SACC 2016 第八届中国系统架构师大会
SYSTEM ARCHITECT CONFERENCE CHINA 2016
架构创新之路

A travel through exploit mitigations in GNU toolchains

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#ls -l

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[00] whoami

> coder whole my life
> worked on SDCC/gputils, GCC/binutils, LLVM
> security engineer
  &
  member of hardenedlinux/h4rdenedzer0
> write a C89 compiler from scratch only for fun(2009-2012)

[01] GCC/ld/Glibc dynamic-linker internals

> 0100 GCC internals
> 0101 ld internals
> 0102 Glibc-dl internals

[0100] GCC internals/source directory overview

```
zet@fuck-GFW ~/dust/gcc/gcc-6.2.0 $ls -lF

ABOUT-NLS     /* gettext*/
boehm-gc/     /* java gc*/
compile*      /* script call gcc by user*/
config/       /* lots of m4 script*/
config.guess*
config-ml.in
config.rpath*
config.sub*
configure*
configure.ac
contrib/      /* download prerequest/generate man pages*/
depcomp*      /* call compiler generate dependency*/
fixincludes/  /* fix(macro) system header to work with gcc*/
gnattools/    /* Ada*/
gotools/      /* golang*/
include/      /* getopt.h, sha1.h, etc*/
INSTALL/      /* html install files*/
```

[0100] GCC internals/source directory overview

```
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install-sh*       /* called by make install*/
intl/             /* gettext*/
libada/
libatomic/        /* __sync/__atomic*/
libbacktrace/     /* output like gdb backtrace*/
libcc1/           /* gdb evalute code on current context*/
libcilkrts/       /* intel cilk runtime*/
libcpp/           /* C preprocessor*/
libdecnumber/     /* decimal float library*/
libffi/           /* part of java runtime*/
libgcc/           /* GCC runtime library: crt, vtv*/
libgfortran/
libgo/
libgomp/          /* OpenMP*/
libiberty/        /* vfork/md5*/
libitm/           /* transaction memory*/
libjava/
libmpx/           /* Intel Memory Protection Extensions*/
```
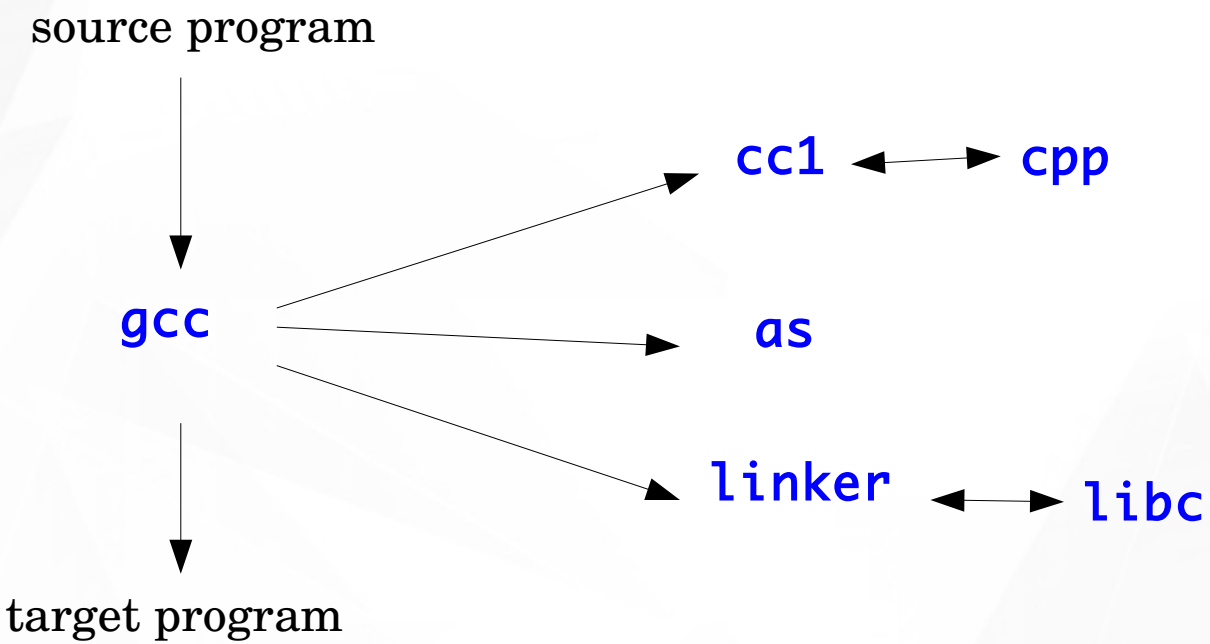

[0100] GCC internals/source directory overview

```
zet@fuck-GFW ~/dust/gcc/gcc-6.2.0 $ls -lF
libobjc/
liboffloadmic/   /* intel MIC runtime offload library*/
libquadmath/     /* quad-precious math operations*/
libsanitizer/    /* leak/use after free/overflow,etc*/
libssp/          /* stack smash protection*/
libstdc++-v3/    /* C++ runtime*/
libvtv/          /* after*/
lto-plugin/      /* link time optimization*/
zlib/            /* part of java runtime*/
gcc/             /* frontend, middleend, backend*/
```

[0100] GCC internals/overview of toolchains



[0100] GCC internals/driver

```
main  /* in file gcc-main.c*/
  driver::main  /* gcc.c*/
    decode_argv
    set_up_specs  /* for cc1/as/ld*/
    do_spec_on_infiles  /* for(n_infiles)*/
      lookup_compiler  /* find compiler from suffix*/
      do_spec
      do_spec_2
        do_spec_1
        execute
          pex_init  /* piped execute*/
          pex_run
            pex_run_in_environment
              obj->funcs->exec_child /* call cc1*/
    maybe_run_linker  /* collect2*/
```

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[0100] GCC internals/driver

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    do_spec_on_infiles  /* for(n_infiles)*/
      lookup_compiler  /* find compiler from suffix*/
      do_spec
      do_spec_2
        do_spec_1
        execute
          pex_init  /* piped execute*/
          pex_run
            pex_run_in_environment
              obj->funcs->exec_child /* call cc1*/
    maybe_run_linker  /* collect2*/
```

[0100] GCC internals/what does specs file do

```
zet@fuck-GFW ~/bin/gcc-6.2.0/bin $./g++ -### main.cc -fvtable-verify=std -o main verified_lib.so

Using built-in specs.
COLLECT_GCC=./g++
COLLECT_LTO_WRAPPER=/home/zet/bin/gcc-6.2.0/libexec/gcc/x86_64-pc-linux-gnu/6.2.0/lto-wrapper
Target: x86_64-pc-linux-gnu
Configured with: ../configure --disable-checking -enable-languages=c,c++ --enable-libstdcxx-threads -
enable-vtable-verify=yes --prefix=/home/zet/bin/gcc-6.2.0
Thread model: posix
gcc version 6.2.0 (GCC)
COLLECT_GCC_OPTIONS='-fvtable-verify=std' '-o' 'main' '-shared-libgcc' '-mtune=generic' '-march=x86-64'
 /home/zet/bin/gcc-6.2.0/libexec/gcc/x86_64-pc-linux-gnu/6.2.0/cc1plus -quiet -imultiarch x86_64-linux-gnu
-D_GNU_SOURCE main.cc -quiet -dumpbase main.cc "-mtune=generic" "-march=x86-64" -auxbase main
 "-fvtable-verify=std" -o /tmp/ccVN0GoS.s
COLLECT_GCC_OPTIONS='-fvtable-verify=std' '-o' 'main'
'-shared-libgcc' '-mtune=generic' '-march=x86-64'
 as --64 -o /tmp/ccUBFg31.o /tmp/ccVN0GoS.s
COMPILER_PATH=/home/zet/bin/gcc-6.2.0/libexec/gcc/x86_64-pc-linux-gnu/6.2.0/:/home/zet/bin/gcc-
6.2.0/libexec/gcc/x86_64-pc-linux-gnu/6.2.0/:/home/zet/bin/gcc-6.2.0/libexec/gcc/x86_64-pc-linux-
gnu/:/home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-linux-gnu/6.2.0/:/home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-
linux-gnu/
LIBRARY_PATH=/home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-linux-gnu/6.2.0/:/home/zet/bin/gcc-
6.2.0/lib/gcc/x86_64-pc-linux-gnu/6.2.0/../../../../lib64/:/lib/x86_64-linux-
gnu/:/lib/../lib64/:/usr/lib/x86_64-linux-gnu/:/home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-linux-
gnu/6.2.0/../../../:/lib/:/usr/lib/
COLLECT_GCC_OPTIONS='-fvtable-verify=std' '-o' 'main' '-shared-libgcc' '-mtune=generic' '-march=x86-64'
 /home/zet/bin/gcc-6.2.0/libexec/gcc/x86_64-pc-linux-gnu/6.2.0/collect2 -plugin /home/zet/bin/gcc-
6.2.0/libexec/gcc/x86_64-pc-linux-gnu/6.2.0/liblto_plugin.so "-plugin-opt=/home/zet/bin/gcc-
6.2.0/libexec/gcc/x86_64-pc-linux-gnu/6.2.0/lto-wrapper" "-plugin-opt=-fresolution=/tmp/cc9F8SHb.res" "-
plugin-opt=-pass-through=-lgcc_s" "-plugin-opt=-pass-through=-lgcc" "-plugin-opt=-pass-through=-lc" "-
plugin-opt=-pass-through=-lgcc_s" "-plugin-opt=-pass-through=-lgcc" --eh-frame-hdr -m elf_x86_64 -dynamic-
linker /lib64/ld-linux-x86-64.so.2 -o main /usr/lib/x86_64-linux-gnu/crt1.o /usr/lib/x86_64-linux-
gnu/crti.o /home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-linux-gnu/6.2.0/crtbegin.o /home/zet/bin/gcc-
6.2.0/lib/gcc/x86_64-pc-linux-gnu/6.2.0/vtv_start.o -L/home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-linux-
gnu/6.2.0 -L/home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-linux-gnu/6.2.0/../../../../lib64 -L/lib/x86_64-
linux-gnu -L/lib/../lib64 -L/usr/lib/x86_64-linux-gnu -L/home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-linux-
gnu/6.2.0/../../.. -lvtv -u_vtable_map_vars_start -u_vtable_map_vars_end /tmp/ccUBFg31.o verified_lib.so
"-lstdc++" -lm -lgcc_s -lgcc -lc -lgcc_s -lgcc /home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-linux-
gnu/6.2.0/vtv_end.o /home/zet/bin/gcc-6.2.0/lib/gcc/x86_64-pc-linux-gnu/6.2.0/crtend.o /usr/lib/x86_64-
linux-gnu/crtn.o
COLLECT_GCC_OPTIONS='-fvtable-verify=std' '-o' 'main' '-shared-libgcc' '-mtune=generic' '-march=x86-64'
```

[0100] GCC internals/gcc core

```
main /* file main.c */
  toplev::main /* file toplev.c */
    decode_options
    do_compile
      compile_file
        lang_hooks.parse_file == c_common_parse_file
        symtab->finalize_compilation_unit
        targetm.asm_out.file_end ==
                file_end_indicate_exec_stack  /* varasm.c*/
```

[0100] GCC internals/gcc core

```
main /* file main.c */
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        symtab->finalize_compilation_unit
        targetm.asm_out.file_end ==
                file_end_indicate_exec_stack  /* varasm.c*/
```

[0100] GCC internals/gcc core

```
main /* file main.c */
  toplev::main /* file toplev.c */
    decode_options
    do_compile
      compile_file
        lang_hooks.parse_file ==
                    c_common_parse_file /* back next*/
        symtab->finalize_compilation_unit  /* last*/
        targetm.asm_out.file_end ==
                  file_end_indicate_exec_stack  /* varasm.c*/
```

[0100] GCC internals/gcc core

```
main /* file main.c */
  toplev::main /* file toplev.c */
    decode_options
    do_compile
      compile_file
        lang_hooks.parse_file == c_common_parse_file
        symtab->finalize_compilation_unit
        targetm.asm_out.file_end ==
                file_end_indicate_exec_stack
                /* .note.GNU-stack in file varasm.c*/
```

[0100] GCC internals/gcc core

```
lang_hooks.parse_file == c_common_parse_file
 c_parse_file
  c_parser_translation_unit
   c_parser_external_declaration
    c_parser_declaration_or_fndef /* function*/
     c_parser_declspecs /* parse specifiers*/
     c_parser_compound_statement
     finish_function /* finish parsing */
      c_genericize  /* frontend tree to GENERIC*/
      cgraph_finalize_function  /* create cgraph_node*/
```

PS.
C/C++ convert directly from frontend tree(c-family/c-common.def) to GIMPLE.

[0100] GCC internals/gcc core

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lang_hooks.parse_file == c_common_parse_file
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PS.
C/C++ convert directly from frontend tree(c-family/c-common.def) to GIMPLE.

[0100] GCC internals/gcc core

```
symtab->finalize_compilation_unit
  analyze_functions  /* create GIMPLE*/
  cgraph_node::analyze
    gimplify_function_tree
      gimplify_body
        gimplify_stmt
          gimplify_expr
  compile  /* transforms & optimizations*/
    ipa_passes
      /* symbol visibility, etc*/
      execute_ipa_pass_list(passes->all_small_ipa_passes)
      /* devirtualization, etc*/
      execute_ipa_pass_list(passes->all_regular_ipa_passes)
    /* target involved*/
    execute_ipa_pass_list(all_late_ipa_passes)
    expand_all_functions
      node→expand
        execute_pass_list(all_passes)
```

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    expand_all_functions
      node→expand
        execute_pass_list(all_passes)
```

[0100] GCC internals/gcc core

```
execute_pass_list(all_passes)
  execute_pass_list_1
    execute_one_pass
      pass_expand::execute  /* pass named expand*/
        expand_gimple_basic_block
          expand_gimple_stmt
            expand_gimple_stmt_1
              expand_assignment
                expand_expr
                  expand_expr_real
                    expand_expr_real_1
              store_expr_with_bounds
                emit_move_insn
                  emit_move_insn_1
                    insn_gen_fn::operator()
                      gen_movsi
                        ix86_expand_move
                          emit_insn
```

[0100] GCC internals/gcc core

```
/* find all the passes*/
gcc-source/gcc/passes.def

/* find all the passes of special type*/
/* optimization pass type.*/
enum opt_pass_type
{
  GIMPLE_PASS,
  RTL_PASS,
  SIMPLE_IPA_PASS,
  IPA_PASS
};
```

[0101] binutils/ld internals

```
main /* ld/ldmain.c*/
  expandargv
  bfd_init
  lang_init
    output_section_statement_table_init
    /* input/output/assignment/gounp */
    stat_ptr = &statement_list;
  ldexp_init  /* for parse sdcript*/
  /* architecture specific init*/
  ldemul_before_parse == gldelf_i386_before_parse
  parse_args
  yyparse  /* next*/
  lang_final  /* add output_file_name to stat_ptr*/
  /* set PIE flag, entry point symbol to undefines*/
  ldemul_after_parse == gldelf_i386_after_parse
  lang_process  /* next*/
  ld_write  /* next*/
```

[0101] binutils/ld internals

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main /* ld/ldmain.c*/
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  lang_init
    output_section_statement_table_init
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  ldemul_after_parse == gldelf_i386_after_parse
  lang_process  /* next*/
  ld_write  /* next*/
```

[0101] binutils/ld internals

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main /* ld/ldmain.c*/
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  bfd_init
  lang_init
    output_section_statement_table_init
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  lang_final  /* add output_file_name to stat_ptr*/
  /* set PIE flag, entry point symbol to undefines*/
  ldemul_after_parse == gldelf_i386_after_parse
  lang_process  /* next*/
  ld_write  /* next*/
```

[0101] binutils/ld internals

The heart of ld : linker script

yypasre()

```
/* bintils-src/ld/ldscripts( generated files)*/
ENTRY(_start)
SECTIONS {
.interp : { *(.interp) }
 …
}

/* binutils-src/ld/ldgram.y*/
section:
  sect_constraint
  '{'
    /* os(output_section) will find/create from
       output_section_statement_table,
       push_stat_ptr (&os->children)*/
    { lang_enter_output_section_statement() }
    statement_list_opt  /* next*/
  '}'
```

[0101] binutils/ld internals

```
statement_list_opt  /* ld/ldgram.y*/
  statement_list
    statement
      input_section_spec
        input_section_spec_no_keep
          wildcard_spec '(' file_NAME_list ')'
          {
            /* important, next*/
            lang_add_wild (&$1, $3, ldgram_had_keep);
          }
```

[0101] binutils/ld internals

```
lang_add_wild (&$1, $3, ldgram_had_keep);
```

```
.interp : { *(.interp) }
```

```
wildcard_spec:
  wildcard_name    // '*'
  {
    $$.name = $1;  /* set other field NULL*/
  }
```

```
/* struct wildcard_spec*/
+-------------------------+
| name = “*”              |
| sorted = none           |
| exclude_name_list=NULL  |
| section_flag_list=NULL  |
+-------------------------+
```

[0101] binutils/ld internals

```
lang_add_wild (&$1, $3, ldgram_had_keep);
```

```
.interp : { *(.interp) }
```

```
file_NAME_list:  /* (.interp)*/
  wildcard_spec
  {
    struct wildcard_list *tmp;
    tmp = (struct wildcard_list *) xmalloc (sizeof *tmp);
    tmp->next = NULL;
    tmp->spec = $1;
    $$ = tmp;
  }
```

```
/* struct wildcard_list*/
+-------------------------------+
| wildcard_list *next = NULL    |
| /* struct wildcard_spec*/     |
| name = “interp”               |
| sorted = none                 |
| exclude_name_list = NULL      |
| section_flag_list = NULL      |
+-------------------------------+
```

[0101] binutils/ld internals

```
lang_add_wild (&$1, $3, ldgram_had_keep);
file_NAME_list:      /* (.interp)*/
  wildcard_spec
  {
    struct wildcard_list *tmp;
    tmp = (struct wildcard_list *) xmalloc (sizeof *tmp);
    tmp->next = NULL;
    tmp->spec = $1;
    $$ = tmp;
  }
```

```
.interp : { *(.interp) }
```

```
/* struct wildcard_spec*/
+-------------------------+
| name = "*"              |
| sorted = none           |
| exclude_name_list=NULL  |
| section_flag_list=NULL  |
+-------------------------+
```

```
/* struct wildcard_list*/
+-------------------------------+
| wildcard_list *next = NULL    |
| /* struct wildcard_spec*/     |
| name = "interp"               |
| sorted = none                 |
| exclude_name_list = NULL      |
| section_flag_list = NULL      |
+-------------------------------+
```

[0101] binutils/ld internals

```
lang_process()
  lang_for_each_statement (ldlang_open_output);
  /* walk all the input files, identify symbols and
     input sections*/
  open_input_bfds
    load_symbols
  lang_do_assignments (lang_mark_phase_enum)
  /* walk link script assign input section to output
     section*/
  map_input_to_output_sections
  ldemul_before_allocation   /* NX*/
  lang_find_relro_sections   /* relro*/
  lang_size_sections (NULL, ! RELAXATION_ENABLED)
  /* known the whole size of everything*/
  ldemul_after_allocation==gldelf_i386_after_allocation
    lang_do_assignments (phase=lang_assigning_phase_enum)
  lang_do_assignments (lang_final_phase_enum)
  /* assign symbol value */
  lang_end
```

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[0101] binutils/ld internals

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  /* assign symbol value */
  lang_end
```

[0101] binutils/ld internals

```
ld_write()
  /* input data/relocation/*/
  lang_for_each_statement (build_link_order)
  /* copy input section to output file*/
  bfd_elf_final_link
    _bfd_elf_compute_section_file_positions
      assign_file_positions_except_relocs()
        assign_file_positions_for_segments()
          map_sections_to_segments()
    /* relocation*/
    elf_link_input_bfd
      /* do*/
      relocate_section = bed->elf_backend_relocate_section
        _bfd_final_link_relocate
```

[0101] binutils/ld internals

```
ld_write()
  /* input data/relocation/*/
  lang_for_each_statement (build_link_order)
  /* copy input section to output file*/
  bfd_elf_final_link
    _bfd_elf_compute_section_file_positions
      assign_file_positions_except_relocs()
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      relocate_section = bed->elf_backend_relocate_section
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```

[0101] binutils/ld internals

```
ld_write()
  /* input data/relocation/*/
  lang_for_each_statement (build_link_order)
  /* copy input section to output file*/
  bfd_elf_final_link
    _bfd_elf_compute_section_file_positions
      assign_file_positions_except_relocs()
        assign_file_positions_for_segments()
          map_sections_to_segments()
    /* relocation*/
    elf_link_input_bfd
      /* do*/
      relocate_section = bed->elf_backend_relocate_section
        _bfd_final_link_relocate
```

[0101] binutils/ld internals

```
ld_write()
  /* input data/relocation/*/
  lang_for_each_statement (build_link_order)
  /* copy input section to output file and apply reloc*/
  bfd_elf_final_link
    _bfd_elf_compute_section_file_positions
      assign_file_positions_except_relocs()
        assign_file_positions_for_segments()
          map_sections_to_segments()   /* NX*/
    /* relocation*/
    elf_link_input_bfd
      /* do*/
      relocate_section = bed->elf_backend_relocate_section
        _bfd_final_link_relocate
```

[0102] Glibc dynamic-linker internals

```
/* kernel entry this after parse
   header INTERP(ldlinux.so.2)*/
_start  /* src/sysdeps/i386/dl-machine.h*/
  _dl_start  /* src/elf/rtld.c*/
    ELF_DYNAMIC_RELOCATE  /* bootstrap*/
      elf_dynamic_do_Rel
  _dl_start_final
    /* read aux vector and call dl_main*/
    _dl_sysdep_start  /* elf/dl-sysdep.c*/
    dl_main
      main_map=_dl_new_object /* link_map for executable*/
      process_envvars  /* env LD_PRELOAD */
      /*PT_GNU_RELRO*/
      main_map->l_relro_addr
      main_map->l_relro_size
      _dl_init_paths  /*DT_RPATH/DT_RUNPATH/
                        env LD_LIBRARY_PATH*/
```

[0102] Glibc dynamic-linker internals

```
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   header INTERP(ldlinux.so.2)*/
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  _dl_start  /* src/elf/rtld.c*/
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  _dl_start_final
    /* read aux vector and call dl_main*/
    _dl_sysdep_start  /* elf/dl-sysdep.c*/
    dl_main
      main_map=_dl_new_object /* link_map for executable*/
      process_envvars  /* env LD_PRELOAD */
      /*PT_GNU_RELRO*/
      main_map->l_relro_addr
      main_map->l_relro_size
      _dl_init_paths  /*DT_RPATH/DT_RUNPATH/
                        env LD_LIBRARY_PATH*/
```

[0102] Glibc dynamic-linker internals

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_start  /* src/sysdeps/i386/dl-machine.h*/
  _dl_start  /* src/elf/rtld.c*/
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      elf_dynamic_do_Rel
  _dl_start_final
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    _dl_sysdep_start  /* elf/dl-sysdep.c*/
    dl_main
      main_map=_dl_new_object /* link_map for executable*/
      process_envvars  /* env LD_PRELOAD */
      /*PT_GNU_RELRO*/
      main_map->l_relro_addr
      main_map->l_relro_size
      _dl_init_paths  /*DT_RPATH/DT_RUNPATH/
                        env LD_LIBRARY_PATH*/
```
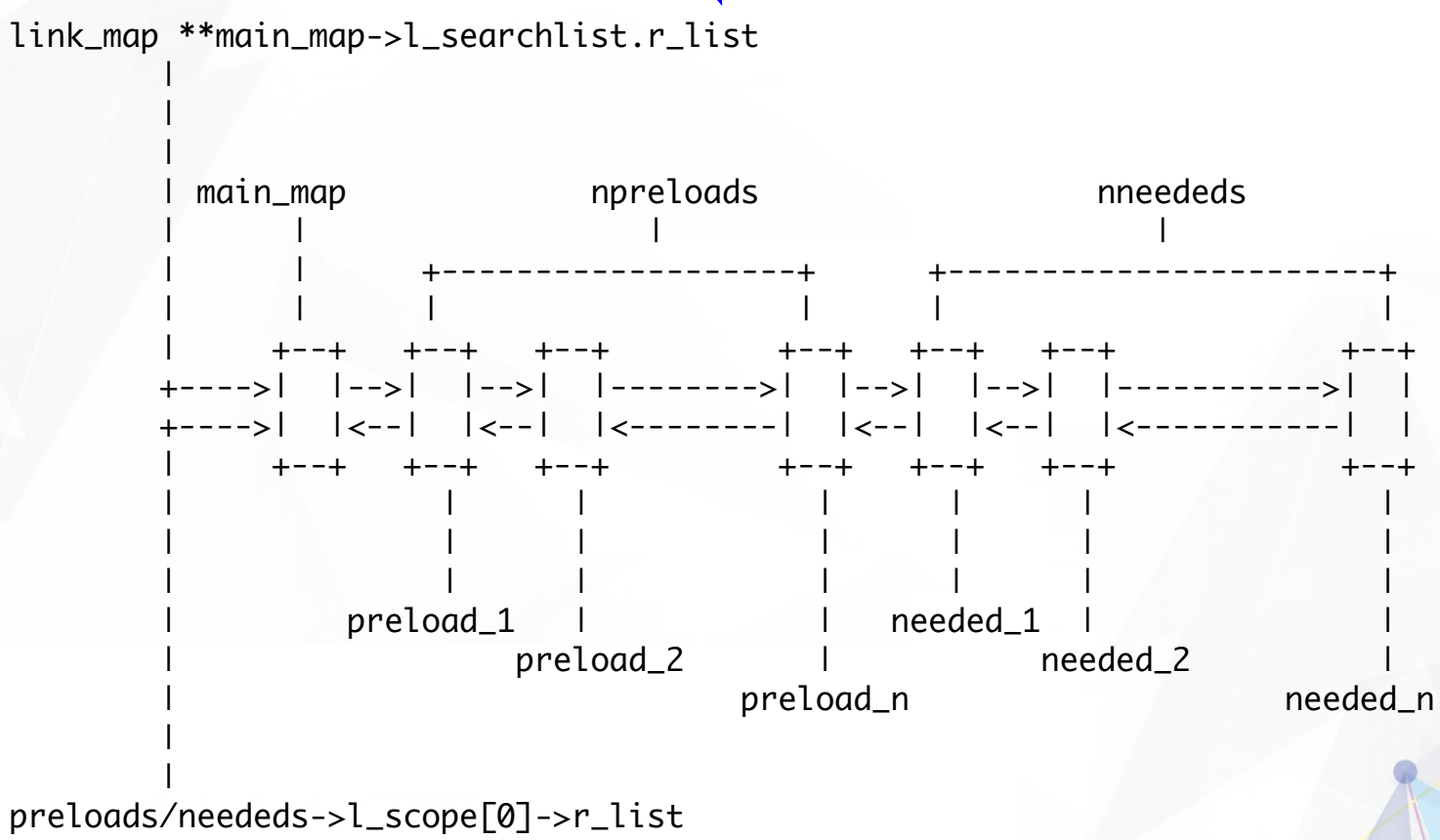

[0102] Glibc dynamic-linker internals

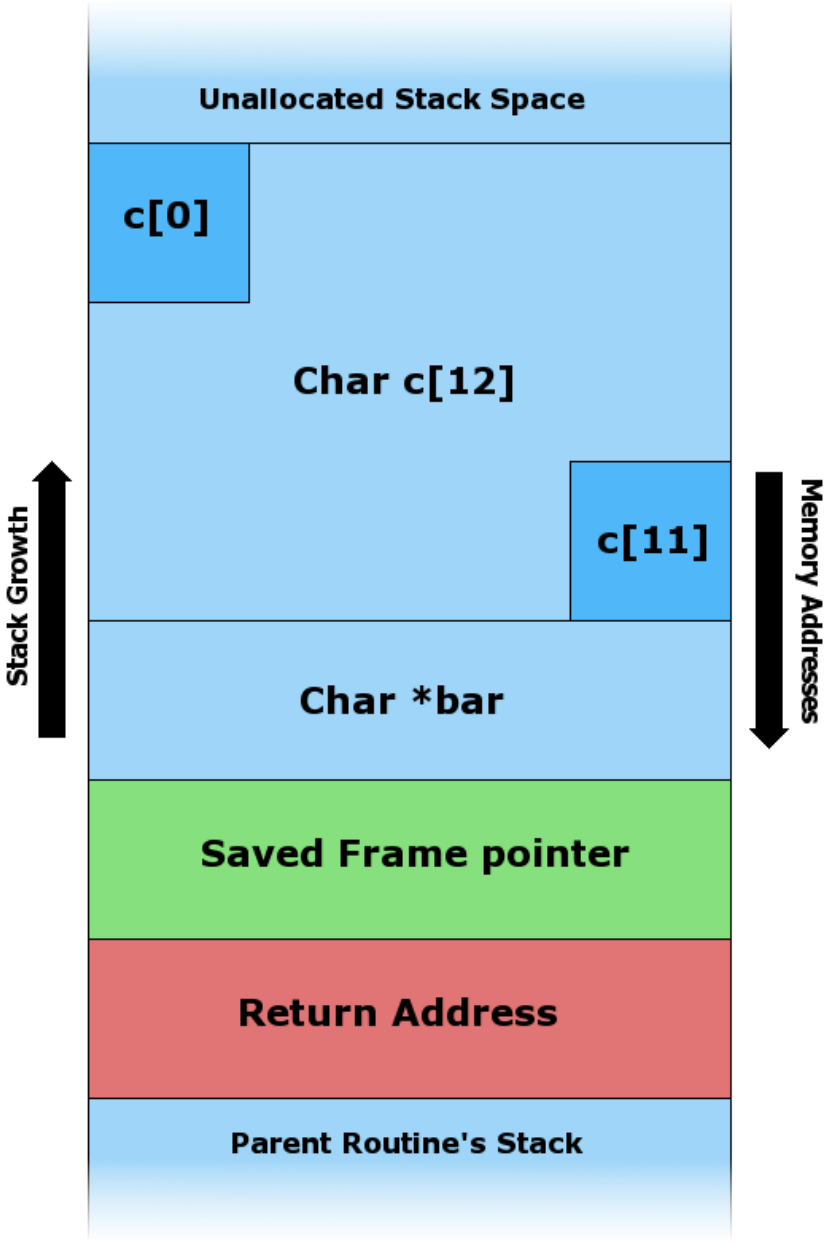
```
dl_main
  /* build symbol search scope*/
  do_preload
  _dl_map_object_deps
```



[0102] Glibc dynamic-linker internals

```
dl_main
  _dl_relocate_object
    ELF_DYNAMIC_RELOCATE
      /* GOT[1]/GOT[2]*/
      elf_machine_runtime_setup
      elf_dynamic_do_Rel()
        elf_machine_rel  /* sysdeps/i386/dl-machine.h*/
          do_lookup_x    /* src/elf/dl-lookup.c*/
    _dl_protect_relro  /* relro*/
      __mprotect
```

[02] smashing the stack



[03] implementation of classical mitigations

> 0300 stack canary
> 0301 NX(No-eXecutable)
> 0302 PIC/PIE & ASLR
> 0303 relro

[0300] stack canary

input source(main.c):

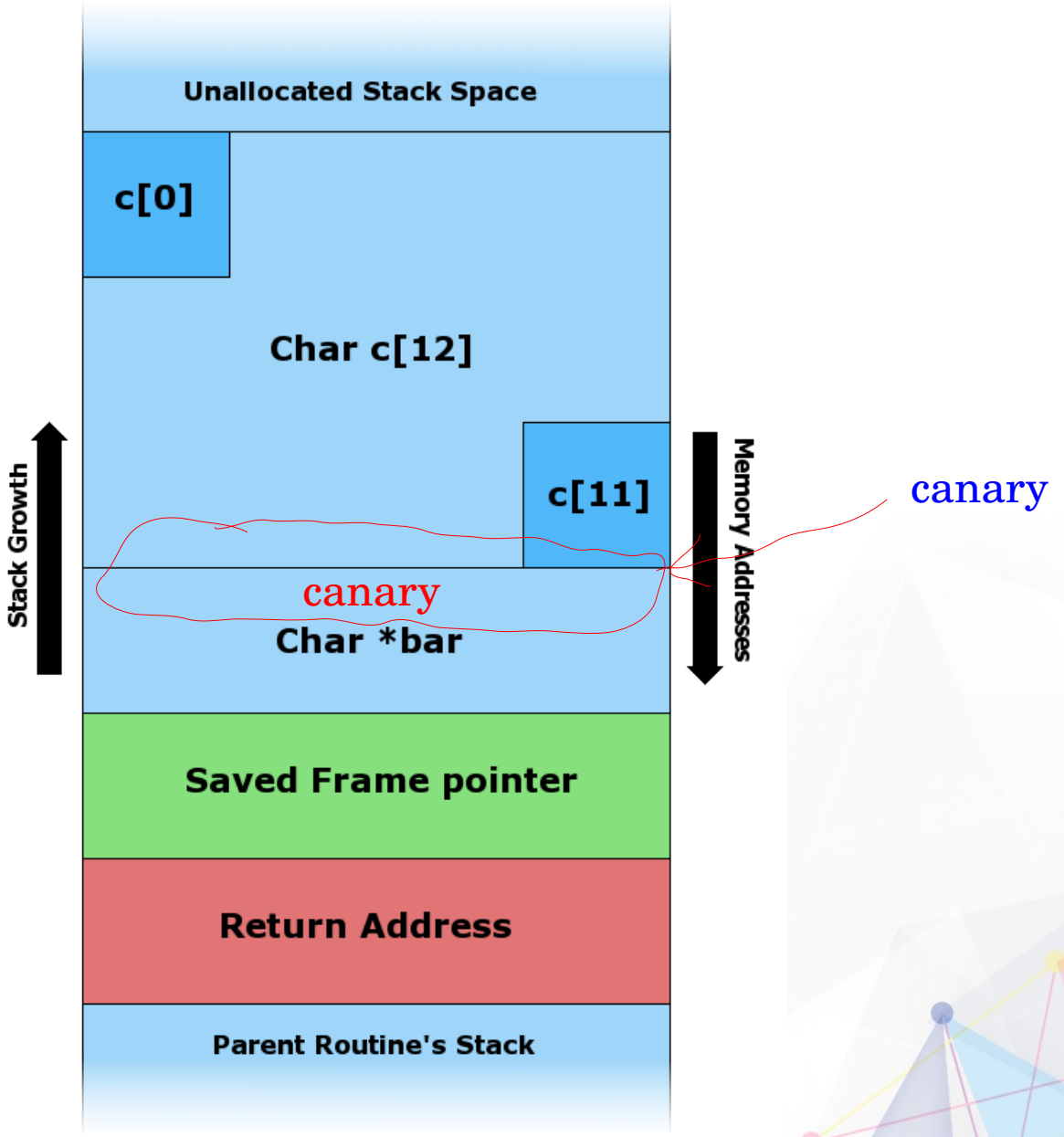
```
void foo(const char* str) {
    char buffer[16];
    strcpy(buffer, str);
}
```

```
gcc -fstack-protector-all main.c
```

output target(a.out):

```
extern uintptr_t __stack_chk_guard;
noreturn void __stack_chk_fail(void);
void foo(const char* str) {
        uintptr_t canary = __stack_chk_guard;
        char buffer[16];
        strcpy(buffer, str);
        if ( (canary = canary ^ __stack_chk_guard) != 0 )
                __stack_chk_fail();
}
```

[02] stack canary



[0300] stack canary

```
/* gcc*/
execute_one_pass
  ::pass_expand::execute  /* GIMPLE to RTL*/
    construct_exit_block
      expand_function_end
        stack_protect_epilogue
          ix86_stack_protect_fail   /* insert rtl*/
```

```
/* glibc*/
dl_main
  security_init
    /* value __stack_chk_guard*/
    _dl_setup_stack_chk_guard
```

[0301] NX(No-eXecutable)

```
main
  lang_process
    ldemul_before_allocation=gldelf_i386_before_allocation
      bfd_elf_size_dynamic_sections
        /* remember execstack flags according these two*/
        elf_stack_flags
        bfd_get_section_by_name (, ".note.GNU-stack")
  ld_write()
    /* input data/relocation/*/
    lang_for_each_statement (build_link_order)
    /* copy input section to output file*/
    bfd_elf_final_link
      _bfd_elf_compute_section_file_positions
        assign_file_positions_except_relocs()
          assign_file_positions_for_segments()
            map_sections_to_segments()  /* PT_GNU_STACK*/
```

[0301] NX(No-eXecutable)

```
/* linux kernel*/
do_execve
  search_binary_handler
    /* alloc for elf header first*/
    linux_binfmt.load_binary==load_elf_binary
      /* PT_GNU_STACK set mm_struct->vm_flag*/
      setup_arg_pages


/* always here*/
do_page_fault & IA32_EFER.NXE
/* hardware will catch no executable page error*/
```

[0302] PIC/PIE & ASLR

-fpic/-fpie/-fPIC/-fPIE == Position Independent Code

```
/* GCC driver*/
main
  toplev::main
    decode_cmdline_options_to_array_default_mask
      decode_cmdline_options_to_array
        prune_options
          /* -fpic category parameters*/
          cancel_option
```

-shared == load-time relocation <= library
-pie == Position Independent Code <= executable

[0303] relro

```
/* linker script*/
.data.rel.ro :
{
  *(.data.rel.ro.local* .gnu.linkonce.d.rel.ro.local.*)
  *(.data.rel.ro .data.rel.ro.* .gnu.linkonce.d.rel.ro.*)
}
```

gcc sees a variable which is constant but requires a dynamic relocation, it puts it into a section named .data.rel.ro

```
-z relro -z now
```

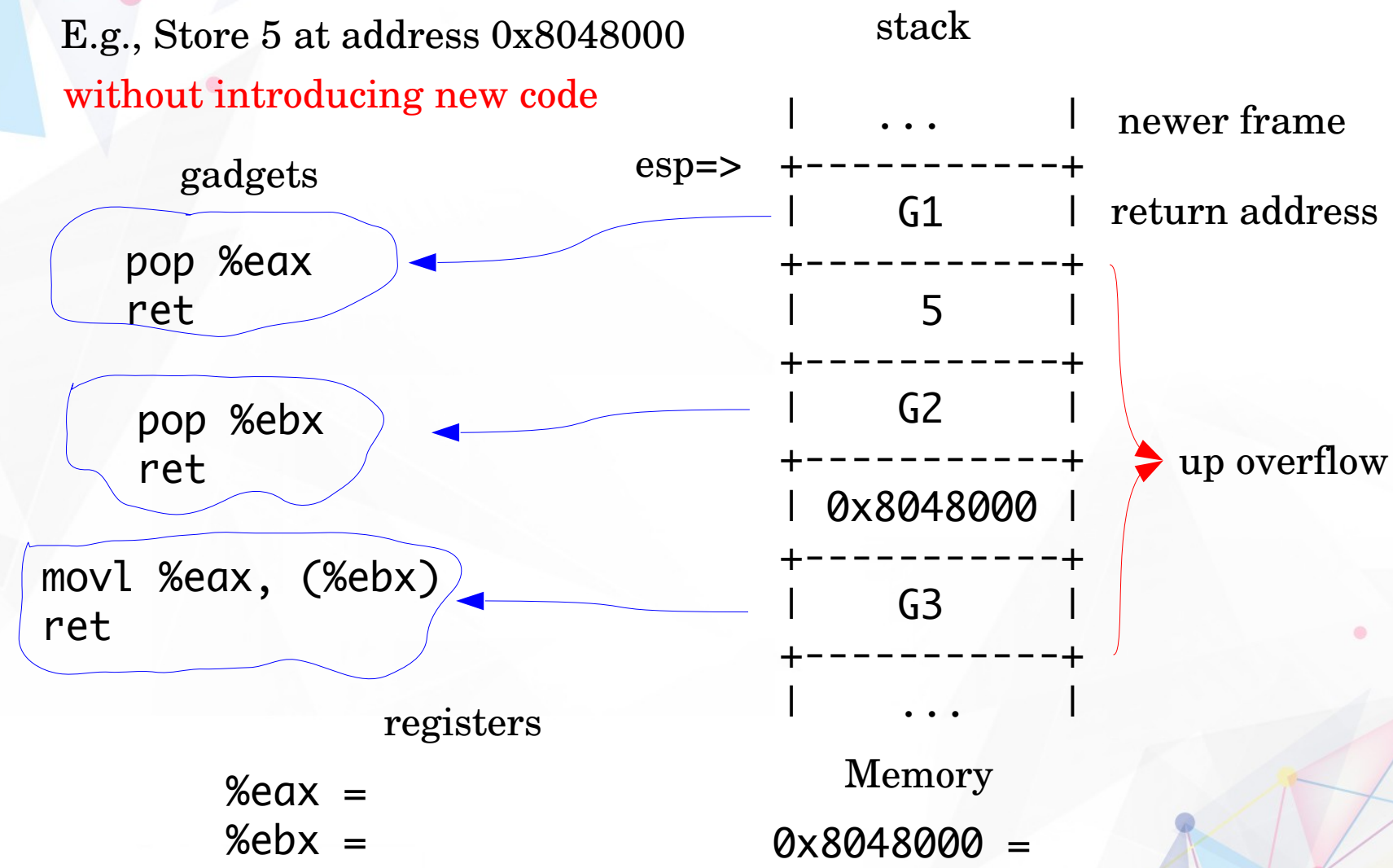
disable lazy link/runtime link, no section .rel.plt ,PLT in read-only

[04] return-oriented programming

Use ESP as program counter

E.g., Store 5 at address 0x8048000

without introducing new code



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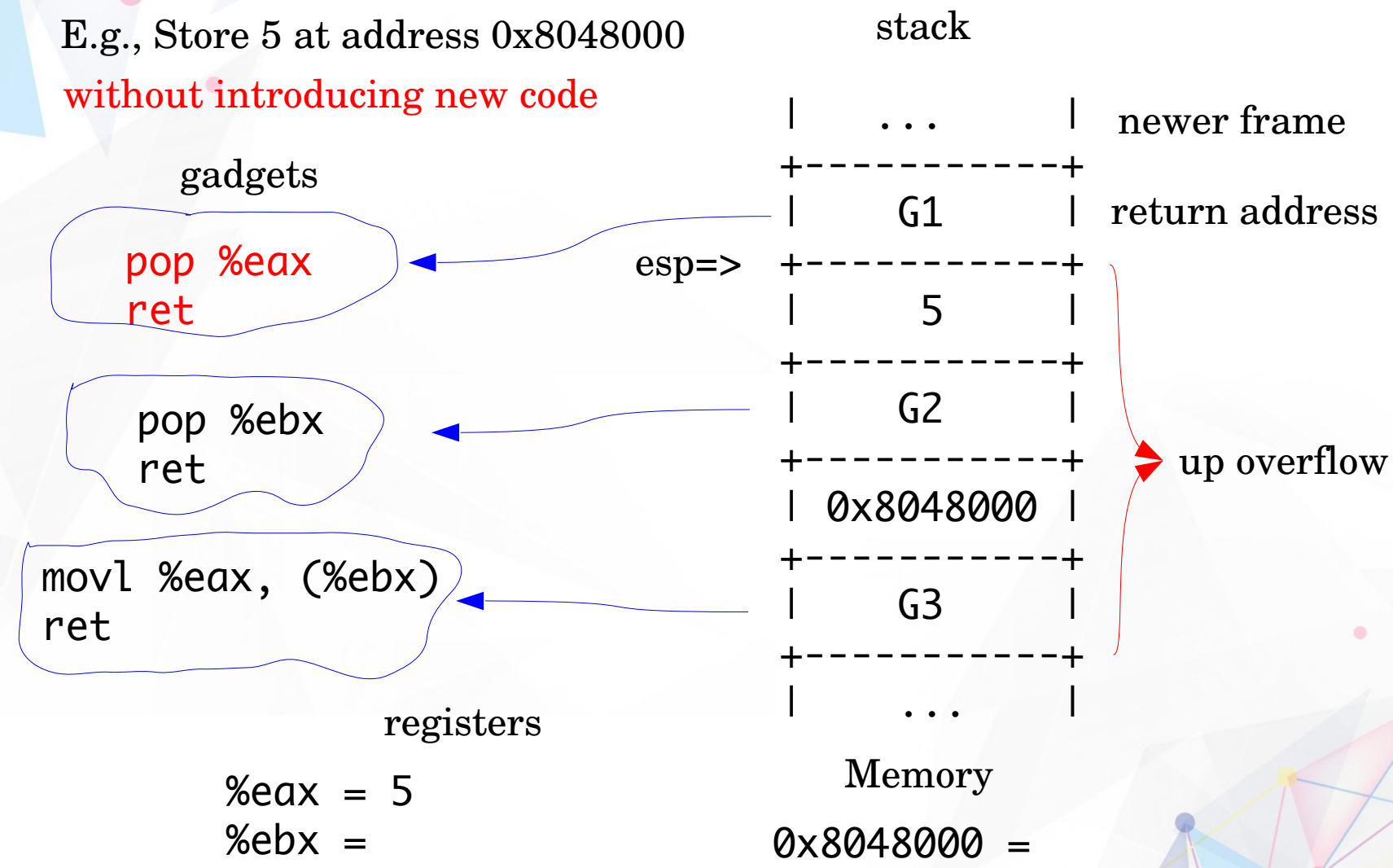

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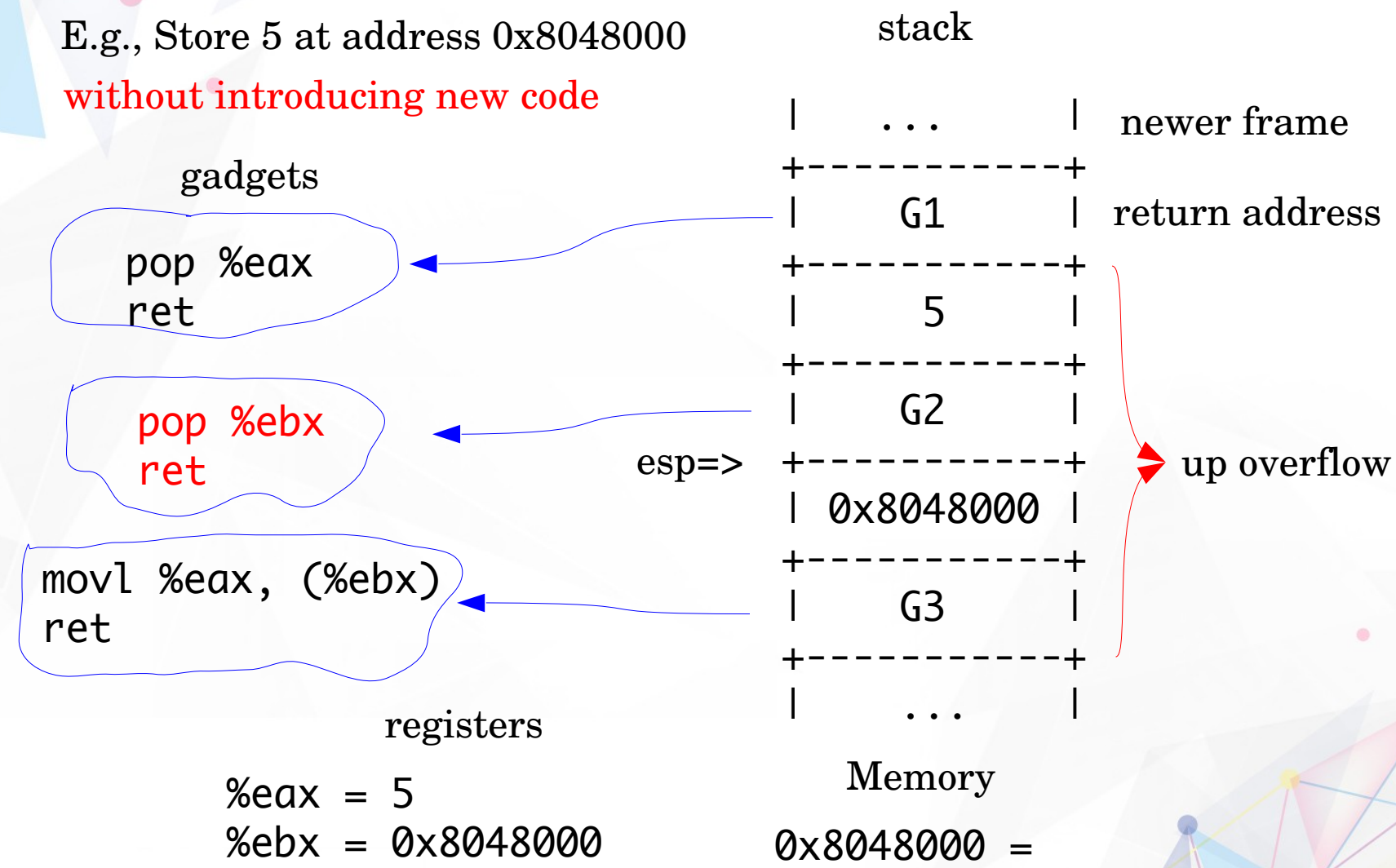

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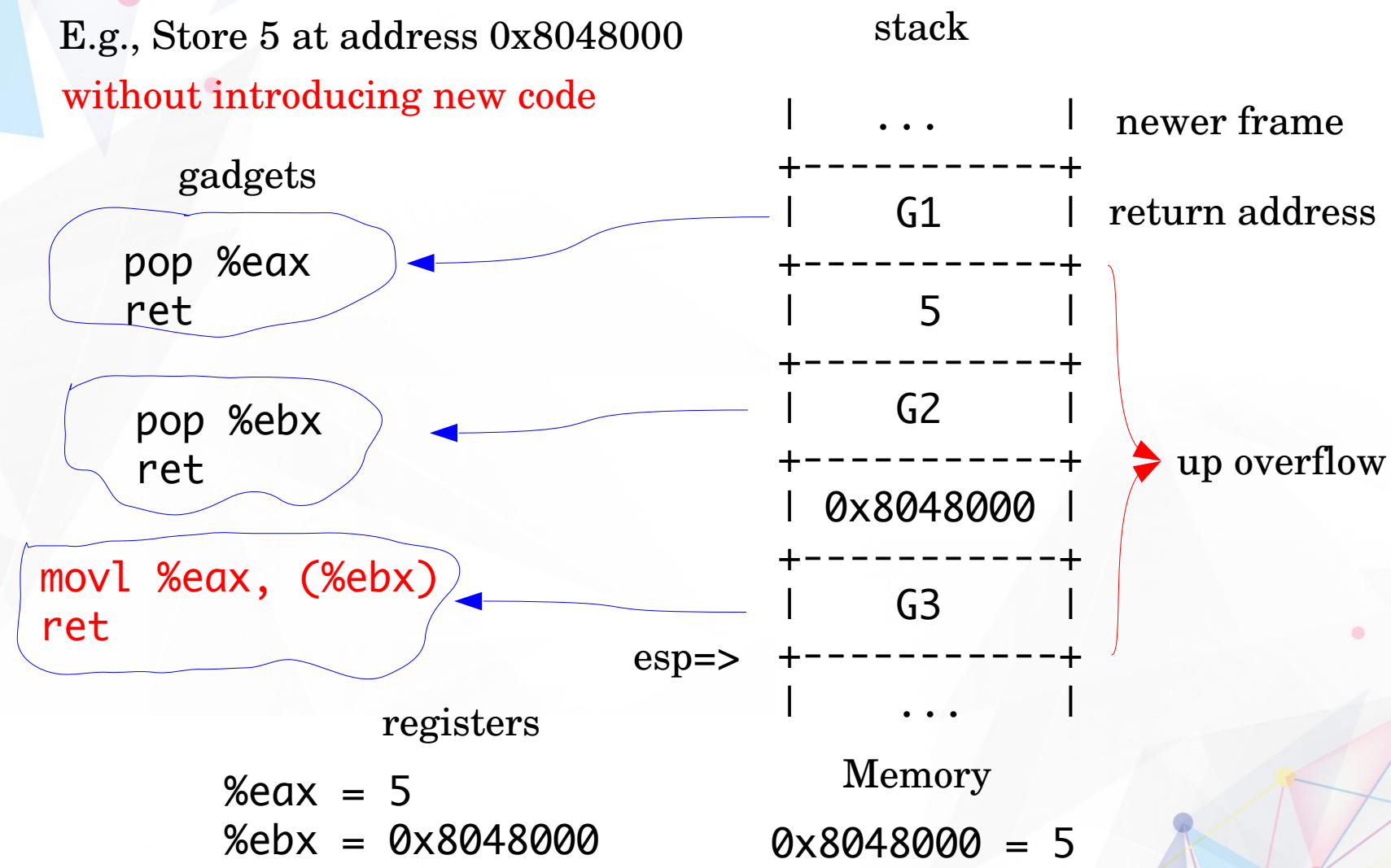

[05] CFI & implementation in GCC

What is Control-Flow Integrity?

Control Flow Integrity (CFI) is a security policy that dictates that the software execution must follow the path of a previously determined control flow graph (CFG).

[05] CFI & implementation in GCC

```
class B {
  public:
    virtual int foo ()
    {...}
};
class D : public B {
  public:
    virtual int foo ()
    {...}
};
B *b_ptr;
D d_obj;
b_ptr = &d_obj;

b_ptr-> foo ();
```

```
D.1 = b_ptr;
D.2 = b_ptr→_vptr.B;


D.3 = *D.2;
D.4 = call(D3 + offset)(D.1);
```

[05] CFI & implementation in GCC

```
class B {
  public:
    virtual int foo ()
    {...}
};
class D : public B {
  public:
    virtual int foo ()
    {...}
};
B *b_ptr;
D d_obj;
b_ptr = &d_obj;

b_ptr-> foo ();
```

```
D.1 = b_ptr;
D.2 = b_ptr→_vptr.B;
D.5 = & "set of valid vtable
         Pointers for class B";
D.6 = VerifyVtablePointer (D.5, D.2);
D.3 = *D.2;
D.4 = call(D3 + offset)(D.1);
```

[05] CFI & implementation in GCC

```
/* src/libvtv/vtvrts.cc*/

void *
__VLTVerifyVtablePointer (set *valid_vtbl_ptrs, void *vtbl_ptr)
{
  if (member (vtbl_ptr, valid_vtbl_ptrs))
    return vtbl_ptr;
  else
    abort ();
}
```

[05] CFI & implementation in GCC

```
/* src/gcc/vtable-verify.c*/
/* before GIMPLE to RTL*/
define pass: pass_vtable_verify
  /* Loop through all the basic blocks in the current
     function, passing them to verify_bb_vtables, which
     searches for virtual calls, and inserts calls to
     __VLTVerifyVtablePointer
     (tree verify_vtbl_ptr_fndecl).*/
  verify_bb_vtables


  /*gcc/cp/vtable-class-hierarchy.c*/
  /* gather vtable info,
     build vtable verify GIMPLE tree*/
  vtv_build_vtable_verify_fndecl
    verify_vtbl_ptr_fndecl  /* tree*/
```

[06] intro to RAP of PaX/Grsecurity

RAP = Reuse Attack Protector

RAP is implemented as a GCC compiler plugin, has two components:

[+] deterministic defense : build cfg has added type information. type information of a program build by a hashing function.

[+] probabilistic defense: ensure that a function can return not just to a group of various call sites as defined by the first defense, but in fact only to the location from which the function was called.

on entry to a function, encrypts the return address prior to any code, The key is stored in a reserved CPU register, generally ensuring that the key itself should not leak

Q&A

Most of my work(article/code) can be found here:

http://tya.company/

http://hardenedlinux.org/

腾御安

THANKS

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