Idioms: A Simple and Effective Framework for Turbo-Charging Local Neural Decompilation with Well-Defined Types

Luke Dramko[1], Claire Le Goues[1], Edward J Schwartz[2]

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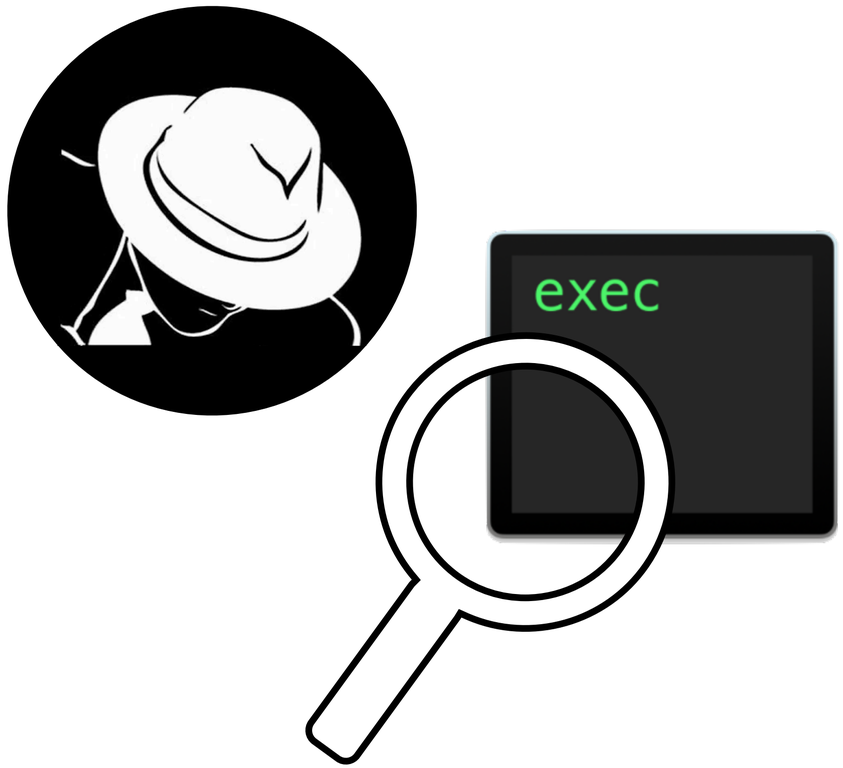
Problem: Security practitioners need to analyze executable programs where the source code is unavailable.



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- Patching Legacy Software

Motivational Example: Hash Table with Linear Probing

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int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
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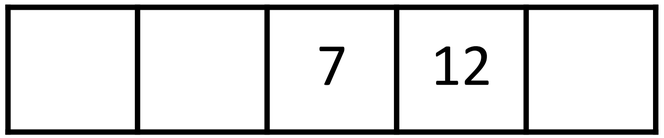

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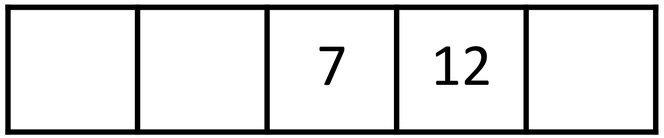

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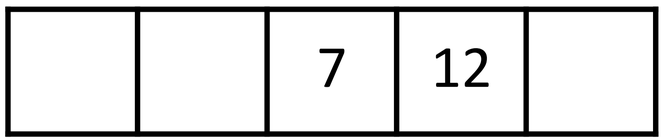

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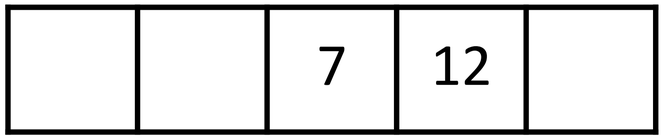

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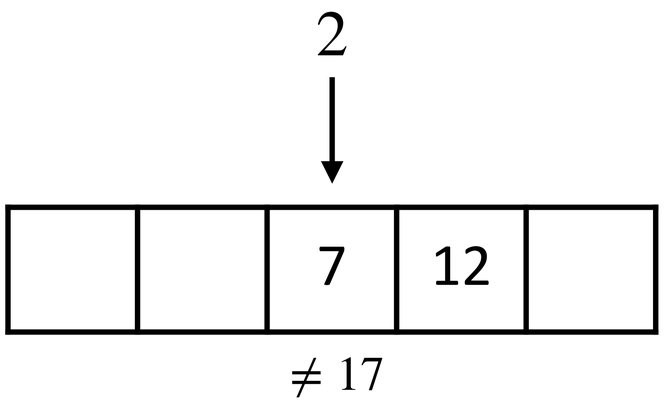

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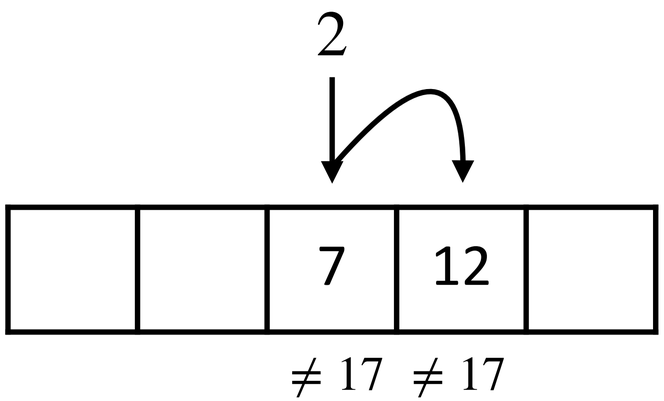

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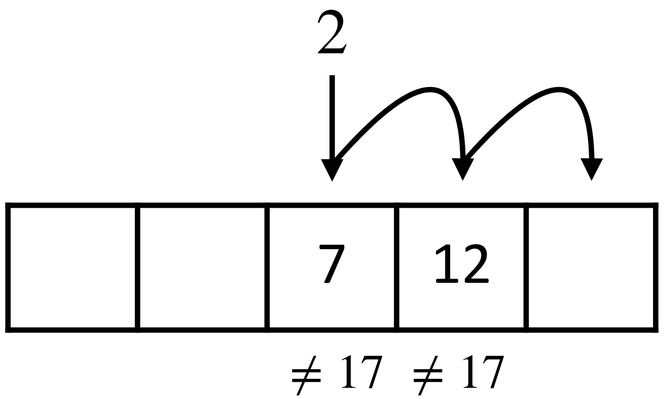

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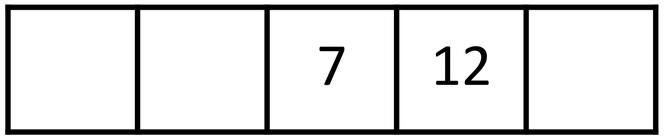

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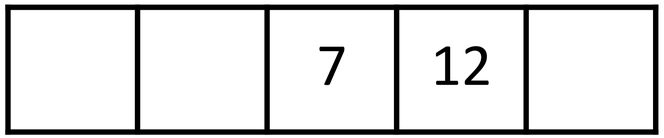


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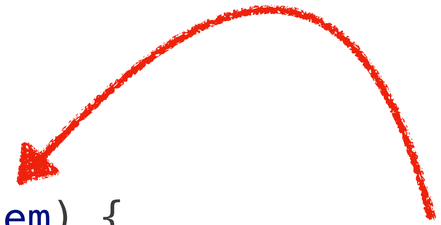

In practice, these are structs that represent network connections.

Compilers convert code from a higher level language into a lower-level language.

Original Source Code

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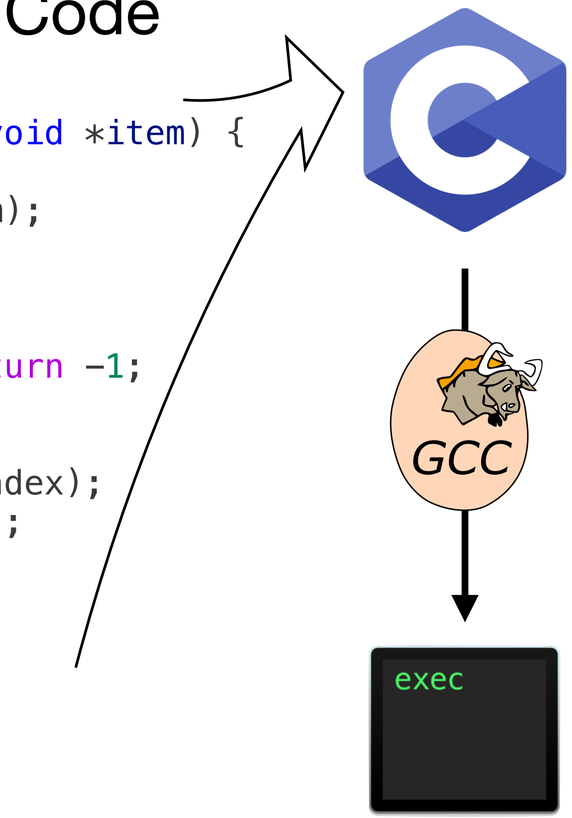

Assembly

(Human-Readable Compiled)

```
155:   push   %rbp
156:   mov    %rsp,%rbp
159:   sub    $0x20,%rsp
15d:   mov    %rdi,-0x18(%rbp)
161:   mov    %rsi,-0x20(%rbp)
165:   mov    -0x20(%rbp),%rdx
169:   mov    -0x18(%rbp),%rax
16d:   mov    %rdx,%rsi
170:   mov    %rax,%rdi
173:   callq  0x94
178:   mov    %eax,-0xc(%rbp)
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182:   mov    -0x18(%rbp),%rax
186:   mov    0x8(%rax),%rax
18a:   mov    -0xc(%rbp),%edx
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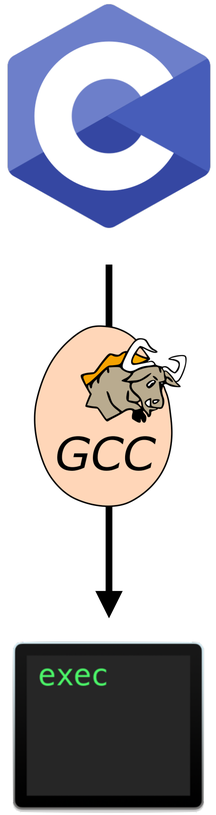

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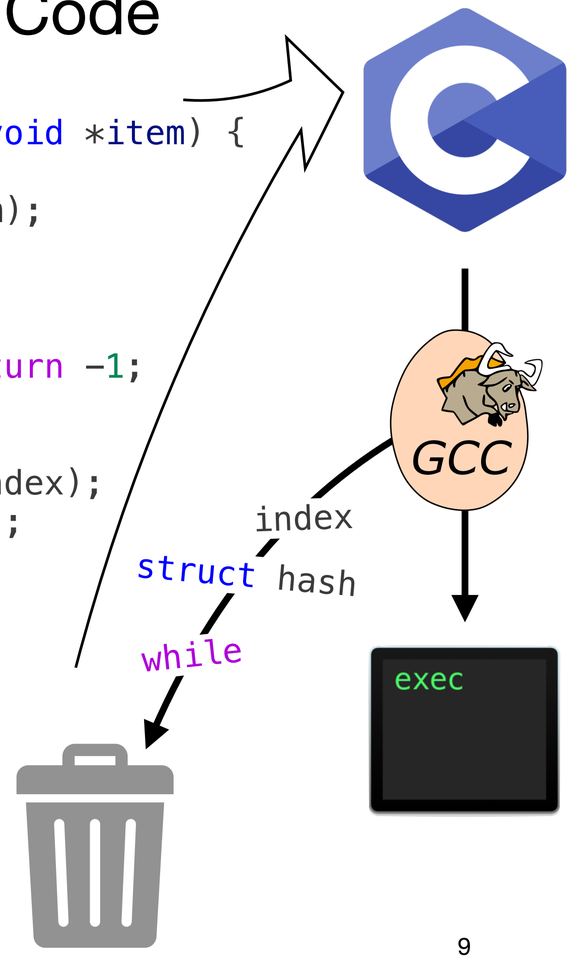

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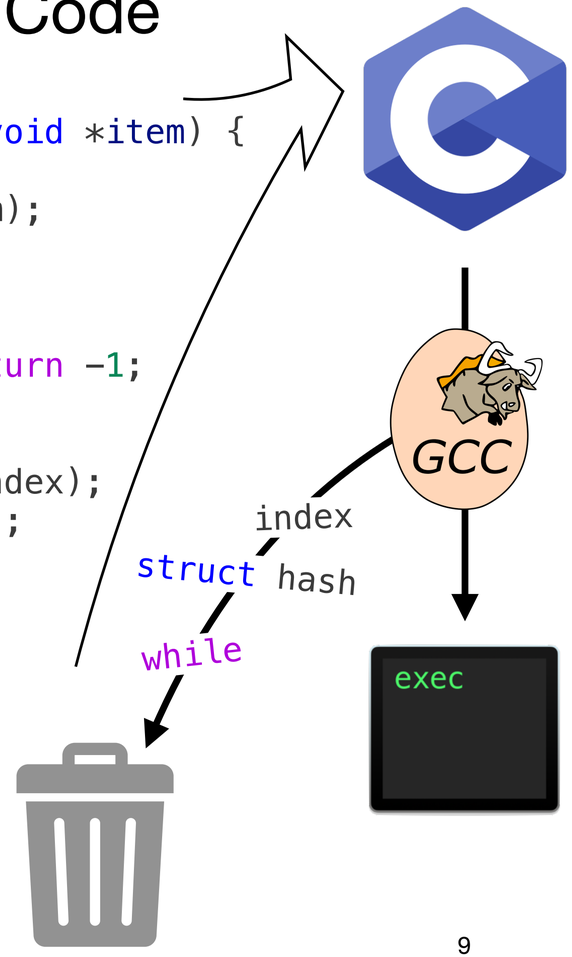

No identifier names

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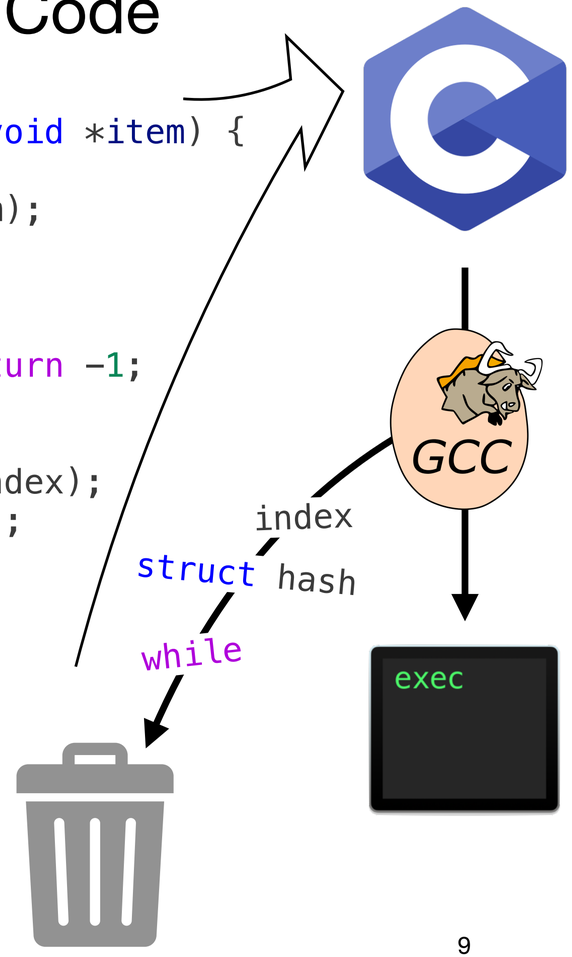

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1a3:   mov    %edx,-0x10(%rbp)
```

Control flow is gotos

Assembly is difficult for humans to read.

Original Source Code

```
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
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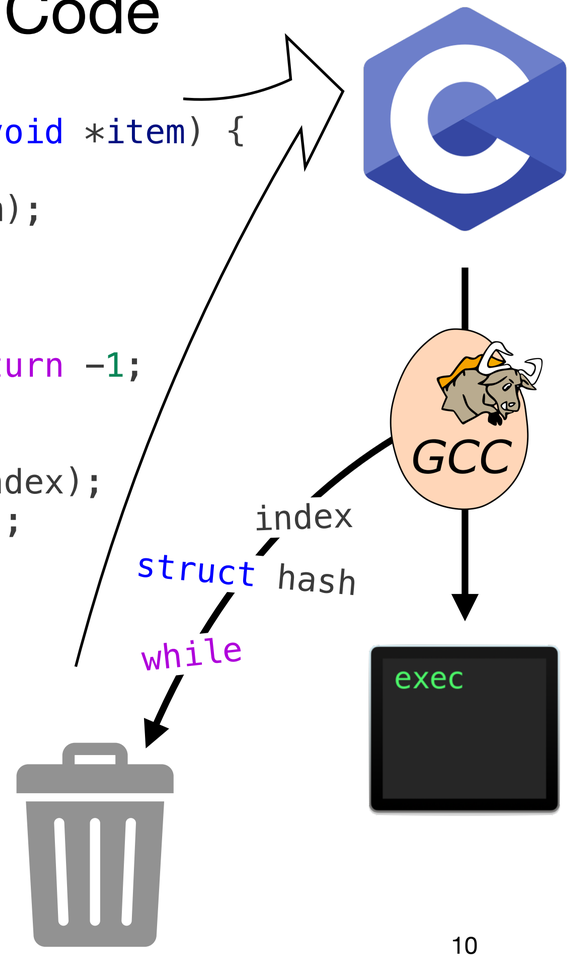
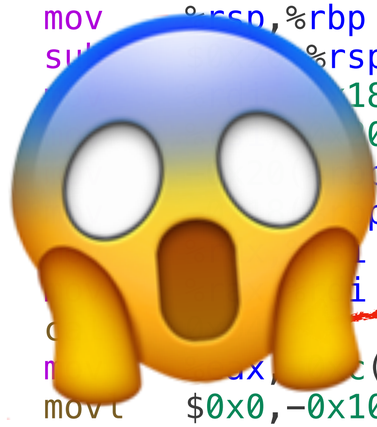


No identifier names

Assembly

(Human-Readable Compiled)

```
155:   push   %rbp
156:   mov    %rsp,%rbp
159:   sub    $0x20,%rsp
15d:   mov    %edi,-0x18(%rbp)
161:   mov    %rsi,-0x20(%rbp)
165:   mov    -0x18(%rbp),%rdx
169:   mov    -0x20(%rbp),%rax
16d:   callq  0x0
170:   mov    %rax,%rdi
173:   callq  0x0
178:   mov    %rax,-0xc(%rbp)
17b:   movl   $0x0,-0x10(%rbp)
182:   mov    -0x18(%rbp),%rax
186:   mov    0x8(%rax),%rax
18a:   mov    -0xc(%rbp),%edx
18d:   mov    %edx,%esi
18f:   mov    %rax,%rdi
192:   callq  0x5e
197:   mov    %rax,-0x8(%rbp)
19b:   jmp    0x200
19d:   mov    -0x10(%rbp),%eax
1a0:   lea    0x1(%rax),%edx
1a3:   mov    %edx,-0x10(%rbp)
```



Control flow is gotos

Decompilers help by reversing the compilation process.

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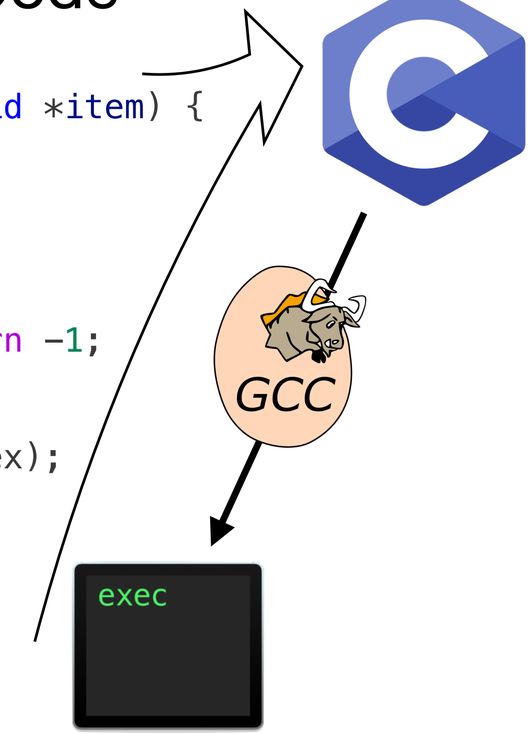

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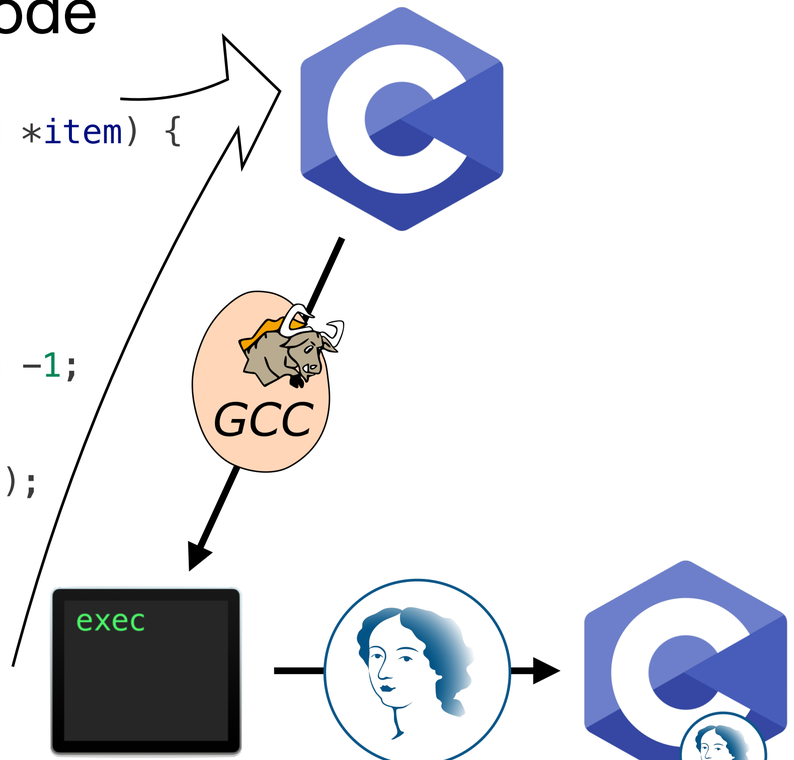

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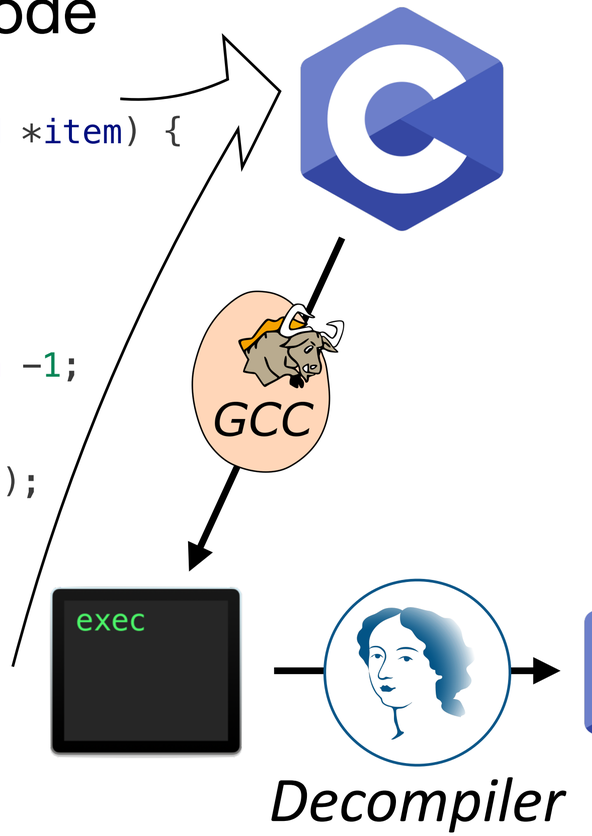

Decompiled Code

```c
__int64 __fastcall func4(__int64 a1, __int64 a2){
  int v2;           // eax
  __int64 result;   // rax
  int v4;           // [rsp+10h] [rbp-10h]
  unsigned int v5; // [rsp+14h] [rbp-Ch]
  __int64 i;        // [rsp+18h] [rbp-8h]

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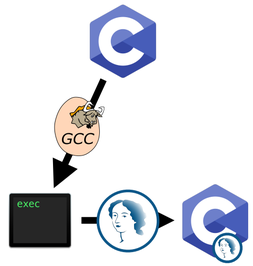

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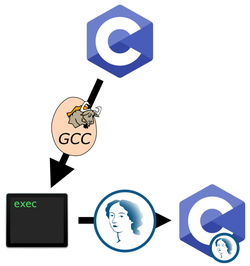

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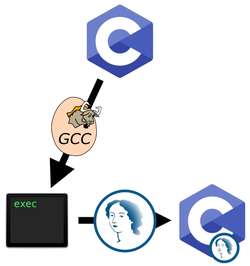

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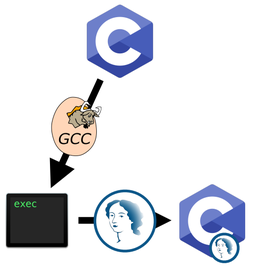

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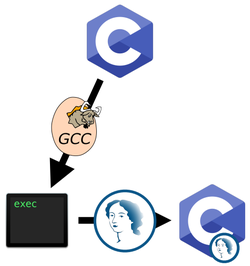

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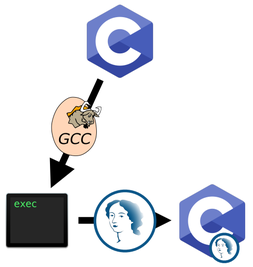

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In general, arbitrary transformations are required to match the original source.

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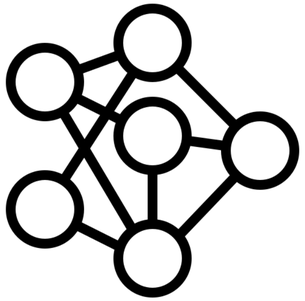
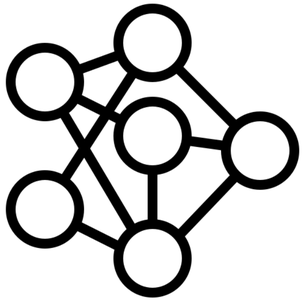
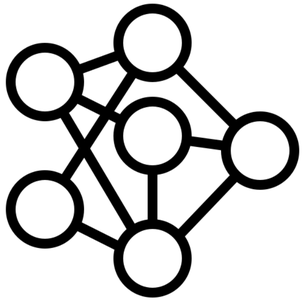
Discarded Details

Discarded Details $\Longrightarrow$  Probabilistic Prediction

Discarded Details $\Longrightarrow$  Probabilistic Prediction

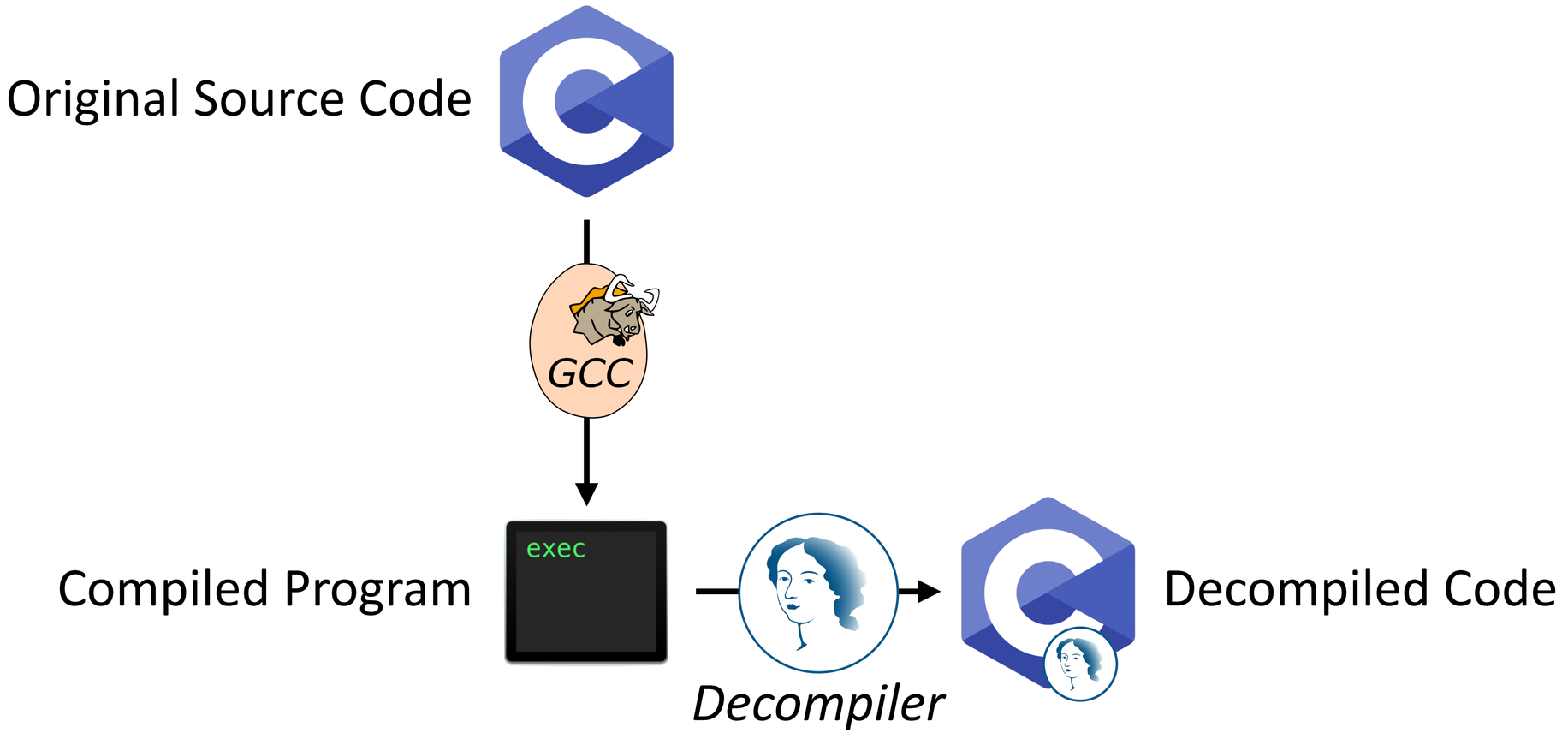
Best performing models for code processing

Discarded Details $\Longrightarrow$  Probabilistic Prediction

LLM✨ ← Best performing models for code processing

We fine-tuned a *local* LLM to perform this task

There are two main ways of doing neural decompilation



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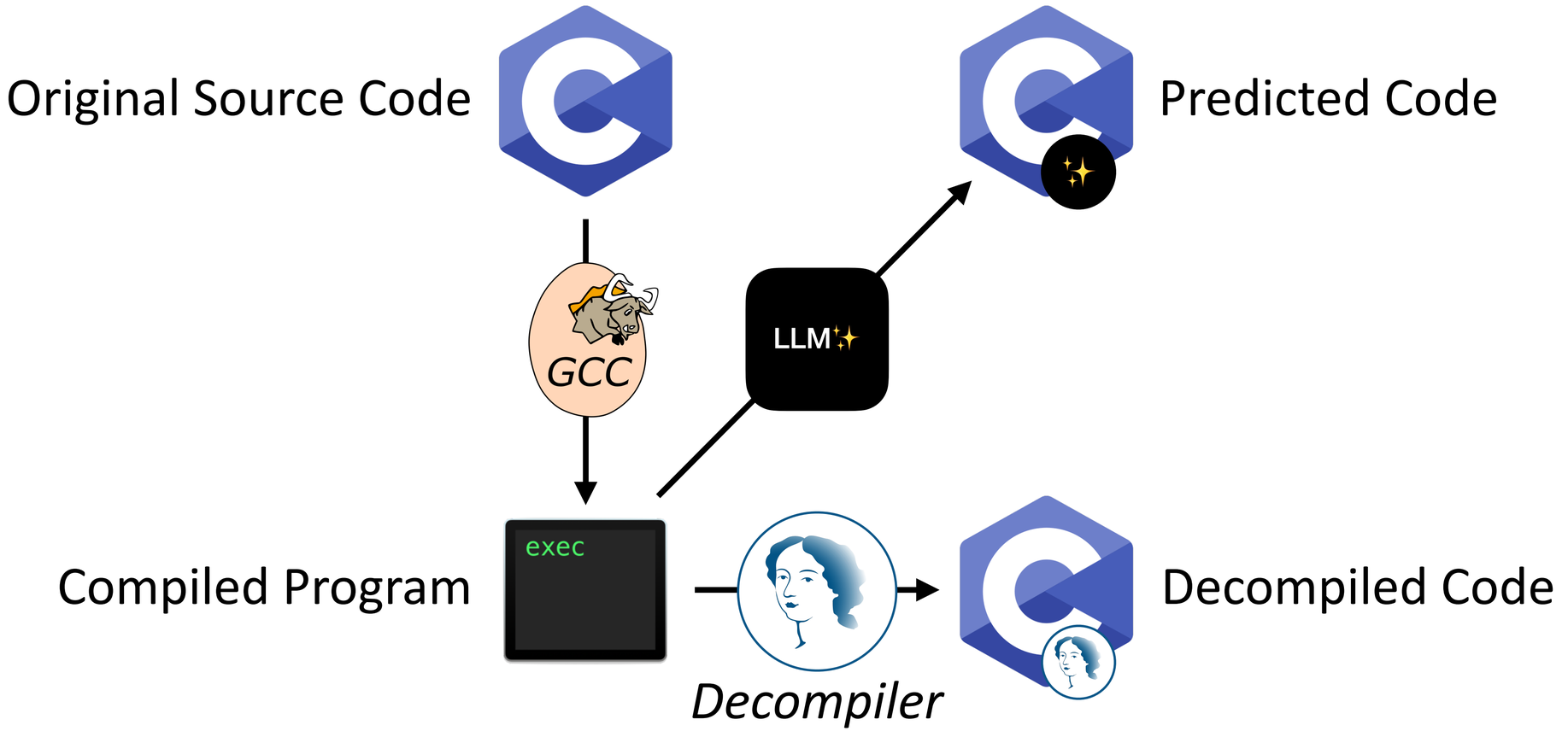

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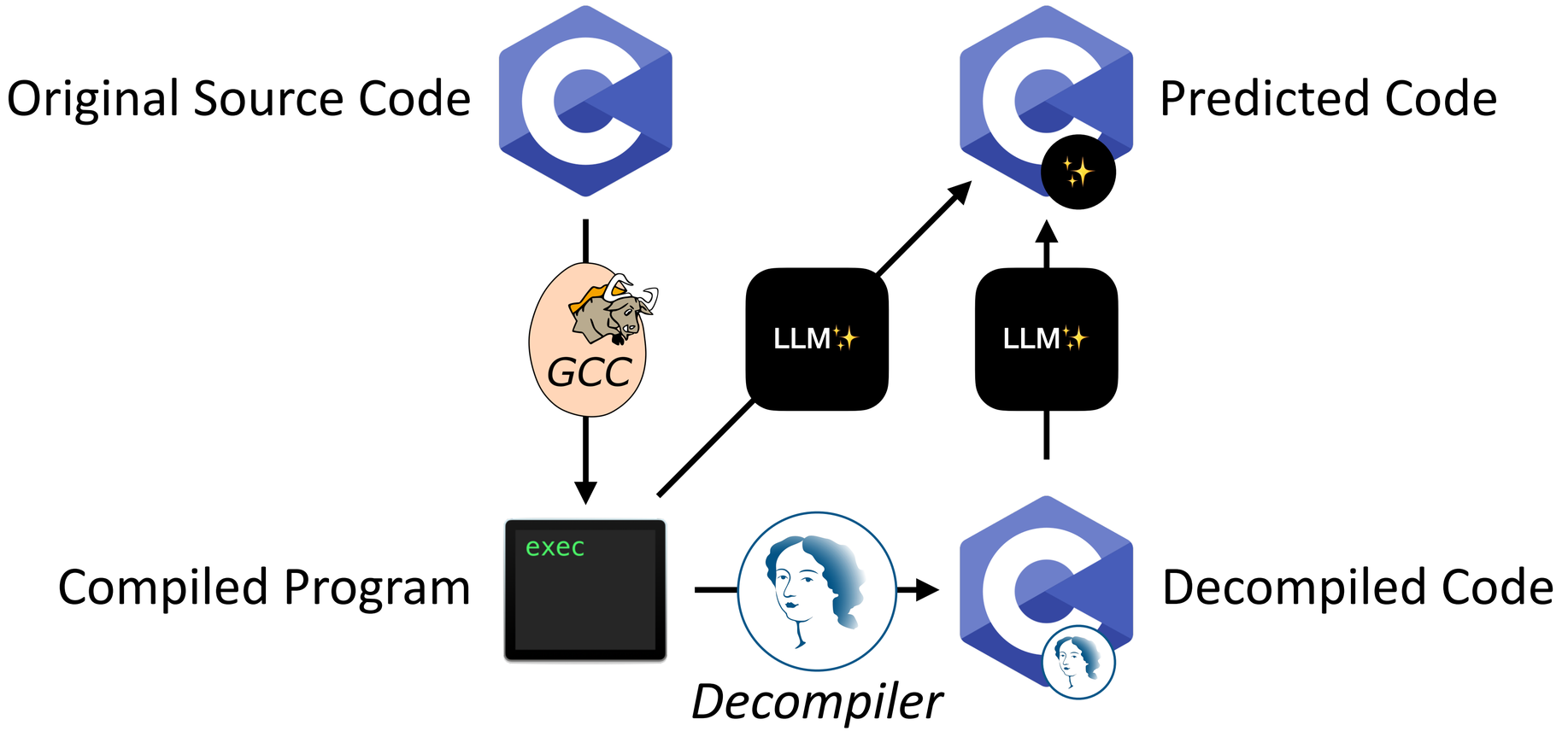
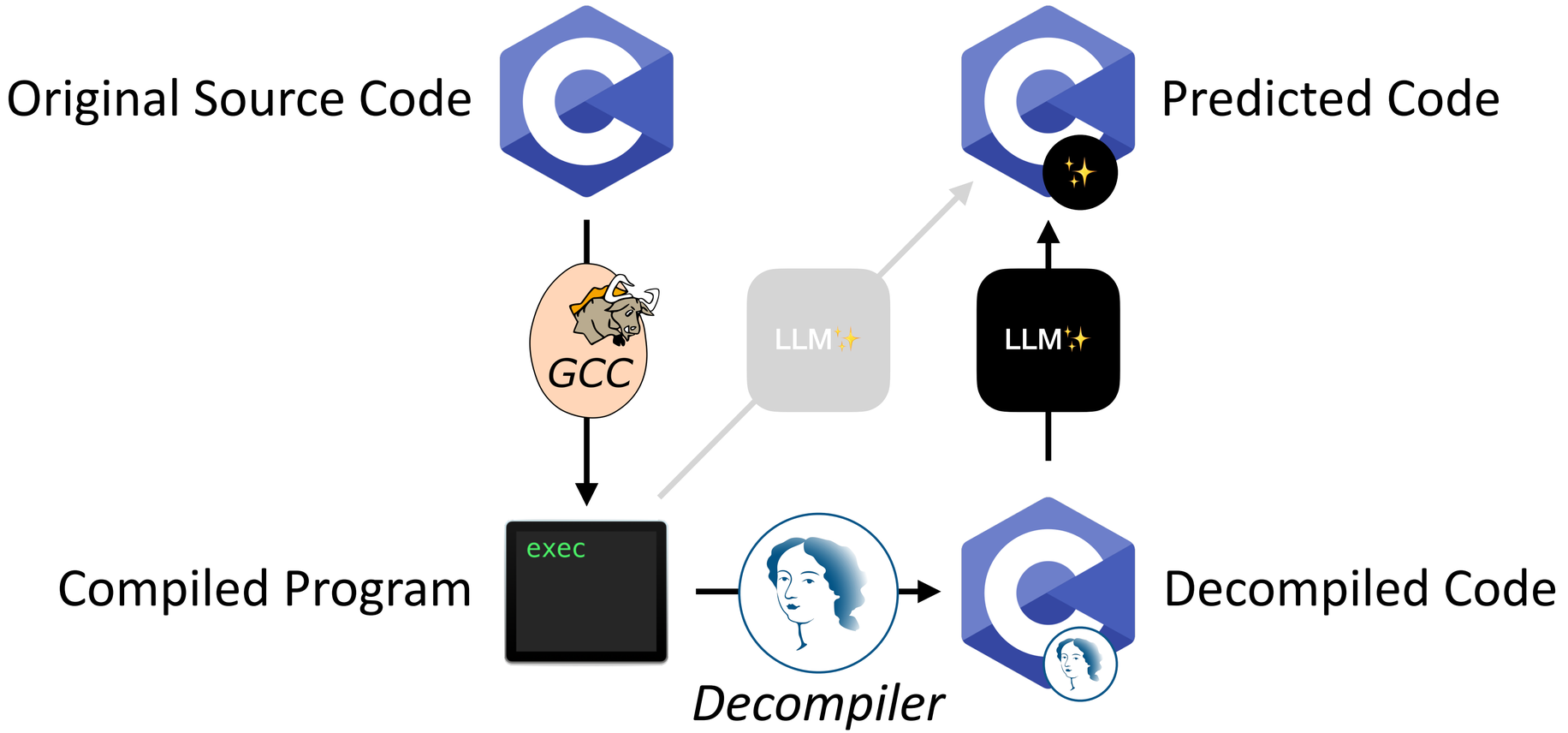


We treat the LLM as the last stage of decompilation



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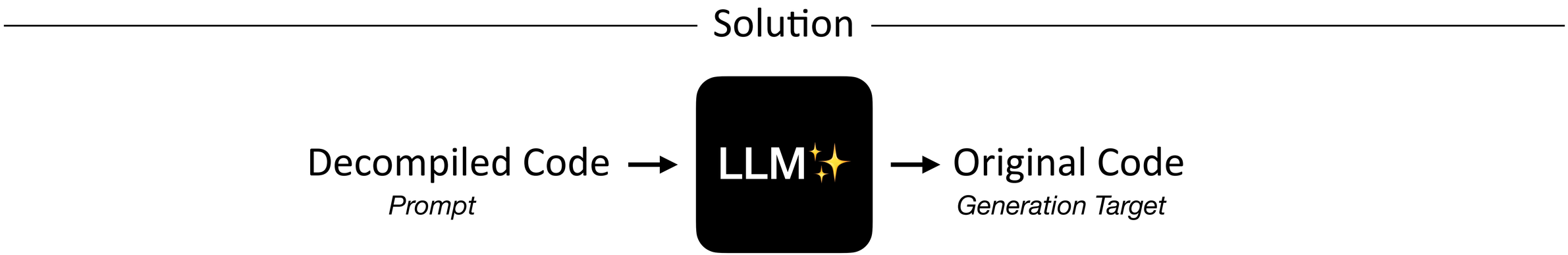

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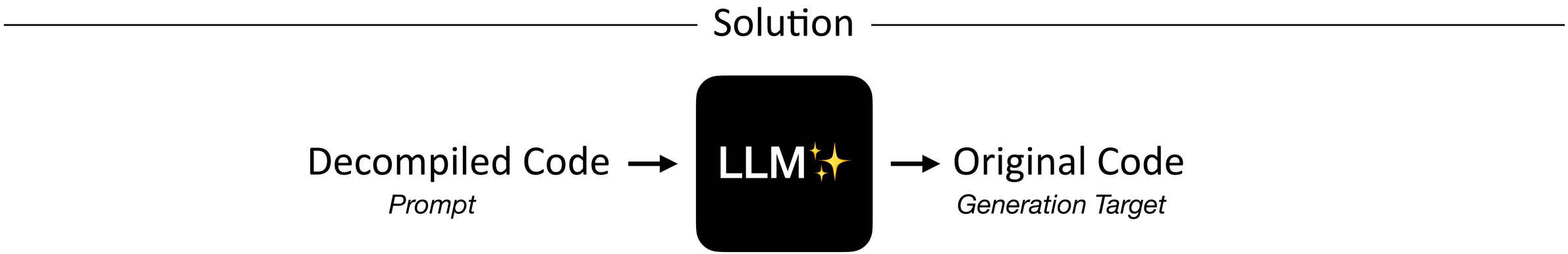
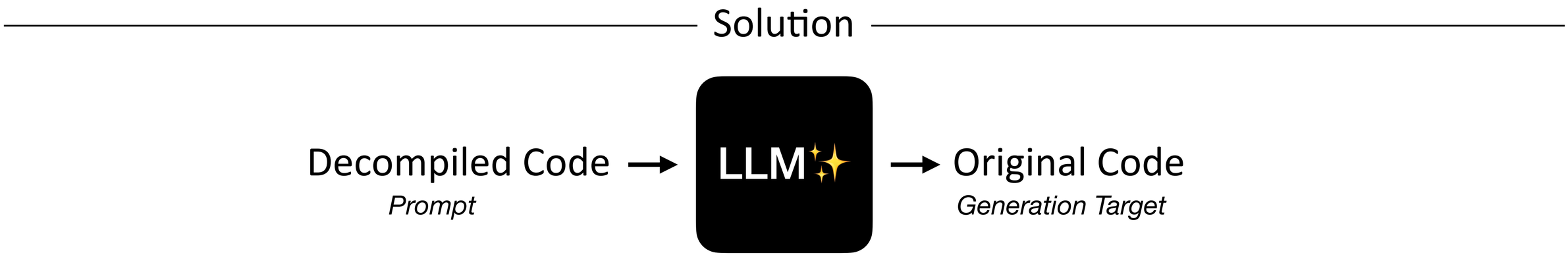
We build upon this base by incorporating problem-specific insights.



This type of textual transformation forms the basis for our solution, which we call *Idioms*

We build upon this base by incorporating problem-specific insights.

We focus on things that are *fundamental*: those which remain true even as general LLM performance improves over time.



Insight 1: Types are integral to the structure of the code.

Types are integral to the structure of the code.

Original Source Code

```
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```

Decompiled Code

```
__int64 __fastcall func4(__int64 a1, __int64 a2) {
  int v2;
  __int64 result;
  int v4;
  unsigned int v5;
  __int64 i;

  v5 = func2(a1, a2);
  v4 = 0;
  for (i = func1(*(_QWORD *)(a1 + 8), v5); i;
       i = func1(*(_QWORD *)(a1 + 8), v5)) {
    v2 = v4++;
    if (v2 > *(_DWORD *)a1)
      return 0xFFFFFFFFLL;
    if (!(*(unsigned int(__fastcall **)
          (__int64, __int64))(a1 + 24))(i, a2))
      break;
    v5 = func3((_DWORD *)a1, v5);
  }
  if (i)
    result = v5;
  else
    result = 0xFFFFFFFFLL;
  return result;
}
```

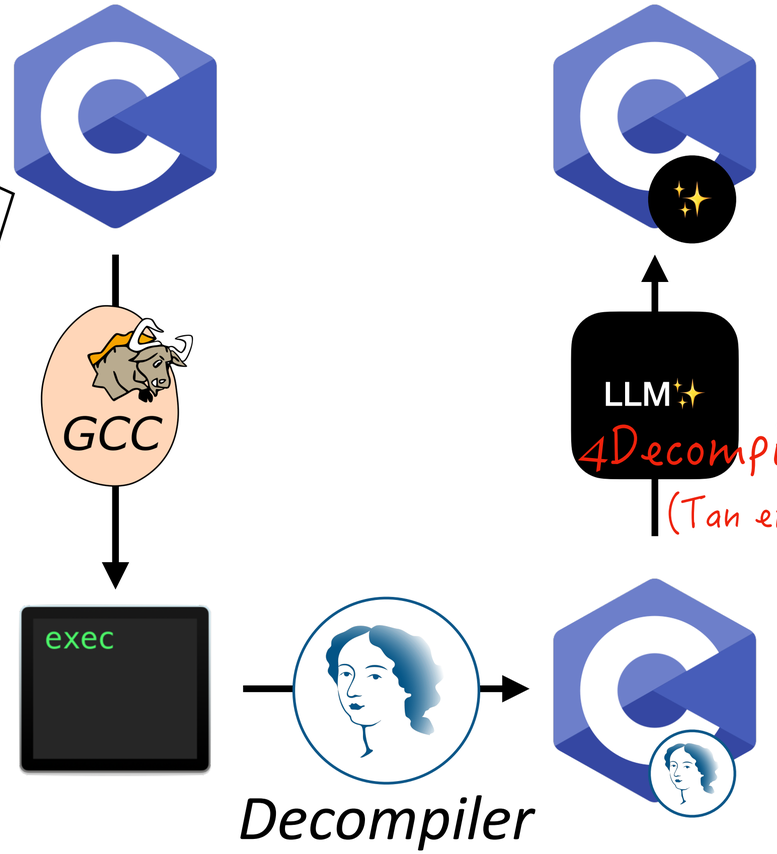
Pointer arithmetic to access struct members

Pointer dereference to access first struct member

Types are necessary to define the behavior of the function

Original Source Code

```c
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```



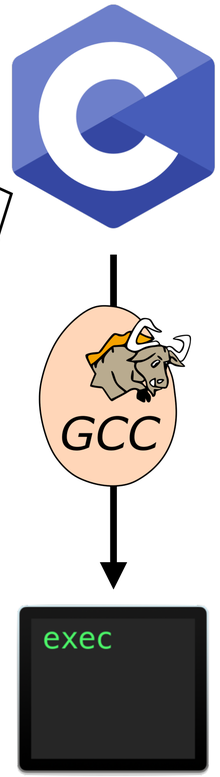
LLM4Decompile Prediction

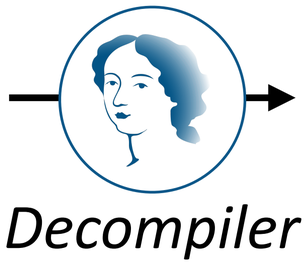
```c
int FUN_00100155 (struct FUN_0009ff84 *VAR_0,
                  void *VAR_1) {
  int VAR_2;
  int VAR_3;
  void *VAR_4;
  VAR_2 = FUN_0009ff86(VAR_0, VAR_1);
  VAR_3 = 0;
  VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
  while (VAR_4) {
    if (VAR_0->VAR_6 < VAR_3) {
      return -1;
    }
    if (!VAR_0->VAR_7(VAR_4, VAR_1)) {
      break;
    }
    VAR_2 = FUN_0009ff89(VAR_0, VAR_2);
    VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
    VAR_3++;
  }
  if (VAR_4) {
    return VAR_2;
  }
  return -1;
}
```

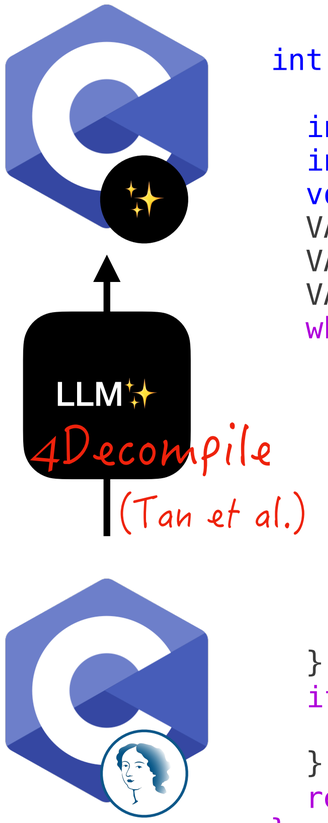
Types are necessary to define the behavior of the function

Original Source Code

```
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```







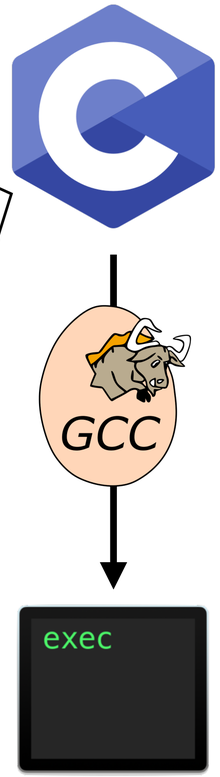
LLM4Decompile Prediction

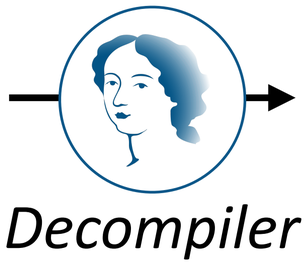
```
struct FUN_0009ff84 *
int FU                    void *VAR_1) {
  int __int64
  int VAR_3;
  void *VAR_4;
  VAR_2 = FUN_0009ff86(VAR_0, VAR_1);
  VAR_3 = 0;
  VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
  while (VAR_4) {
    if (VAR_0->VAR_6 < VAR_3) {
      return -1;
    }
    if (!VAR_0->VAR_7(VAR_4, VAR_1)) {
      break;
    }
    VAR_2 = FUN_0009ff89(VAR_0, VAR_2);
    VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
    VAR_3++;
  }
  if (VAR_4) {
    return VAR_2;
  }
  return -1;
}
```

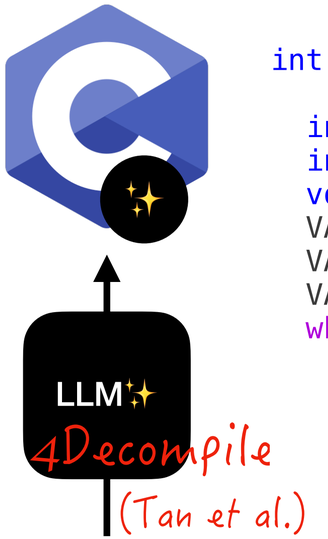
Types are necessary to define the behavior of the function

Original Source Code

```c
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```







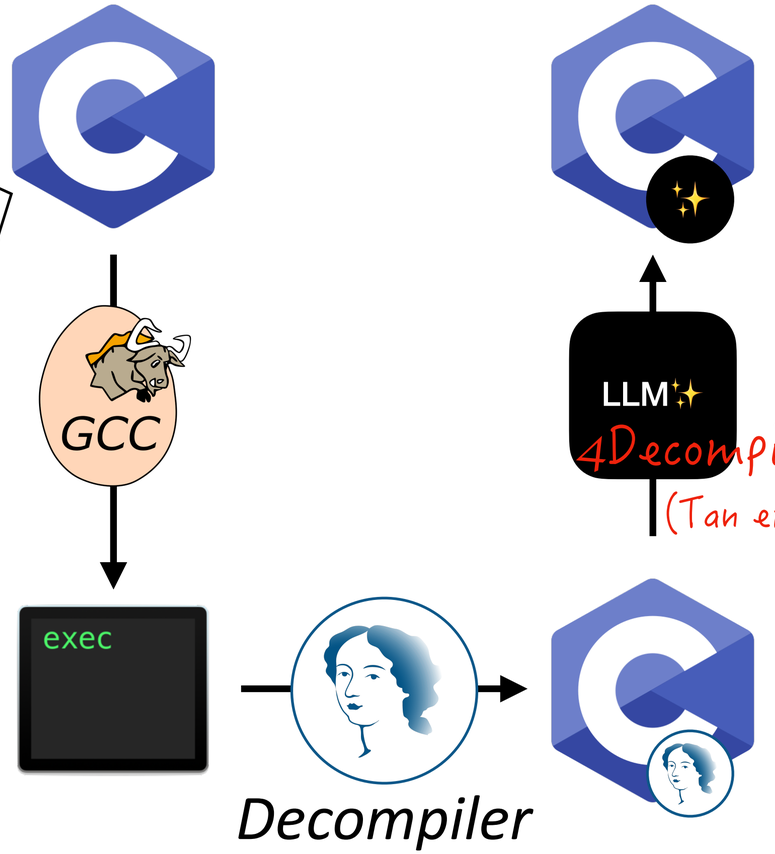
LLM4Decompile Prediction

```c
struct FUN_0009ff84 *
int FU                    void *VAR_1) {
  int ___                 t64
  int VA                  3;
  void *VAR_4;
  VAR_2 = FUN_0009ff86(VAR_0, VAR_1);
  VAR_3 = 0;
  VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
  while (VAR_4) {
    if (VAR_0->VAR_6 < VAR_3) {
      return -1;
    }
    if (!VAR_0->VAR_7(VAR_4, VAR_1)) {
      break;
    }
    VAR_2 = FUN_0009ff89(VAR_0, VAR_2);
    VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
    VAR_3++;
  }
  if (VAR_4) {
    return VAR_2;
  }
  return -1;
}
```

Types are necessary to define the behavior of the function

Original Source Code

```c
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```



LLM4Decompile Prediction

```c
int FU                                    void *VAR_1) {
  int ___                                 t64
  int VA                                  3;
  void *VAR_4;
  VAR_2 = FUN_0009ff86(VAR_0, VAR_1);
  VAR_3 = 0;
  VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
  while (VAR_4) {
    if (VAR_0->VAR_6 < VAR_3) {
      return -1;
    }
    if (!VAR_0->VAR_7(VAR_4, VAR_1)) {
      VAR_2 = FUN_00                      R_2);
      VAR_4 = FUN_00
      VAR_3++;
    }
    if (VAR_4) {
      return VAR_2;
    }
    return -1;
  }
```

struct FUN_0009ff84 *

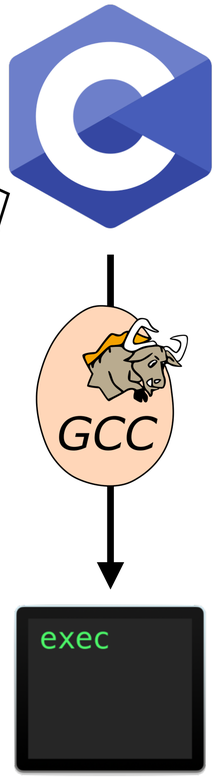
*(_QWORD *)(a1 + 8)

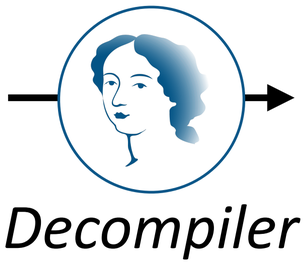
VAR_0->VAR_5

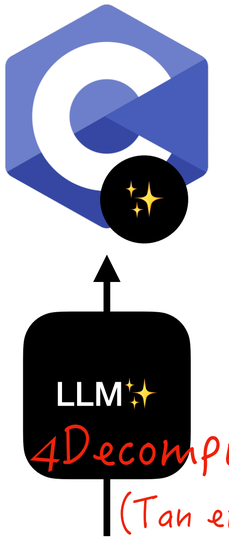
Types are necessary to define the behavior of the function

Original Source Code

```c
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```







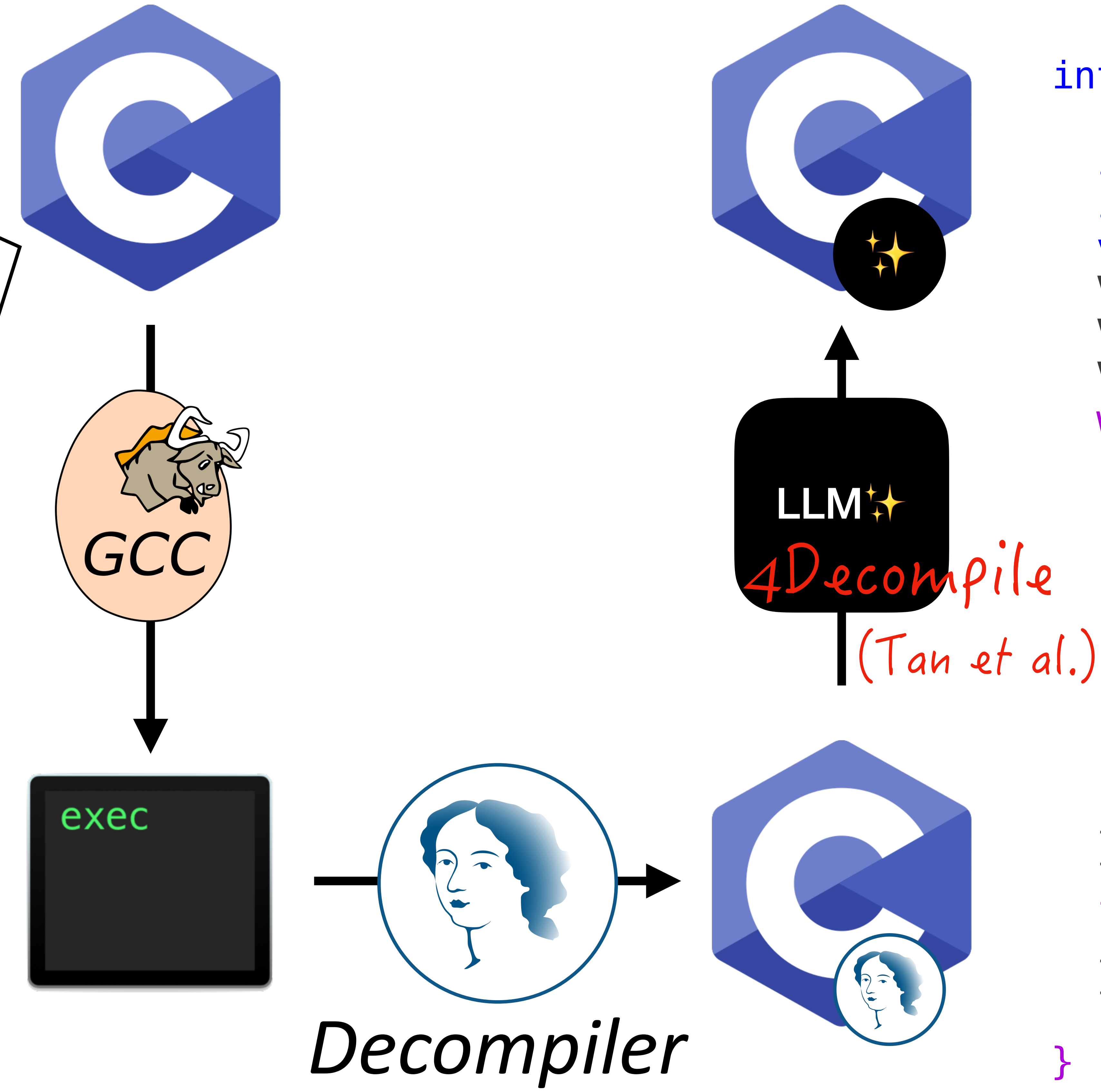
LLM4Decompile Prediction

```c
int FU                                    struct FUN_0009ff84 *
                                          void *VAR_1) {
  int ___                                 t64
  int VA
  void *VAR_4;
  VAR_2 = FUN_0009ff86(VAR_0, VAR_1);
  VAR_3 = 0;
  VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
  while (VAR_4) {
    if (VAR_0->VAR_6 < VAR_3) {
      return -1;
    }
    if (!VAR_0->VA                        7(  AR_4, VAR_1)) {
      *(_QWORD                            )(a1 + 8)
      VAR_2 = FUN_0
      VAR_4 = FUN_00                      VAR_0->VAR_5      _2);
      VAR_3++;
    }
    if (VAR_4) {
      return VAR_2;
    }
    return -1;
  }
```

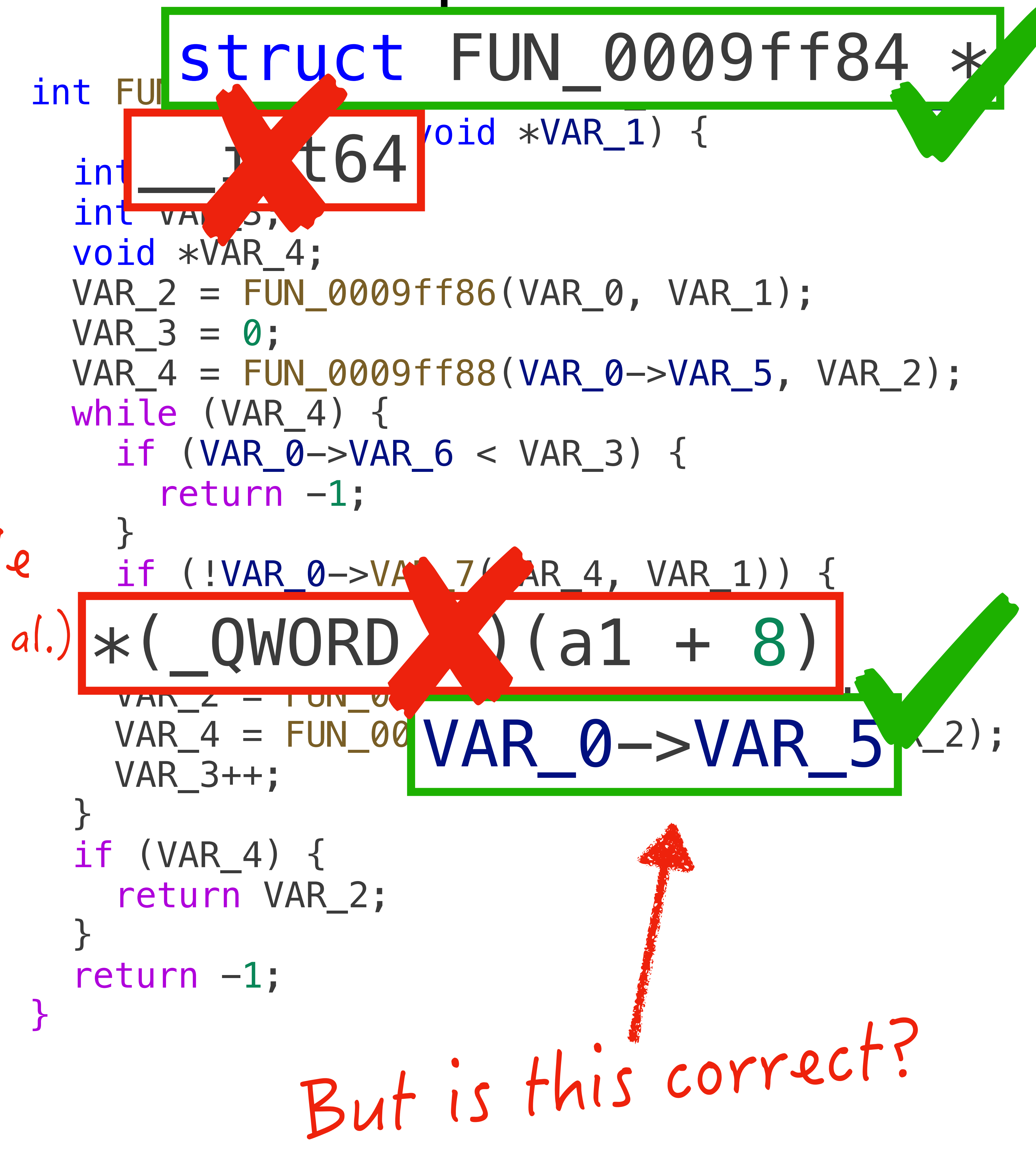
Types are necessary to define the behavior of the function

Original Source Code

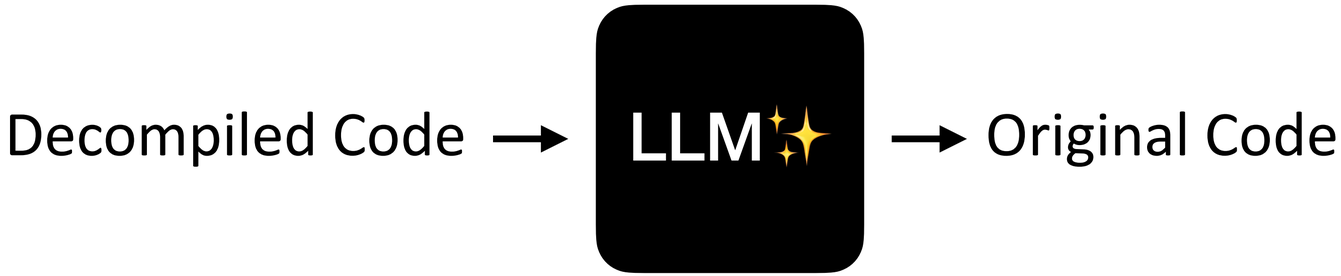
```c
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```



LLM4Decompile Prediction

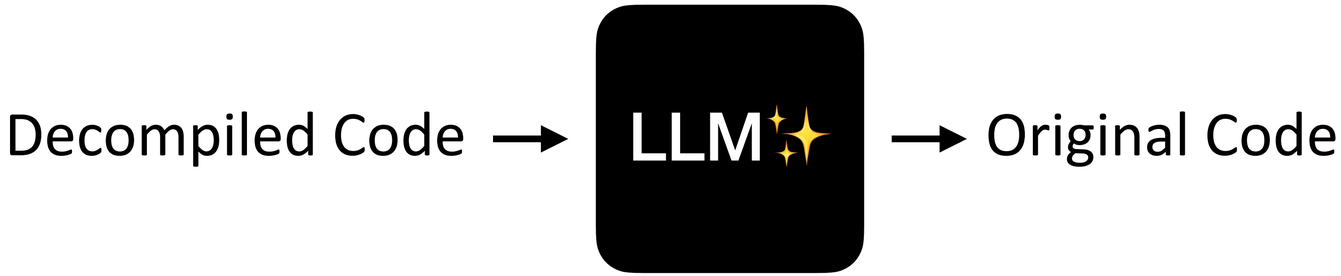


Solution



Solution: Predict necessary type definitions along with the original code

Solution



Solution: Predict necessary type definitions along with the original code

Solution

Our solution, *Idioms*, jointly predicts code and types.

Our Solution (*Idioms*) Prediction

```c
int hash_find(struct hash_t *hash, void *key)
{
    int index = hash_index(hash, key);
    int i = 0;
    void *item = hash_get(hash->table, index);
    while (item != ((void *)0)) {
        if (i++ > hash->size) {
            return -1;
        }
        if (hash->cmp(item, key) == 0) {
            break;
        }
        index = hash_next(hash, index);
        item = hash_get(hash->table, index);
    }
    return (item == ((void *)0)) ? -1 : index;
}

struct hash_t {
    int size;
    int count;
    struct hash_table_t *table;
    int (*hash)(void *key);
    int (*cmp)(void *key1, void *key2);
};
```

```c
struct hash_table_t {
    int size;
    void **items;
};
```

LLM4Decompile Prediction

```c
int FUN_00100155 (struct FUN_0009ff84 *VAR_0,
                  void *VAR_1) {
  int VAR_2;
  int VAR_3;
  void *VAR_4;
  VAR_2 = FUN_0009ff86(VAR_0, VAR_1);
  VAR_3 = 0;
  VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
  while (VAR_4) {
    if (VAR_0->VAR_6 < VAR_3) {
      return -1;
    }
    if (!VAR_0->VAR_7(VAR_4, VAR_1)) {
      break;
    }
    VAR_2 = FUN_0009ff89(VAR_0, VAR_2);
    VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
    VAR_3++;
  }
  if (VAR_4) {
    return VAR_2;
  }
  return -1;
}
```

Our solution, *Idioms*, jointly predicts code and types.

Our Solution (*Idioms*) Prediction

```
int hash_find(struct hash_t *hash, void *key)
{
    int index = hash_index(hash, key);
    int i = 0;
    void *item = hash_get(hash->table, index);
    while (item != ((void *)0)) {
        if (i++ > hash->size) {
            return -1;
        }
        if (hash->cmp(item, key) == 0) {
            break;
        }
        index
        item =
    }
    return (item == ((void *)0)) ? -1 : index;
}
```

What's a hash->table?

```
struct hash_t {
    int size;
    int count;
    struct hash_table_t *table;
    int (*hash)(void *key);
    int (*cmp)(void *key1, void *key2);
};
```

```
struct hash_table_t {
    int size;
    void **items;
};
```

LLM4Decompile Prediction

```
int FUN_00100155 (struct FUN_0009ff84 *VAR_0,
                  void *VAR_1) {
  int VAR_2;
  int VAR_3;
  void *VAR_4;
  VAR_2 = FUN_0009ff86(VAR_0, VAR_1);
  VAR_3 = 0;
  VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
  while (VAR_4) {
    if (VAR_0->VAR_6 < VAR_3) {
      return -1;
    }
    if (!VAR_0->VAR_7(VAR_4, VAR_1)) {
      break;
    }
    VAR_2 = FUN_0009ff89(VAR_0, VAR_2);
    VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
    VAR_3++;
  }
  if (VAR_4) {
    return VAR_2;
  }
  return -1;
}
```

Our solution, *Idioms*, jointly predicts code and types.

Our Solution (*Idioms*) Prediction

```
int hash_find(struct hash_t *hash, void *key)
{
    int index = hash_index(hash, key);
    int i = 0;
    void *item = hash_get(hash->table, index);
    while (item != ((void *)0)) {
        if (i++ > hash->size) {
            return -1;
        }
        if (hash->cmp(item, key) == 0) {
            break;
        }
        index
        item =
    }
    return (item == ((void *)0)) ? -1 : index;
}

struct hash_t {
    int size;
    int count;
    struct hash_table_t *table;
    int (*hash)(void *key);
    int (*cmp)(void *key1, void *key2);
};
```

What's a hash->table?

```
struct hash_table_t {
    int size;
    void **items;
};
```

LLM4Decompile Prediction

```
int FUN_00100155 (struct FUN_0009ff84 *VAR_0,
                  void *VAR_1) {
  int VAR_2;
  int VAR_3;
  void *VAR_4;
  VAR_2 = FUN_0009ff86(VAR_0, VAR_1);
  VAR_3 = 0;
  VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
  while (VAR_4) {
    if (VAR_0->VAR_6 < VAR_3) {
      return -1;
    }
    if (!VAR_0->VAR_7(VAR_4, VAR_1)) {
      break;
    }
    VAR_2 = FUN_0009ff89(VAR_0, VAR_2);
    VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
    VAR_3++;
  }
  if (VAR_4) {
    return VAR_2;
  }
  return -1;
}
```

Our solution, *Idioms*, jointly predicts code and types.

Our Solution (*Idioms*) Prediction

```c
int hash_find(struct hash_t *hash, void *key)
{
    int index = hash_index(hash, key);
    int i = 0;
    void *item = hash_get(hash->table, index);
    while (item != ((void *)0)) {
        if (i++ > hash->size) {
            return -1;
        }
        if (hash->cmp(item, key) == 0) {
            break;
        }
        index
        item =
    }
    return (item == ((void *)0)) ? -1 : index;
}

struct hash_t {
    int size;
    int count;
    struct hash_table_t *table;
    int (*hash)(void *key);
    int (*cmp)(void *key1, void *key2);
};

struct hash_table_t {
    int size;
    void **items;
};
```

What's a hash->table?

LLM4Decompile Prediction

```c
int FUN_00100155 (struct FUN_0009ff84 *VAR_0,
                  void *VAR_1) {
  int VAR_2;
  int VAR_3;
  void *VAR_4;
  VAR_2 = FUN_0009ff86(VAR_0, VAR_1);
  VAR_3 = 0;
  VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
  while (VAR_4) {
    if (VAR_0->VAR_6 < VAR_3) {
      return -1;
    }
    if (!VAR_0->VAR_7(VAR_4, VAR_1)) {
      break;
    }
    VAR_2 = FUN_0009ff89(VAR_0, VAR_2);
    VAR_4 = FUN_0009ff88(VAR_0->VAR_5, VAR_2);
    VAR_3++;
  }
  if (VAR_4) {
    return VAR_2;
  }
  return -1;
}
```

Insight 2: Type recovery requires interprocedural analysis in general—especially for composite types

Type recovery requires interprocedural analysis in general—especially for composite types

Original Source Code

```
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```

Decompiled Code

```
__int64 __fastcall func4(__int64 a1, __int64 a2) {
  int v2;
  __int64 result;
  int v4;
  unsigned int v5;
  __int64 i;

  v5 = func2(a1, a2);
  v4 = 0;
  for (i = func1(*(_QWORD *)(a1 + 8), v5); i;
       i = func1(*(_QWORD *)(a1 + 8), v5)) {
    v2 = v4++;
    if (v2 > *(_DWORD *)a1)
      return 0xFFFFFFFFLL;
    if (!(*(unsigned int(__fastcall **)
          (__int64, __int64))(a1 + 24))(i, a2))
      break;
    v5 = func3((_DWORD *)a1, v5);
  }
  if (i)
    result = v5;
  else
    result = 0xFFFFFFFFLL;
  return result;
}
```

Type recovery requires interprocedural analysis in general—especially for composite types

Original Source Code

```c
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```

Decompiled Code

```c
__int64 __fastcall func4(__int64 a1, __int64 a2) {
  int v2;
  __int64 result;
  int v4;
  unsigned int v5;
  __int64 i;

  v5 = func2(a1, a2);
  v4 = 0;
  for (i = func1(*(_QWORD **)(a1 + 8), v5); i;
       i = func1(*(_QWORD *)(a1 + 8), v5)) {
    v2 = v4++;
    if (v2 > *(_DWORD *)a1)
      return 0xFFFFFFFFLL;
    if (!(*(unsigned int(__fastcall **)
          (__int64, __int64))(a1 + 24))(i, a2))
      break;
    v5 = func3((_DWORD *)a1, v5);
  }
  if (i)
    result = v5;
  else
    result = 0xFFFFFFFFLL;
  return result;
}
```

What's the type of the field at a1 + 8?

Type recovery requires interprocedural analysis in general—especially for composite types

Original Source Code

```
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```

```
__int64 __fastcall func1(__int64 a1, int a2) {
    __int64 result; // rax

    if ( a2 < *(_DWORD *)a1 )
        result = *(_QWORD *)(*(_QWORD *)(a1 + 8) + 8LL * a2);
    else
        result = 0LL;
    return result;
}
```

Decompiled Code

```
__int64 __fastcall func4(__int64 a1, __int64 a2) {
  int v2;
  __int64 result;
  int v4;
  unsigned int v5;
  __int64 i;

  v5 = func2(a1, a2);
  v4 = 0;
  for (i = func1(*(_QWORD **)(a1 + 8), v5); i;
        i = func1(*(_QWORD *)(a1 + 8), v5)) {
    v2 = v4++;
    if (v2 > *(_DWORD *)a1)
      return 0xFFFFFFFFLL;
    if (!(*(unsigned int(__fastcall **)
          (__int64, __int64))(a1 + 24))(i, a2))
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    v5 = func3((_DWORD *)a1, v5);
  }
  if (i)
    result = v5;
  else
    result = 0xFFFFFFFFLL;
  return result;
}
```

What's the type of the field at a1 + 8?

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    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
}
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}
```

Decompiled Code

```
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  int v4;
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  __int64 i;

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    v2 = v4++;
    if (v2 > *(_DWORD *)a1)
      return 0xFFFFFFFFLL;
    if (!(*(unsigned int(__fastcall **)
          (__int64, __int64))(a1 + 24))(i, a2))
      break;
    v5 = func3((_DWORD *)a1, v5);
  }
  if (i)
    result = v5;
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    result = 0xFFFFFFFFLL;
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What's the type of the field at a1 + 8?

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    void *cnx;
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        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```

```
__int64 __fastcall func1(__int64 a1, int a2) {
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        result = *(_QWORD *)(*(_QWORD *)(a1 + 8) + 8LL * a2);
    else
        result = 0LL;
    return result;
}
```

Decompiled Code

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        i = func1(*(_QWORD *)(a1 + 8), v5)) {
    v2 = v4++;
    if (v2 > *(_DWORD *)a1)
      return 0xFFFFFFFFLL;
    if (!(*(unsigned int(__fastcall **)
          (__int64, __int64))(a1 + 24))(i, a2))
      break;
    v5 = func3((_DWORD *)a1, v5);
  }
  if (i)
    result = v5;
  else
    result = 0xFFFFFFFFLL;
  return result;
}
```
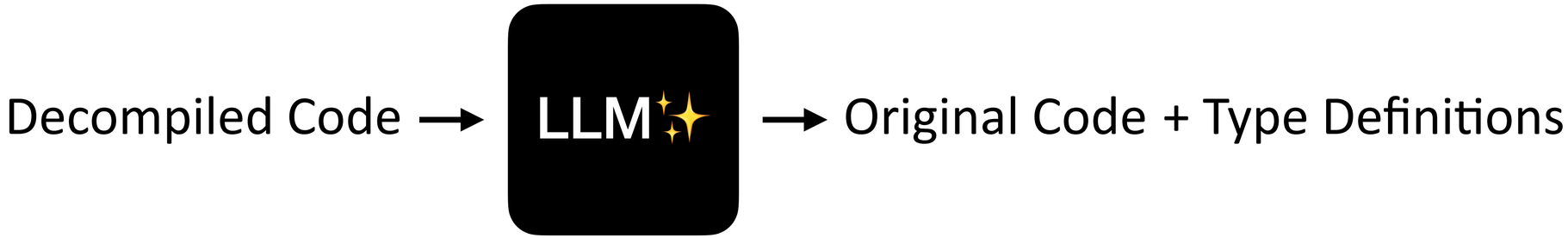
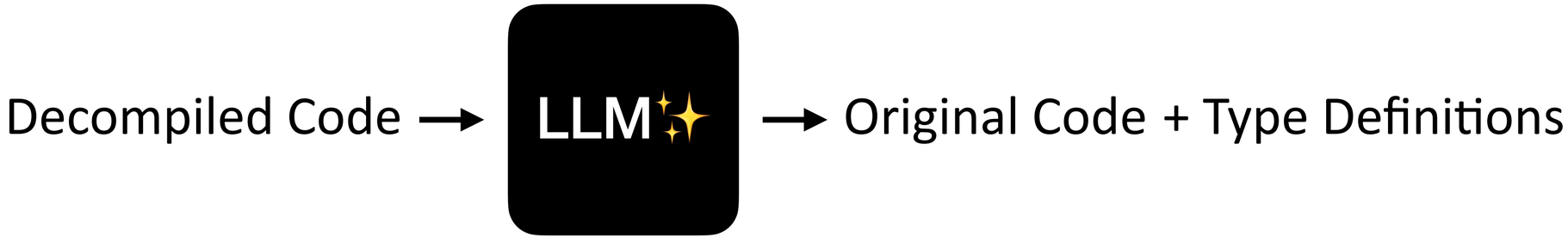

What's the type of the field at a1 + 8?

Solution



Solution: Include the bodies of other decompiled functions in the context

Solution



Solution: Include the bodies of other decompiled functions in the context

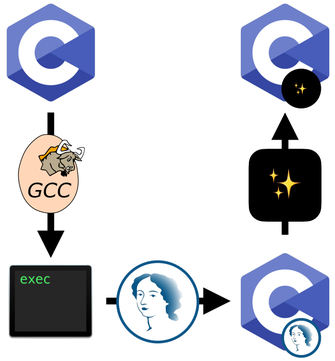
Solution

Decompiled Code + Other Functions → LLM ✨ → Original Code + Type Definitions

The context of the target function alone may be insufficient to correctly interpret that function.

Original Source Code

```c
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```




```c
struct hash {
    int hash_size;
    int item_cnt;
    struct gap_array *data;
    int (*hash_make_key)(void *item);
    int (*cmp_item)(void *item1, void *item2);
}
```

```c
struct gap_array {
    int len;
    void **array;
}
```

The context of the target function alone may be insufficient to correctly interpret that function.

Original Source Code

```c
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}
```

```c
struct hash {
    int hash_size;
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    int (*hash_make_key)(void *item);
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}
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struct gap_array {
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    void **array;
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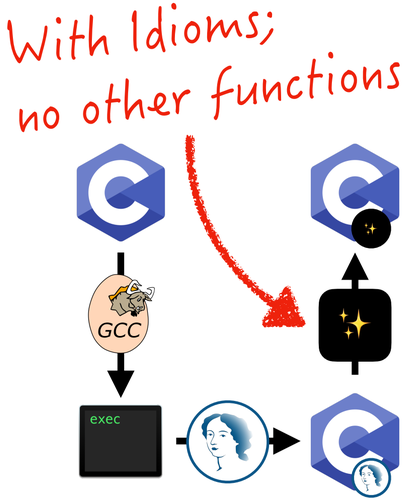

The context of the target function alone may be insufficient to correctly interpret that function.

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    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
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}

struct hash {
    int hash_size;
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struct gap_array {
    int len;
    void **array;
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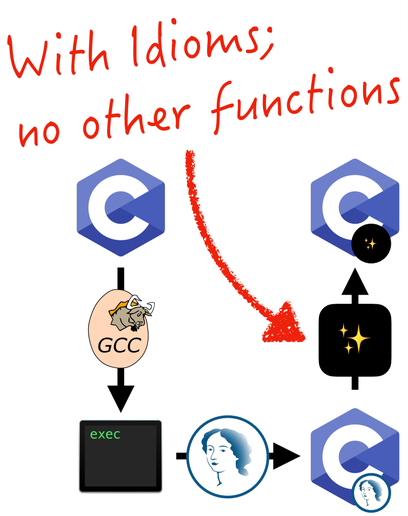


Bad Idioms: NO additional context

```c
int hash_table_find(struct hash_table *ht, void *key) {
    struct hash_entry *he;
    int hash_val = hash_table_hash(ht, key);
    int i = 0;
    for (he = hash_table_get(ht->ht, hash_val); he;
         he = hash_table_get(ht->ht, hash_val)) {
        if (i++ > ht->size)
            return -1;
        if (!ht->cmp(he, key))
            break;
        hash_val = hash_table_next(ht, hash_val);
    }
    if (he)
        return hash_val;
    return -1;
}

struct hash_table {
    int size;
    struct hash_entry **ht;
    int (*cmp)(void *, void *);
    int (*hash)(void *);
};
```

```c
struct hash_entry {
    void *key;
    void *value;
    struct hash_entry *next;
};
```

The context of the target function alone may be insufficient to correctly interpret that function.

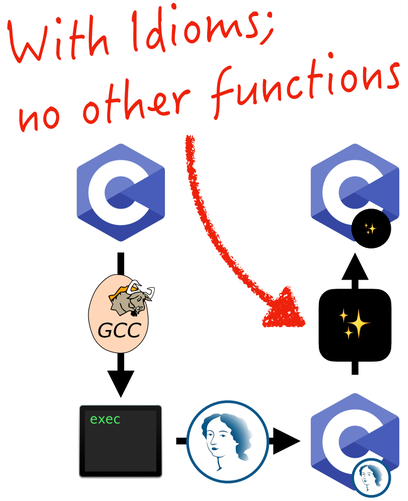
Original Source Code

```
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}

struct hash {
    int hash_size;
    int item_cnt;
    struct gap_array *data;
    int (*hash_make_key)(void *item);
    int (*cmp_item)(void *item1, void *item2);
}
```

All data is stored in an array

```
struct gap_array {
    int len;
    void **array;
}
```



Bad Idioms: NO additional context

```
int hash_table_find(struct hash_table *ht, void *key) {
    struct hash_entry *he;
    int hash_val = hash_table_hash(ht, key);
    int i = 0;
    for (he = hash_table_get(ht->ht, hash_val); he;
         he = hash_table_get(ht->ht, hash_val)) {
        if (i++ > ht->size)
            return -1;
        if (!ht->cmp(he, key))
            break;
        hash_val = hash_table_next(ht, hash_val);
    }
    if (he)
        return hash_val;
    return -1;
}

struct hash_table {
    int size;
    struct hash_entry **ht;
    int (*cmp)(void *, void *);
    int (*hash)(void *);
};
```

```
struct hash_entry {
    void *key;
    void *value;
    struct hash_entry *next;
};
```

The context of the target function alone may be insufficient to correctly interpret that function.

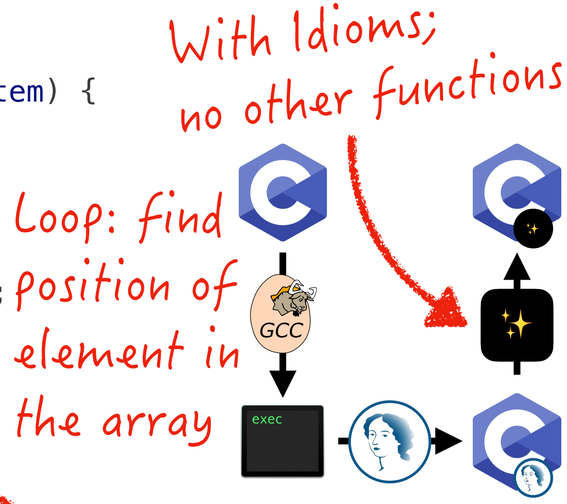
Original Source Code

```c
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}

struct hash {
    int hash_size;
    int item_cnt;
    struct gap_array *data;
    int (*hash_make_key)(void *item);
    int (*cmp_item)(void *item1, void *item2);
}
```

All data is stored in an array

```c
struct gap_array {
    int len;
    void **array;
}
```



Bad Idioms: NO additional context

```c
int hash_table_find(struct hash_table *ht, void *key) {
    struct hash_entry *he;
    int hash_val = hash_table_hash(ht, key);
    int i = 0;
    for (he = hash_table_get(ht->ht, hash_val); he;
         he = hash_table_get(ht->ht, hash_val)) {
        if (i++ > ht->size)
            return -1;
        if (!ht->cmp(he, key))
            break;
        hash_val = hash_table_next(ht, hash_val);
    }
    if (he)
        return hash_val;
    return -1;
}

struct hash_table {
    int size;
    struct hash_entry **ht;
    int (*cmp)(void *, void *);
    int (*hash)(void *);
};
```

```c
struct hash_entry {
    void *key;
    void *value;
    struct hash_entry *next;
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The context of the target function alone may be insufficient to correctly interpret that function.

Original Source Code

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int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}

struct hash {
    int hash_size;
    int item_cnt;
    struct gap_array *data;
    int (*hash_make_key)(void *item);
    int (*cmp_item)(void *item1, void *item2);
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```

All data is stored in an array

```
struct gap_array {
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    void **array;
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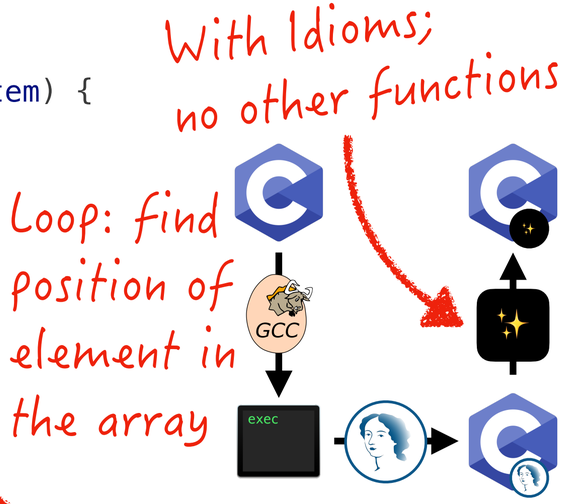
```



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int hash_table_find(struct hash_table *ht, void *key) {
    struct hash_entry *he;
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    for (he = hash_table_get(ht->ht, hash_val); he;
         he = hash_table_get(ht->ht, hash_val)) {
        if (i++ > ht->size)
            return -1;
        if (!ht->cmp(he, key))
            break;
        hash_val = hash_table_next(ht, hash_val);
    }
    if (he)
        return hash_val;
    return -1;
}

struct hash_table {
    int size;
    struct hash_entry **ht;
    int (*cmp)(void *, void *);
    int (*hash)(void *);
};
```

```
struct hash_entry {
    void *key;
    void *value;
    struct hash_entry *next;
};
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Original Source Code

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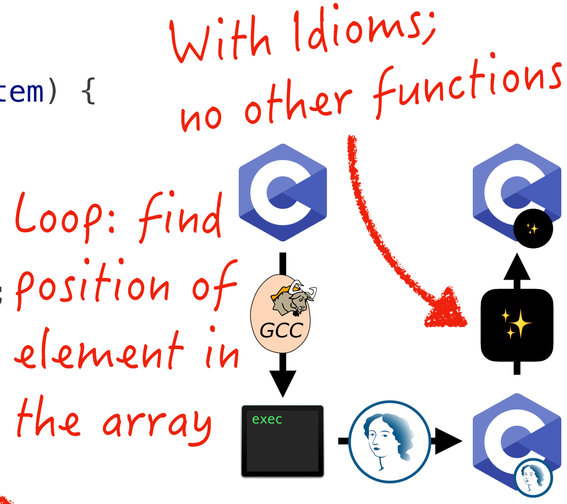
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}

struct hash {
    int hash_size;
    int item_cnt;
    struct gap_array *data;
    int (*hash_make_key)(void *item);
    int (*cmp_item)(void *item1, void *item2);
}
```

All data is stored in an array

```
struct gap_array {
    int len;
    void **array;
}
```



Bad Idioms: NO additional context

```
int hash_table_find(struct hash_table *ht, void *key) {
    struct hash_entry *he;
    int hash_val = hash_table_hash(ht, key);
    int i = 0;
    for (he = hash_table_get(ht->ht, hash_val); he;
         he = hash_table_get(ht->ht, hash_val)) {
        if (i++ > ht->size)
            return -1;
        if (!ht->cmp(he, key))
            break;
        hash_val = hash_table_next(ht, hash_val);
    }
    if (he)
        return hash_val;
    return -1;
}

struct hash_table {
    int size;
    struct hash_entry **ht;
    int (*cmp)(void *, void *);
    int (*hash)(void *);
};
```

```
struct hash_entry {
    void *key;
    void *value;
    struct hash_entry *next;
};
```

An array of linked lists

The context of the target function alone may be insufficient to correctly interpret that function.

Original Source Code

```
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}

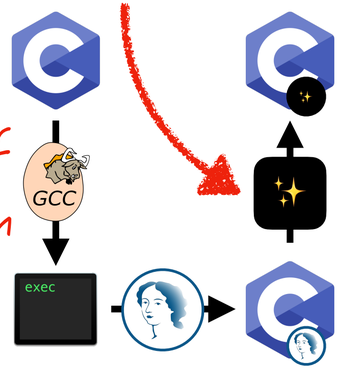
struct hash {
    int hash_size;
    int item_cnt;
    struct gap_array *data;
    int (*hash_make_key)(void *item);
    int (*cmp_item)(void *item1, void *item2);
}
```

All data is stored in an array

```
struct gap_array {
    int len;
    void **array;
}
```

With Idioms; no other functions

Loop: find position of element in the array



Bad Idioms: NO additional context

```
int hash_table_find(struct hash_table *ht, void *key) {
    struct hash_entry *he;
    int hash_val = hash_table_hash(ht, key);
    int i = 0;
    for (he = hash_table_get(ht->ht, hash_val); he;
         he = hash_table_get(ht->ht, hash_val)) {
        if (i++ > ht->size)
            return -1;
        if (!ht->cmp(he, key))
            break;
        hash_val = hash_table_next(ht, hash_val);
    }
    if (he)
        return hash_val;
    return -1;
}

struct hash_table {
    int size;
    struct hash_entry **ht;
    int (*cmp)(void *, void *);
    int (*hash)(void *);
};
```

Loop: search the linked list for the element

```
struct hash_entry {
    void *key;
    void *value;
    struct hash_entry *next;
};
```

An array of linked lists

The context of the target function alone may be insufficient to correctly interpret that function.

Original Source Code

```
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}

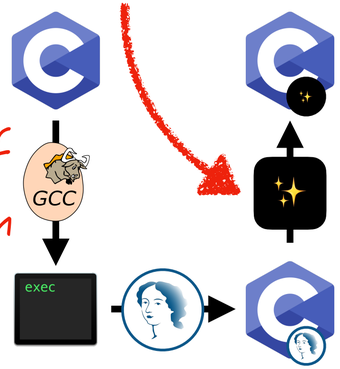
struct hash {
    int hash_size;
    int item_cnt;
    struct gap_array *data;
    int (*hash_make_key)(void *item);
    int (*cmp_item)(void *item1, void *item2);
}
```

All data is stored in an array

```
struct gap_array {
    int len;
    void **array;
}
```

With Idioms; no other functions

Loop: find position of element in the array



Bad Idioms: NO additional context

```
int hash_table_find(struct hash_table *ht, void *key) {
    struct hash_entry *he;
    int hash_val = hash_table_hash(ht, key);
    int i = 0;
    for (he = hash_table_get(ht->ht, hash_val); he;
         he = hash_table_get(ht->ht, hash_val)) {
        if (i++ > ht->size)
            return -1;
        if (!ht->cmp(he, key))
            break;
        hash_val = hash_table_next(ht, hash_val);
    }
    if (he)
        return hash_val;
    return -1;
}

struct hash_table {
    int size;
    struct hash_entry **ht;
    int (*cmp)(void *, void *);
    int (*hash)(void *);
};
```

Loop: search the linked list for the element

```
struct hash_entry {
    void *key;
    void *value;
    struct hash_entry *next;
};
```

An array of linked lists

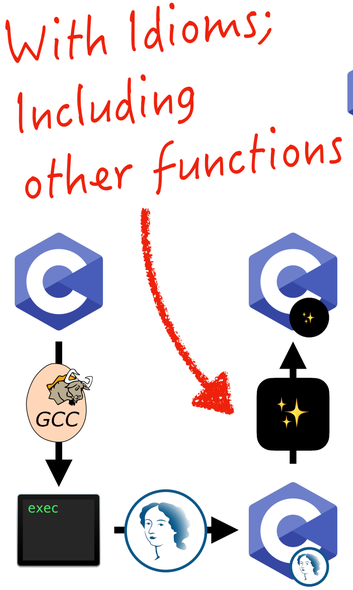
The additional context from other functions improves prediction correctness

Original Source Code

```
int hash_find_index(struct hash *h, void *item) {
    void *cnx;
    int index = hash_make_key(h, item);
    int cnt = 0;
    cnx = gap_get(h->data, index);
    while (cnx != NULL) {
        if (cnt++ > h->hash_size) return -1;
        if (!h->cmp_item(cnx, item))
            break;
        index = hash_next_index(h, index);
        cnx = gap_get(h->data, index);
    }
    if (cnx == NULL) return -1;
    return index;
}

struct hash {
    int hash_size;
    int item_cnt;
    struct gap_array *data;
    int (*hash_make_key)(void *item);
    int (*cmp_item)(void *item1, void *item2);
}
```

```
struct gap_array {
    int len;
    void **array;
}
```



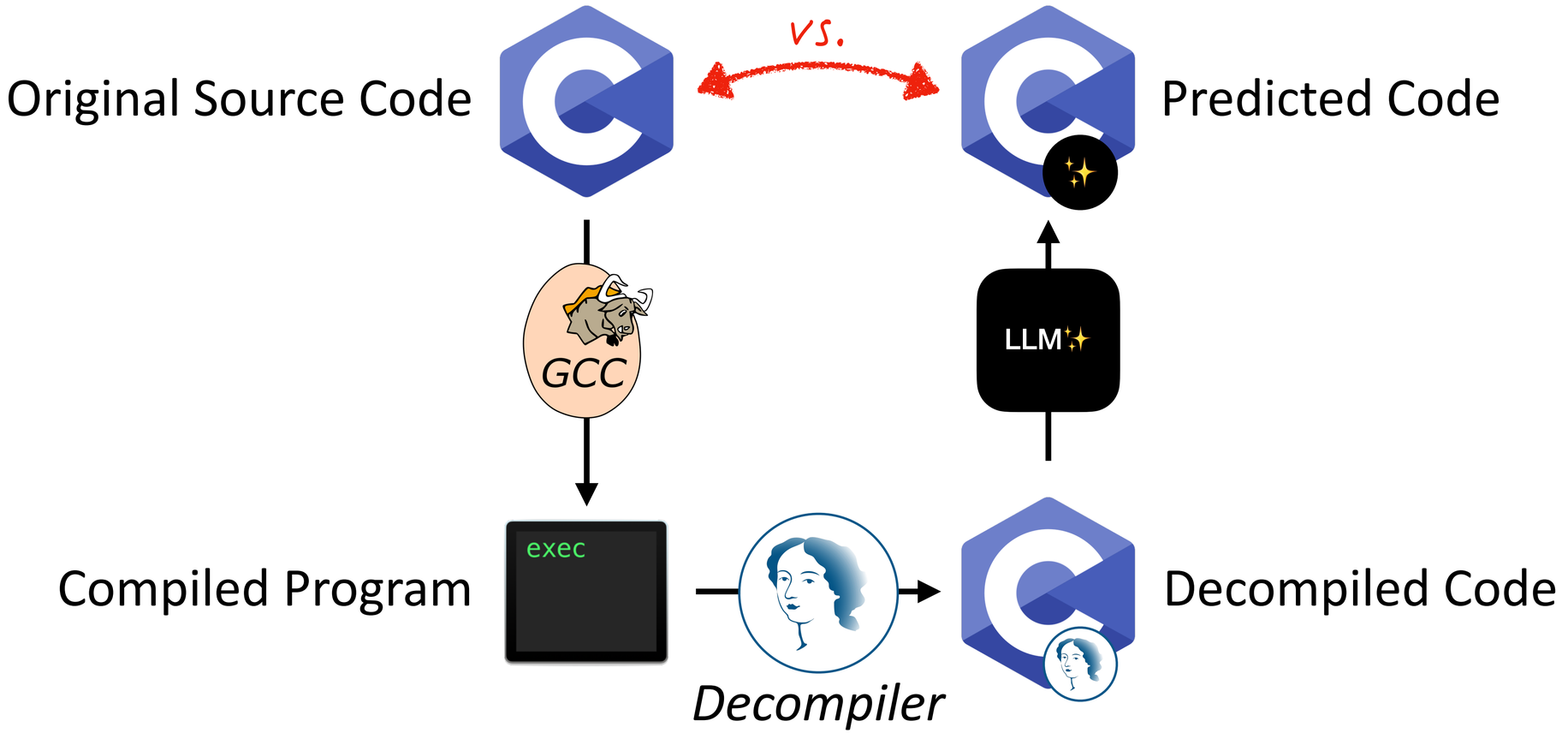
Idioms: YES additional context

```
int hash_find(struct hash_t *hash, void *key)
{
    int index = hash_index(hash, key);
    int i = 0;
    void *item = hash_get(hash->table, index);
    while (item != ((void *)0)) {
        if (i++ > hash->size) {
            return -1;
        }
        if (hash->cmp(item, key) == 0) {
            break;
        }
        index = hash_next(hash, index);
        item = hash_get(hash->table, index);
    }
    return (item == ((void *)0)) ? -1 : index;
}

struct hash_t {
    int size;
    int count;
    struct hash_table_t *table;
    int (*hash)(void *key);
    int (*cmp)(void *key1, void *key2);
};
```

```
struct hash_table_t {
    int size;
    void **items;
};
```

To evaluate, we compare the predicted and original code.



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  - *Want to measure*: How frequently are neural decompilers correct?
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  - *Want to measure*: Quality of improvements made to the code.

We built a new benchmark focused on user-defined types (UDTs): `structs` and `unions`

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For more info, check out this paper!

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Our metrics evaluate both correctness and improvements made to the code.

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Improvements	Variable Name Accuracy
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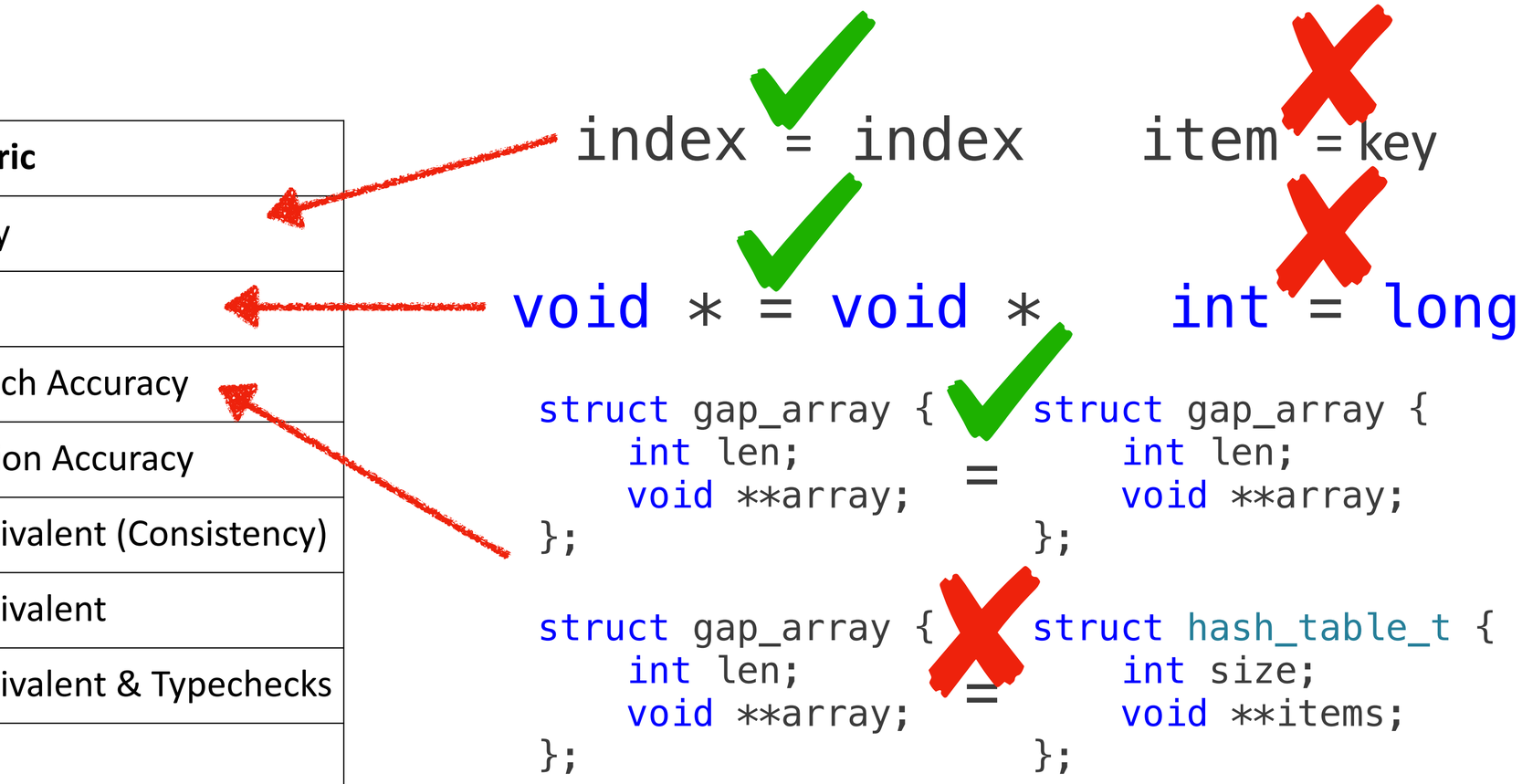

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AND all non-UDT types are correct
AND all UDTs match compositionally.

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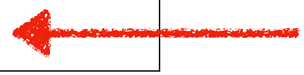

Only applies to the exebench dataset

Our evaluation shows that our modeling approach offers significant improvement over prior work

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Correctness	Dependency-based Equivalent (Consistency)	24.8	27.9	**34.1**	16.6	10.6	**32.3**
	Dependency-based Equivalent	23.9	27.4	**33.7**	6.7	7.3	**21.6**
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Idioms full paper

I’m on the industry job market!

My website