    return 2;  /* return module result and loader data */
}

static void findloader (lua_State *L, const char *name) {
  ...
  //searchers表在createsearcherstable函数初始化，
  //searchers表保存的是几个函数指针，分别是searcher_preload、searcher_Lua、searcher_C、
searcher_Croot
  if (l_unlikely(lua_getfield(L, lua_upvalueindex(1), "searchers")
                != LUA_TTABLE))
    luaL_error(L, "'package.searchers' must be a table");

  //首先在preload表中查找
  //调用searcher_Lua，最终会执行lua_load加载解析lua文件，生成LClosure对象。成功则返回
  //searcher_C、searcher_Croot加载的是C库
  ...
}
```

- 因此lua脚本热更新只需要将对应的package.loaded["文件名"]=nil，然后再require("文件名")就可以了。
  但需要注意的是重新加载的文件中定义的变量的继承问题，这个是热更新的重点。
  一个简单的例子：
  A.lua的代码如下：

```
    local ATest = {1,2,3}
    return ATest
```

  B.lua的代码如下所示：

```
    BTest = require("A")
    BTest[0] = 4
    BTest[1] = 5
    BTest[2] = 6
```

  当A.lua重新require后，BTest的数据还是4、5、6。