Function pointers

```c
int strcmp(const char *a, const char *b);

// This does not work:
// int *comparator(const char *a, const char *b) = strcmp;

int (*my_comparator)(const char *a, const char *b) = strcmp;

// OK, let's typedef it
typedef int (*comparator_t)(const char *, const char *);

comparator_t comparator = strcmp;

int result1 = (*comparator)("Roger", "David");
int result2 = comparator("Nick", "Rick");

qsort(..., comparator, ...);
```

Trying to typedef functions directly does not work

```
// int (comparator2)(const char *a, const char *b) = strcmp;

typedef int (comparator_t2)(const char *, const char *); // useless

// comparator_t2 comparator2 = strcmp;
// ^ error: function ‘comparator2’ is initialized like a variable
```

GCC integer overflow builtins

```
bool __builtin_add_overflow (type1 a, type2 b, type3 *res);
bool __builtin_sub_overflow (type1 a, type2 b, type3 *res);
bool __builtin_mul_overflow (type1 a, type2 b, type3 *res);

char a = 100, b = 200, c;
int d;

__builtin_add_overflow(a, b, &c);
// -> true == overflow

__builtin_add_overflow(a, b, &d);
// -> false == no overflow
```

Printing fixed-size types

The problem:

```
uint32_t var;
printf("%...", var); // ???
printf("%d", var);   // fails on Win16
printf("%ld", var);  // fails on 64-bit systems

scanf("%...", &var); // even worse
```

String literal joining

```
char *longstring = "There is no pain, "
                   "you are receding";
```

```c
#include <inttypes.h>

#define PRId32 "d"
#define PRIu32 "u"
#define PRId64 "ld"
#define PRIu64 "lu"
#define SCNi32 "i"
#define SCNiPTR "li"

uint32_t var;
uintptr_t ptr;
printf("%" PRId32 "\n", var);
scanf("%" SCNi32 "\n", &var);
scanf("%" SCNiPTR "\n", &ptr);
```

Dynamic memory

```c
// man malloc
#include <stdlib.h>

// C11, POSIX
void *malloc(size_t size);
void free(void *ptr);
void *calloc(size_t nmemb, size_t size);
void *realloc(void *ptr, size_t size);

// nonstandard
void *reallocarray(void *ptr, size_t nmemb, size_t size);
```

```
enum {buf_size = 20};

char *buf = malloc(buf_size);
// type conversion is automatic
// buf == NULL -> allocation error
// otherwise, contents of buf undefined here

strcpy(buf, "arc de Triomphe");
buf[0] = 'A';
...

free(buf);   // OK
//free(buf); // UB -- double free
buf = NULL;
free(buf);   // OK, free is a no-op here
```

```c
int *array = calloc(30, sizeof(*array));
```

Similar to, but not the same thing as:

```c
int *array = malloc(30 * sizeof(*array));
// ...check for NULL...
memset(array, 0, 30 * sizeof(*array));
```

```c
// same as malloc(100)
void *ptr = realloc(NULL, 100);

// don't do this
// ptr = realloc(ptr, 200);

void *tmp = realloc(ptr, 200);
if (!tmp) {
    perror("realloc");
    free(ptr);
    return;
} else {
    ptr = tmp;
}
```

Dynamic array

```
struct DynArray {
    size_t size;
    size_t capacity;
    int *ptr;
} array = {};

void append(struct DynArray *arr, int value) {
    if (arr->size + 1 > arr->capacity) {
        size_t newcap = 2 * (arr->capacity + 1);
        int *tmp = realloc(arr->ptr, newcap * sizeof(*tmp));
        if (!tmp) {
            // Handle allocation error
        }
        arr->ptr = tmp;
        arr->capacity = newcap;
    }
    arr->ptr[size++] = value;
}
```

Better yet:

```
int *tmp = reallocarray(arr->ptr, newcap, sizeof(*tmp));
```

Where `reallocarray` is not available:

```
size_t size;
if (__builtin_mul_overflow(newcap, sizeof(arr->ptr[0]), &size)) {
    // Handle overflow
}
int *tmp = realloc(..., size);
```

Example: delete from list

This won't work:

```
struct List {
    int data;
    struct List *next;
};
void remove(struct List *list, int key) {
    while (list && list->data != key) {
        list = list->next;
    }
    if (!list) {
        return;
    }
    free(list);
    list = list->next; // use after free
    // no way to update the pointer
}
```

```
struct List {
    int data;
    struct List *next;
};

void remove(struct List **list, int key) {
    while (*list && (*list)->data != key) {
        list = &(*list)->next;
    }
    if (!*list) {
        return;
    }
    struct List *next = (*list)->next;
    free(*list);
    *list = next;
}
```

Example: BST insertion

```
struct TreeNode {
    int data;

    struct TreeNode *left;
    struct TreeNode *right;
};

int main(void) {
    struct TreeNode *root = NULL;
    ...
}
```

```
struct TreeNode **descend(struct TreeNode **root, int key) {
    while (*root && (*root)->data != key) {
        if ((*root)->data > key) {
            root = &(*root)->left;
        } else {
            root = &(*root)->right;
        }
    }
    return root;
}

void insert(struct TreeNode **root, int key) {
    struct TreeNode **where = descend(root, key);
    if (!*where) {
        *where = calloc(1, sizeof(struct TreeNode));
        ...
        (*where)->data = key;
    }
}
```

Sometimes fixed-size buffers are inconvenient:

```
char buf[100];
// scanf("%s", buf); <- banned
scanf("%99s", buf);
...
snprintf(buf, sizeof(buf), "%d bottles of beer on the wall", 50)
...
fgets(buf, sizeof(buf), stdin);
// gets(buf);  <- banned from C11
```

```c
char *buf = NULL;
scanf("%ms", &buf); // POSIX
...
free(buf);
```

```c
char *buf = NULL;
asprintf(&buf,
         "%d little Soldier Boys "
         "went out to dine", 10); // GNU / BSD
...
free(buf);
```

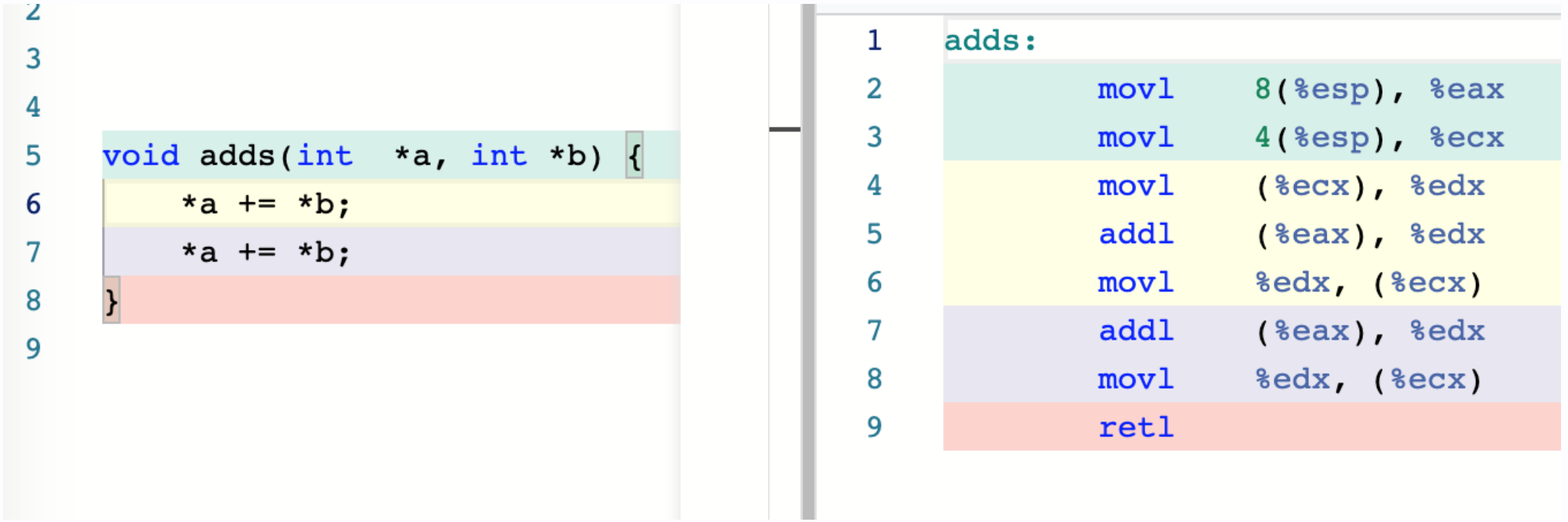
```c
// ssize_t getline(char **lineptr, size_t *n, FILE *stream);
char *line = NULL;
size_t linesize = 0;
getline(&line, &linesize, stdin); // POSIX
...
free(line);
```

6.3.2.3 Pointers

1 A pointer to **void** may be converted to or from a pointer to any object type. A pointer to any object type may be converted to a pointer to **void** and back again; the result shall compare equal to the original pointer.

7 A pointer to an object type may be converted to a pointer to a different object type. If the resulting pointer is not correctly aligned[68] for the referenced type, the behavior is undefined. Otherwise, when converted back again, the result shall compare equal to the original pointer. When a pointer to an object is converted to a pointer to a character type, the result points to the lowest addressed byte of the object. Successive increments of the result, up to the size of the object, yield pointers to the remaining bytes of the object.

8 A pointer to a function of one type may be converted to a pointer to a function of another type and back again; the result shall compare equal to the original pointer. If a converted pointer is used to call a function whose type is not compatible with the referenced type, the behavior is undefined.


2
3
4
5 void adds(int *a, int *b) {
6 *a += *b;
7 *a += *b;
8 }
9
1 adds:
2 movl 8(%esp), %eax
3 movl 4(%esp), %ecx
4 movl (%ecx), %edx
5 addl (%eax), %edx
6 movl %edx, (%ecx)
7 addl (%eax), %edx
8 movl %edx, (%ecx)
9 retl

```
void adds(int *restrict a,
          int *restrict b) {
    *a += *b;
    *a += *b;
}
```

```
1  adds:
2          movl    4(%esp), %eax
3          movl    8(%esp), %ecx
4          movl    (%ecx), %ecx
5          addl    %ecx, %ecx
6          addl    %ecx, (%eax)
7          retl
```

Strict aliasing

7 An object shall have its stored value accessed only by an lvalue expression that has one of the following types:[88)]

— a type compatible with the effective type of the object,

— a qualified version of a type compatible with the effective type of the object,

— a type that is the signed or unsigned type corresponding to the effective type of the object,

— a type that is the signed or unsigned type corresponding to a qualified version of the effective type of the object,

— an aggregate or union type that includes one of the aforementioned types among its members (including, recursively, a member of a subaggregate or contained union), or

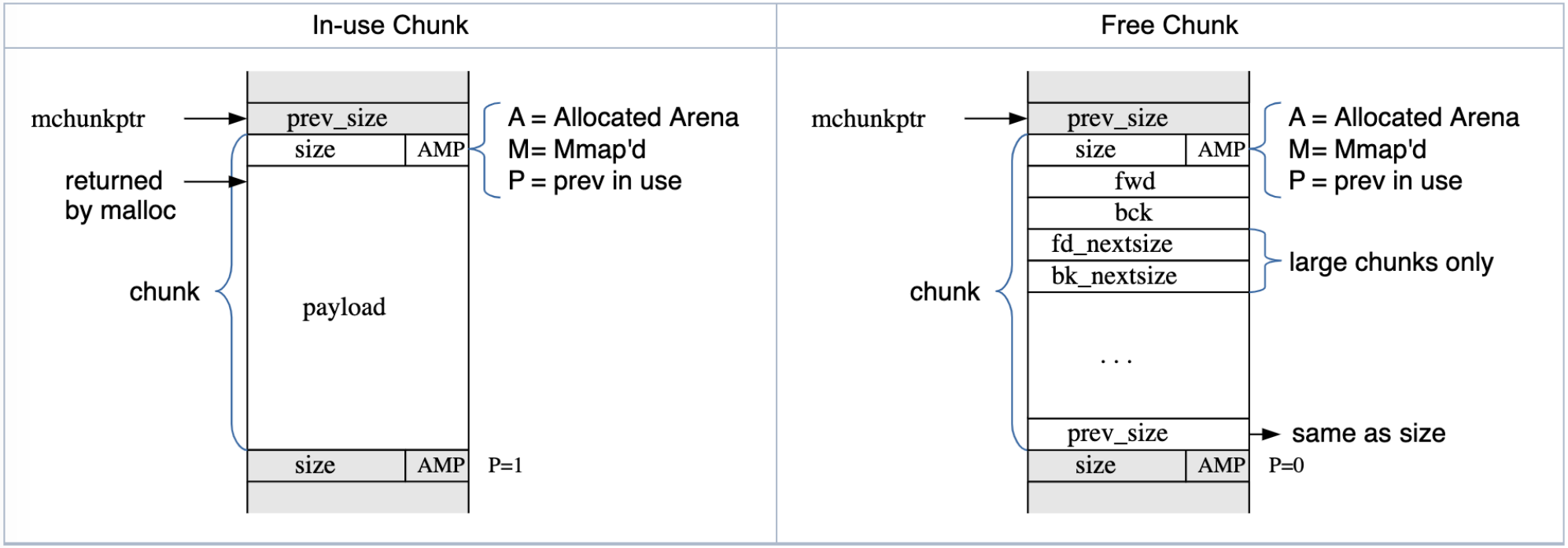
— a character type.

Union types

```
union U {
    uint32_t u;
    float f;
    char bytes[4];
}

assert(sizeof(union U) == 4);
```

Glibc malloc



- C++'s `new` uses malloc
- Python: malloc + reference counting + GC
- Go, Java: garbage collection

- Overcommit. OOM killer.
- Memory leaks, double free, use after free.

Address sanitizer

```
gcc -fsanitize=address myprog.c
```

Valgrind

Valgrind is in essence a virtual machine using just-in-time (JIT) compilation techniques, including dynamic recompilation. Nothing from the original program ever gets run directly on the host processor. Instead, Valgrind first translates the program into a temporary, simpler form called Intermediate Representation (IR), which is a processor-neutral, SSA-based form. ...

...usually, code run with Valgrind ...runs at 20% to 25% of the speed of the normal program.