Better Code

Sean Parent | Principal Scientist

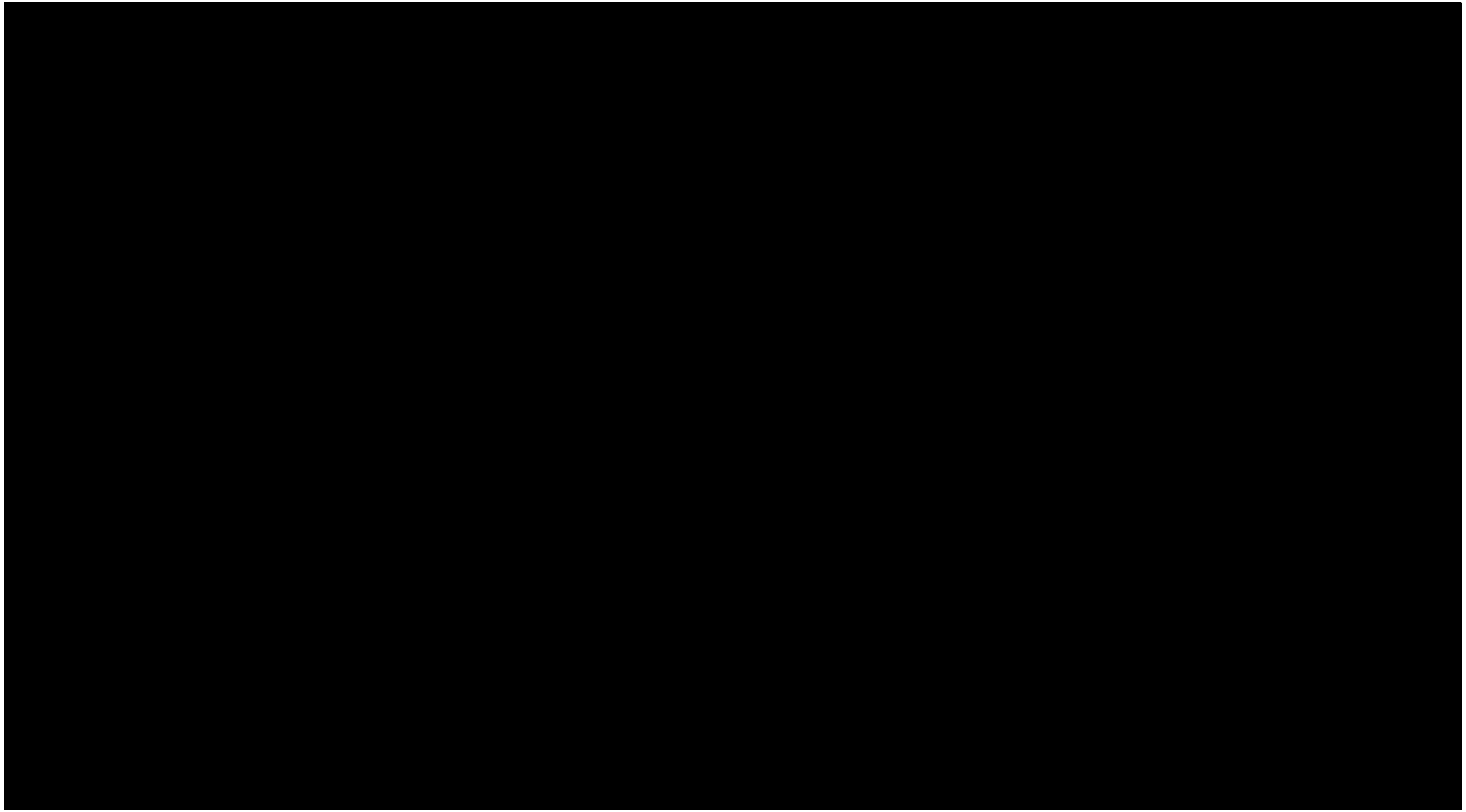
Bē
GMUNK

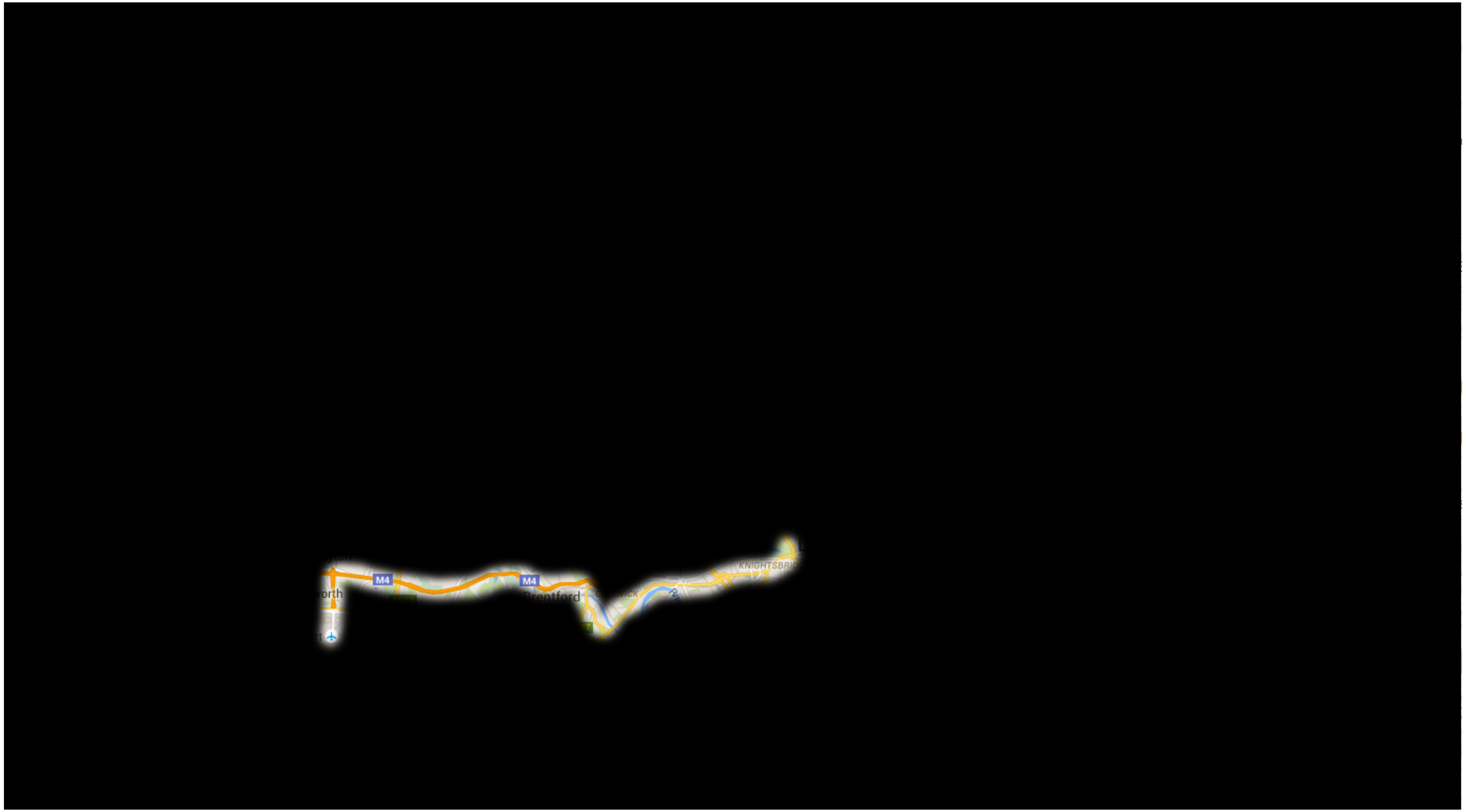
Better Code

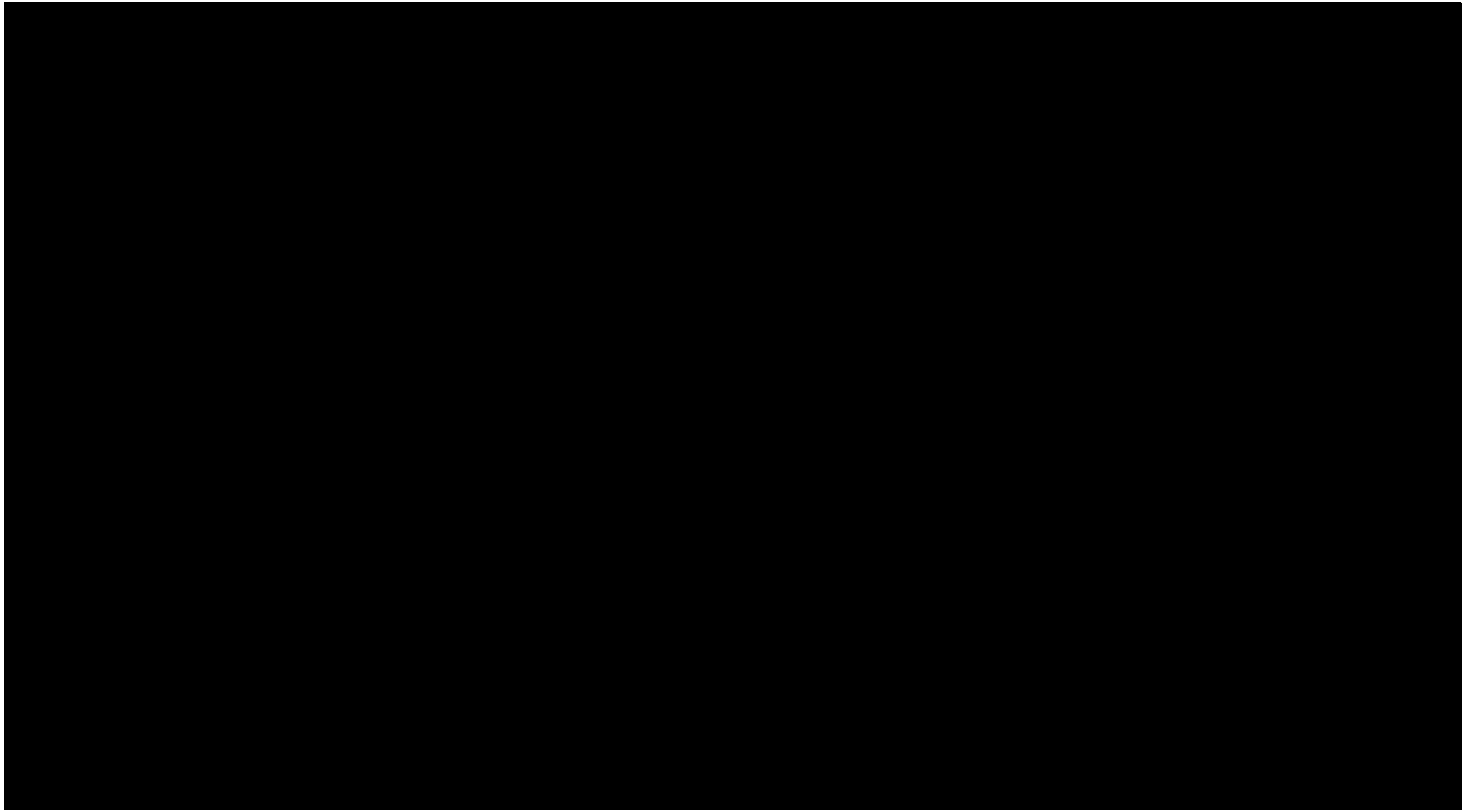
- Regular Types
  - Goal: No Incomplete Types
- Algorithms
  - Goal: No Raw Loops
- Data Structures
  - Goal: No Incidental Data Structures
- Runtime Polymorphism
  - Goal: No Inheritance
- Concurrency
  - Goal: No Raw Synchronization Primitives

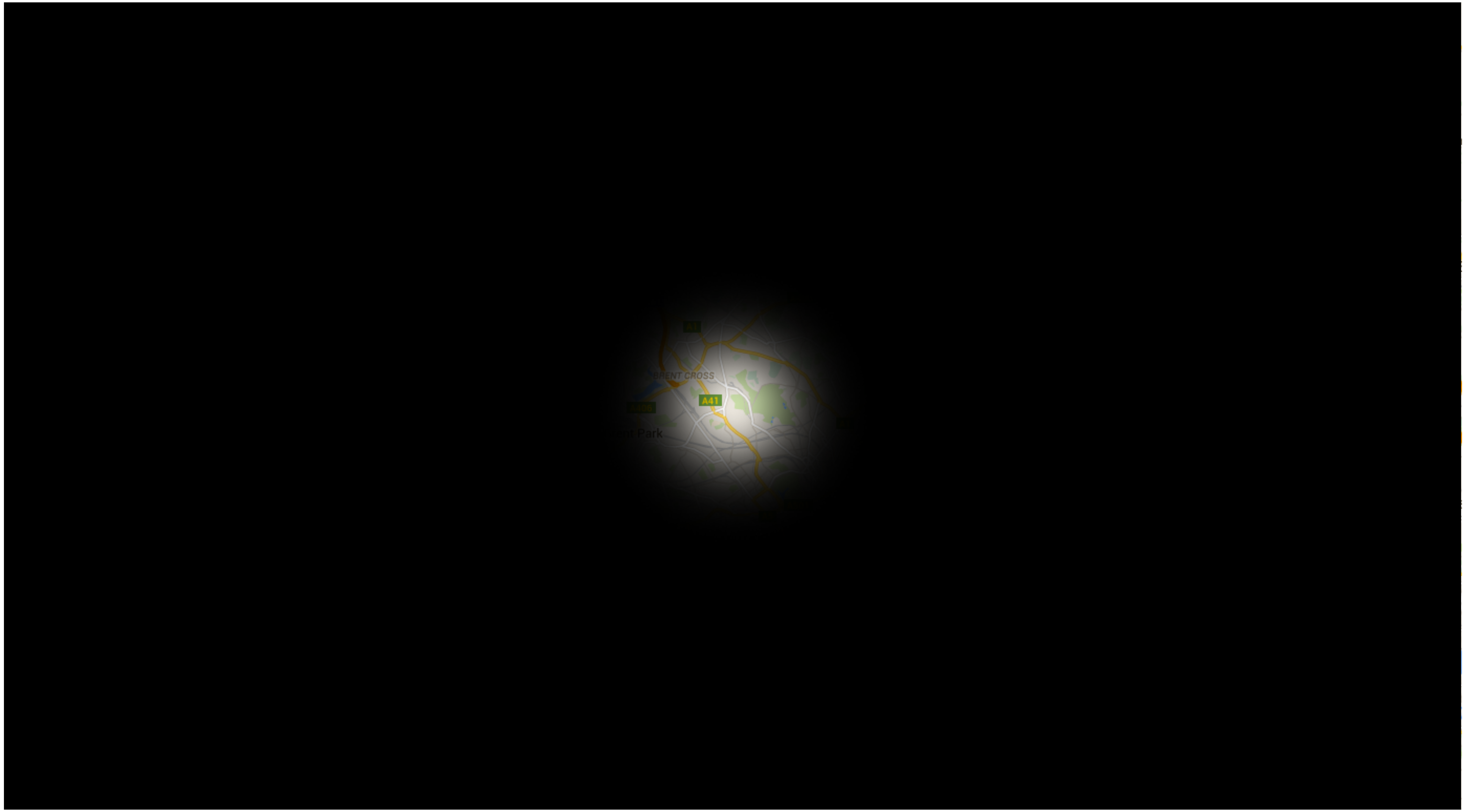
http://sean-parent.stlab.cc/papers-and-presentations

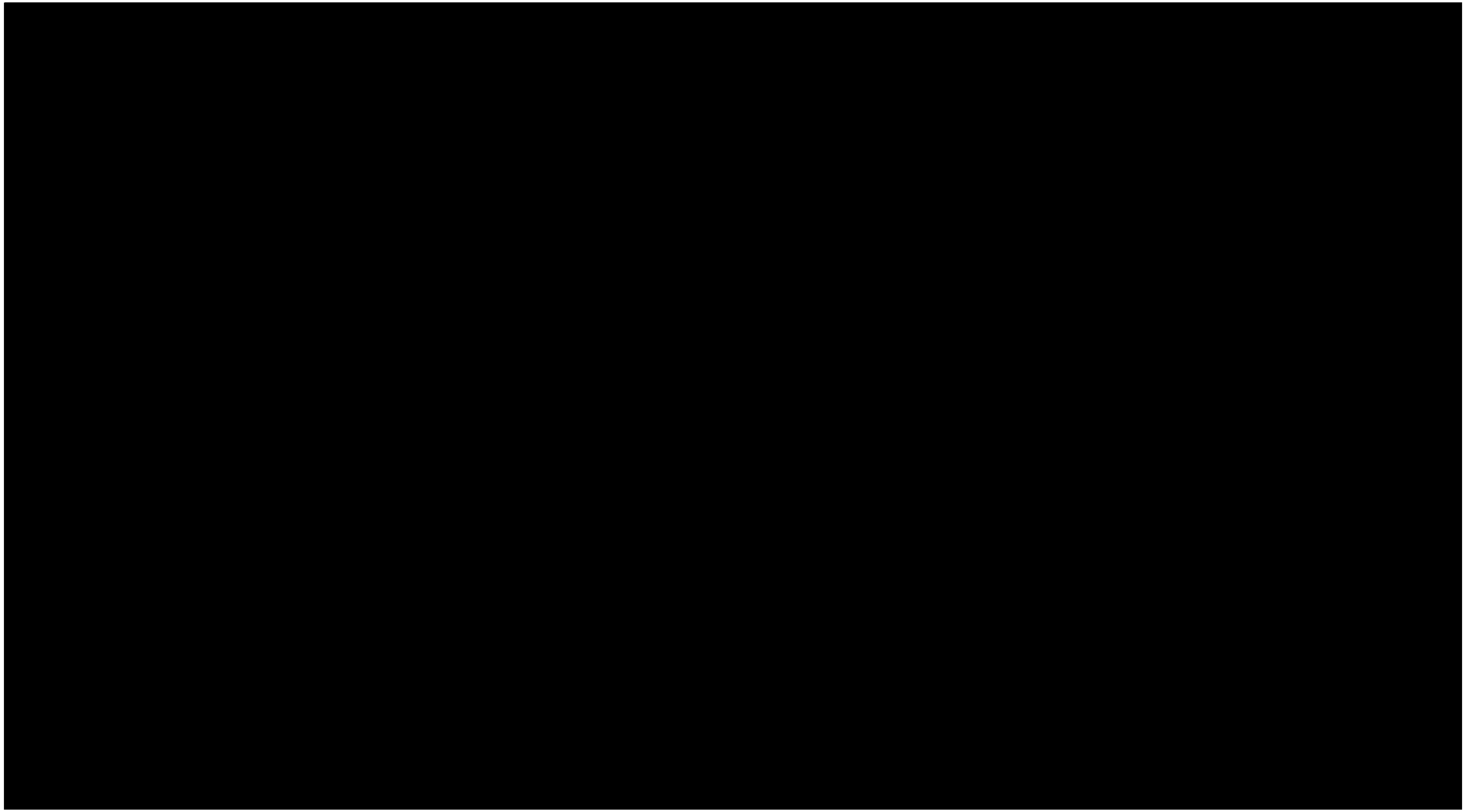
The Knowledge

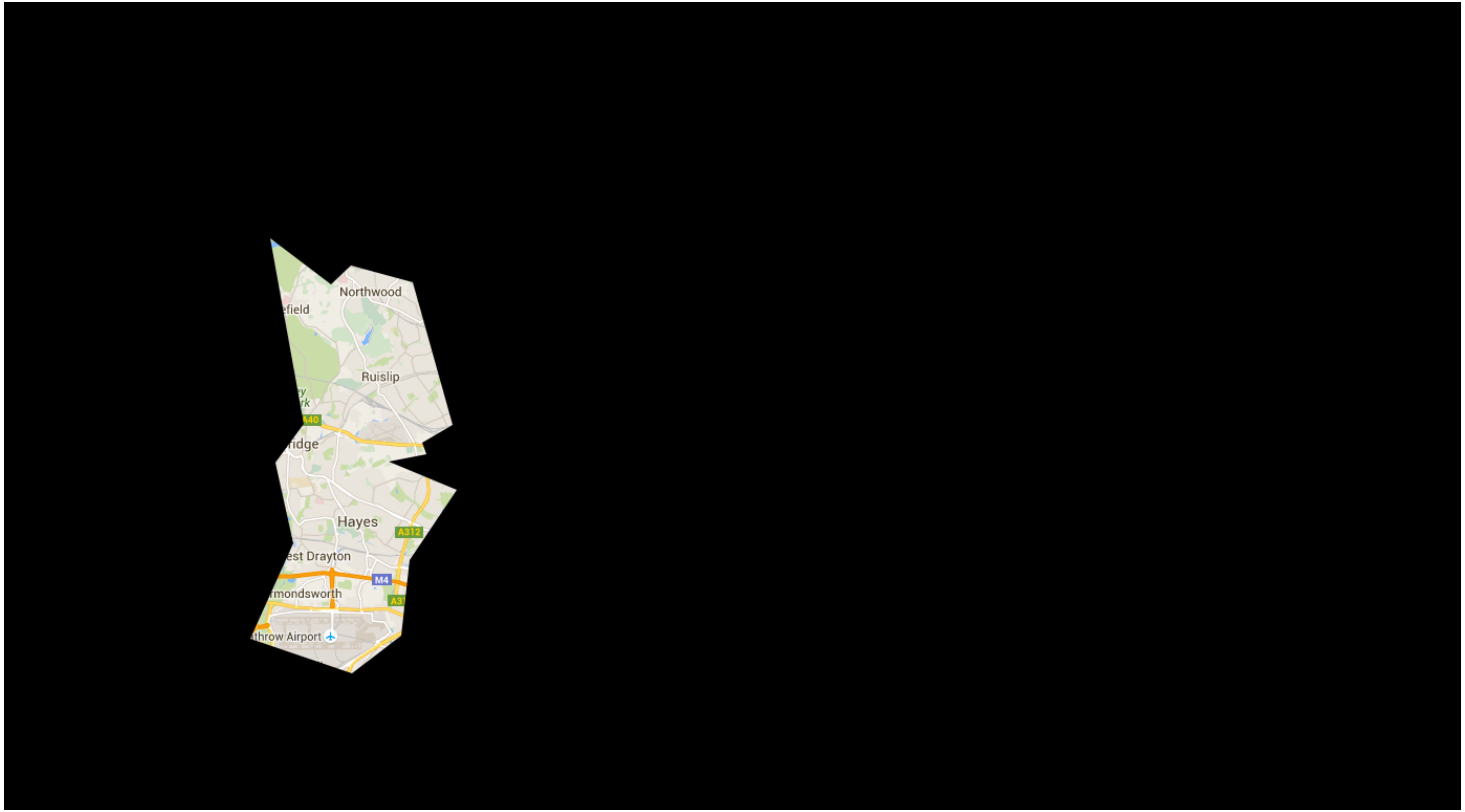



M4
M4




A1
BRENT CROSS
A41
A406




Northwood
efield
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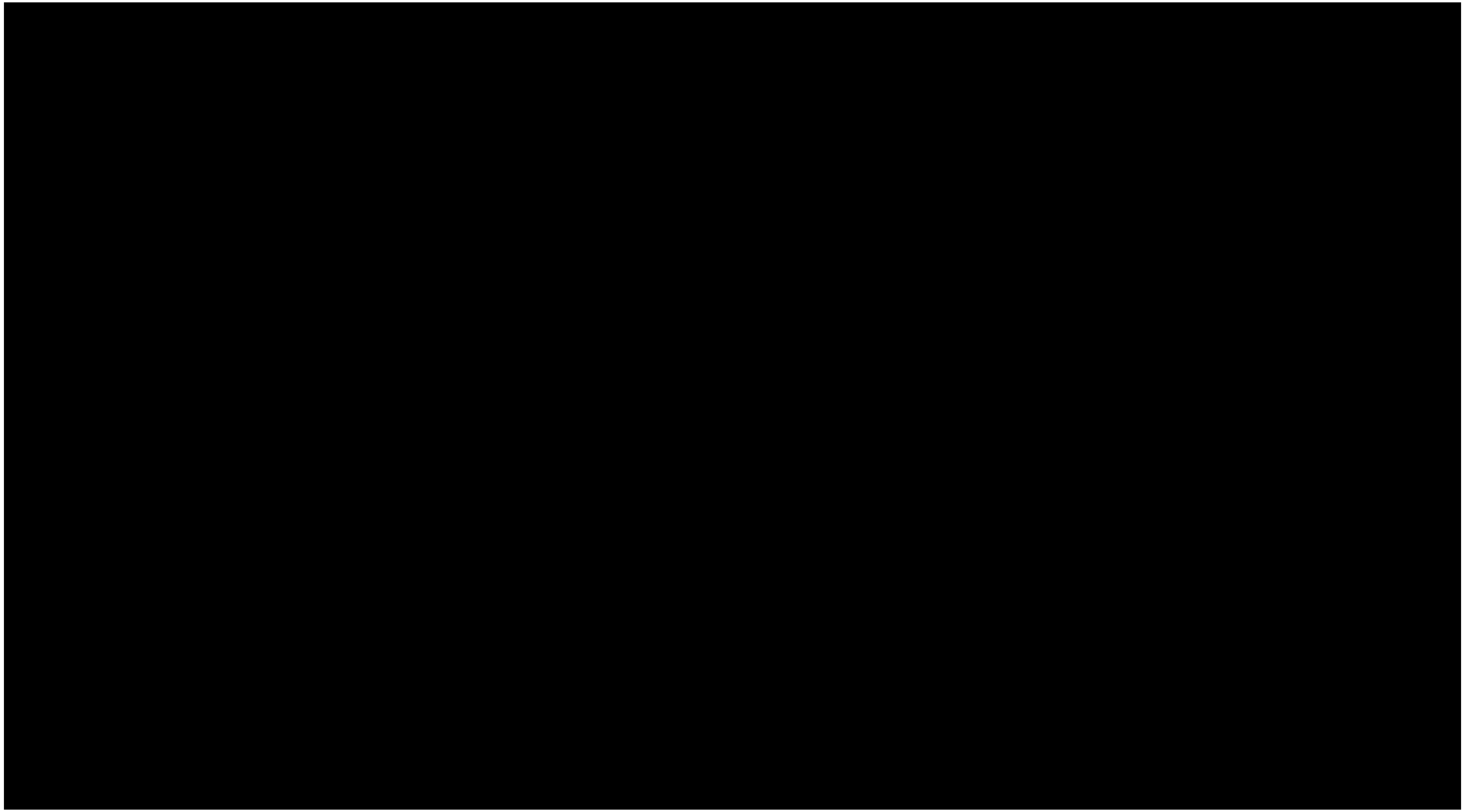
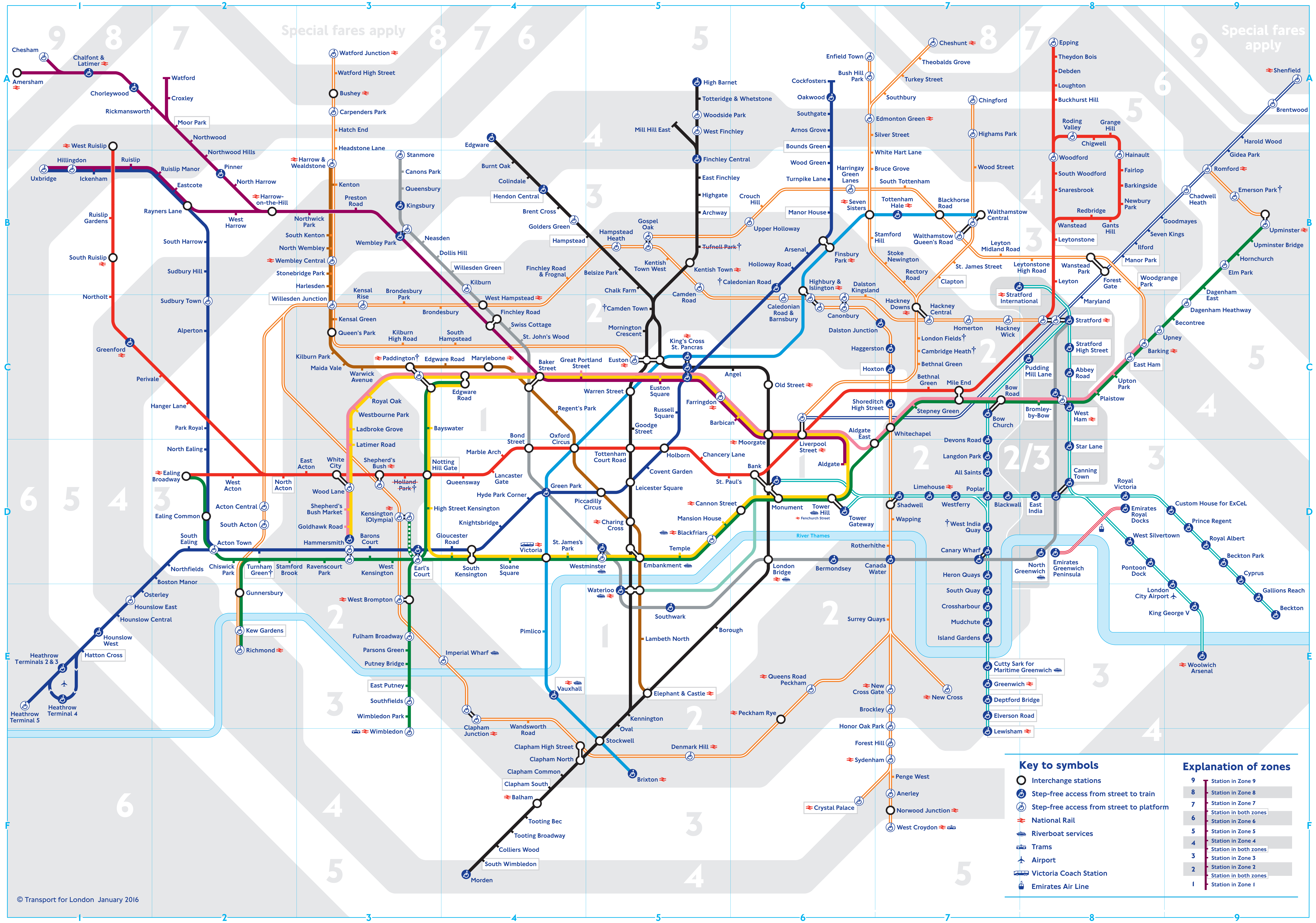
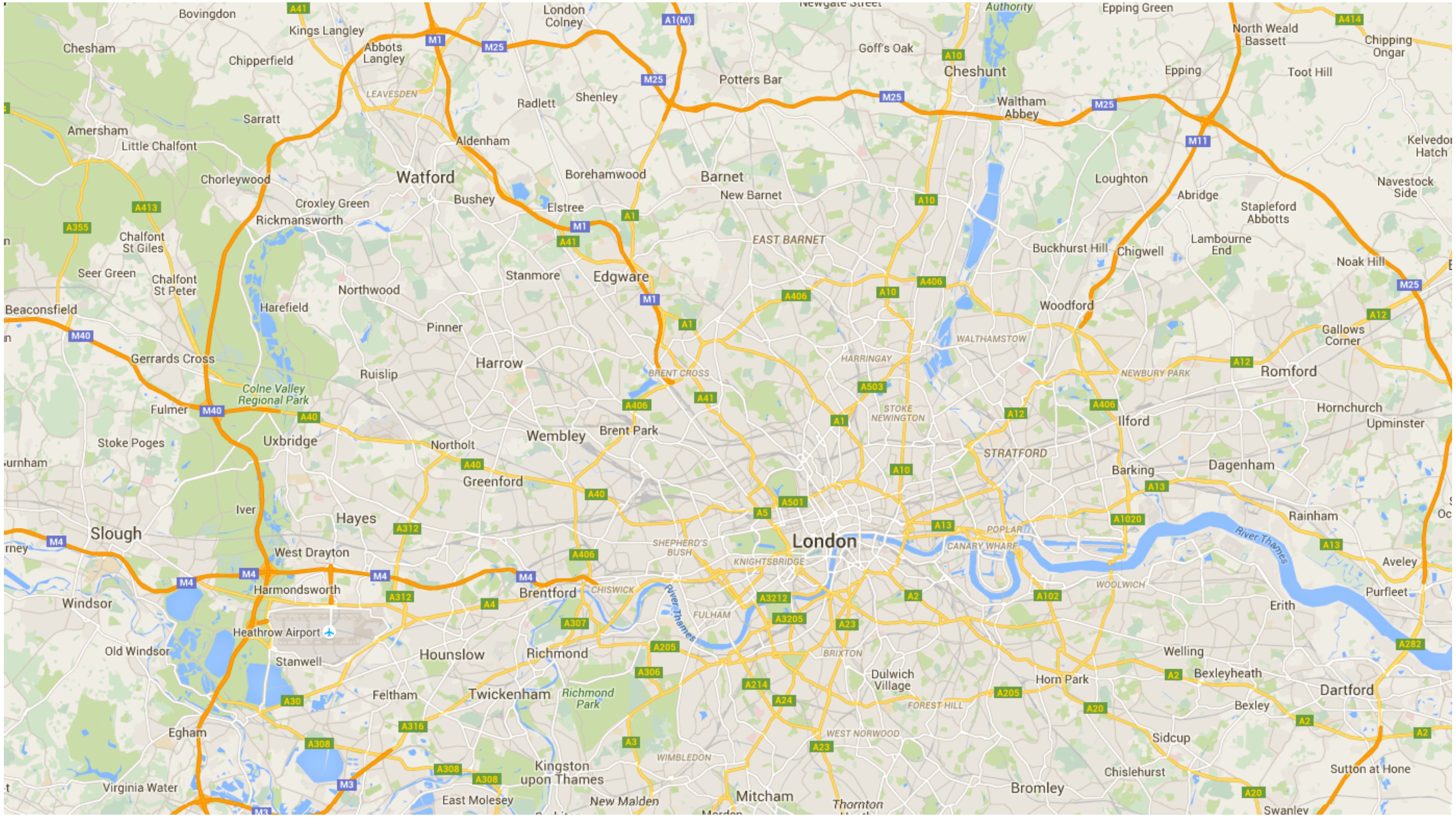
A40
ridge
Hayes
A312
est Drayton
M4
rmondsworth
throw Airport



Adobe


Special fares apply
Key to symbols
Interchange stations
Step-free access from street to train
Step-free access from street to platform
National Rail
Riverboat services
Trams
Airport
Victoria Coach Station
Emirates Air Line
Explanation of zones
Station in Zone 9
Station in Zone 8
Station in Zone 7
Station in both zones
Station in Zone 6
Station in Zone 5
Station in Zone 4
Station in both zones
Station in Zone 3
Station in Zone 2
Station in both zones
Station in Zone 1
© Transport for London January 2016


Bovingdon
Kings Langley
London Colney
Chesham
Chipperfield
Abbots Langley
Goff's Oak
Epping Green
North Weald Bassett
Chipping Ongar
Potters Bar
Cheshunt
Epping
Toot Hill
LEAVESDEN
Radlett
Shenley
Waltham Abbey
Amersham
Sarratt
Little Chalfont
Aldenham
Kelvedon Hatch
Chorleywood
Watford
Borehamwood
Barnet
Loughton
New Barnet
Abridge
Navestock Side
Croxley Green
Bushey
Elstree
Stapleford Abbotts
Rickmansworth
EAST BARNET
Chalfont St Giles
Buckhurst Hill
Chigwell
Lambourne End
Seer Green
Stanmore
Edgware
Noak Hill
Chalfont St Peter
Northwood
Harefield
Woodford
Beaconsfield
Pinner
WALTHAMSTOW
Gallows Corner
Gerrards Cross
Harrow
HARRINGAY
BRENT CROSS
Ruislip
NEWBURY PARK
Romford
Colne Valley Regional Park
STOKE NEWINGTON
Hornchurch
Fulmer
Upminster
Ilford
Brent Park
Wembley
Uxbridge
Stoke Poges
Northolt
STRATFORD
Barking
Dagenham
Greenford
Iver
Hayes
Rainham
Slough
London
POPLAR
SHEPHERD'S BUSH
CANARY WHARF
West Drayton
KNIGHTSBRIDGE
River Thames
Aveley
Windsor
Harmondsworth
Brentford
CHISWICK
WOOLWICH
Purfleet
Erith
FULHAM
Heathrow Airport
Old Windsor
Stanwell
Hounslow
Richmond
BRIXTON
Welling
Dulwich Village
Horn Park
Bexleyheath
Dartford
Feltham
Twickenham
Richmond Park
FOREST HILL
Bexley
Egham
WEST NORWOOD
Sidcup
WIMBLEDON
Kingston upon Thames
Chislehurst
Sutton at Hone
Virginia Water
East Molesey
New Malden
Mitcham
Thornton
Bromley
Swanley
M1
M4
M25
M40
M11
M3
A1(M)
A1
A2
A3
A4
A5
A10
A12
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A23
A24
A30
A40
A41
A102
A205
A214
A282
A306
A307
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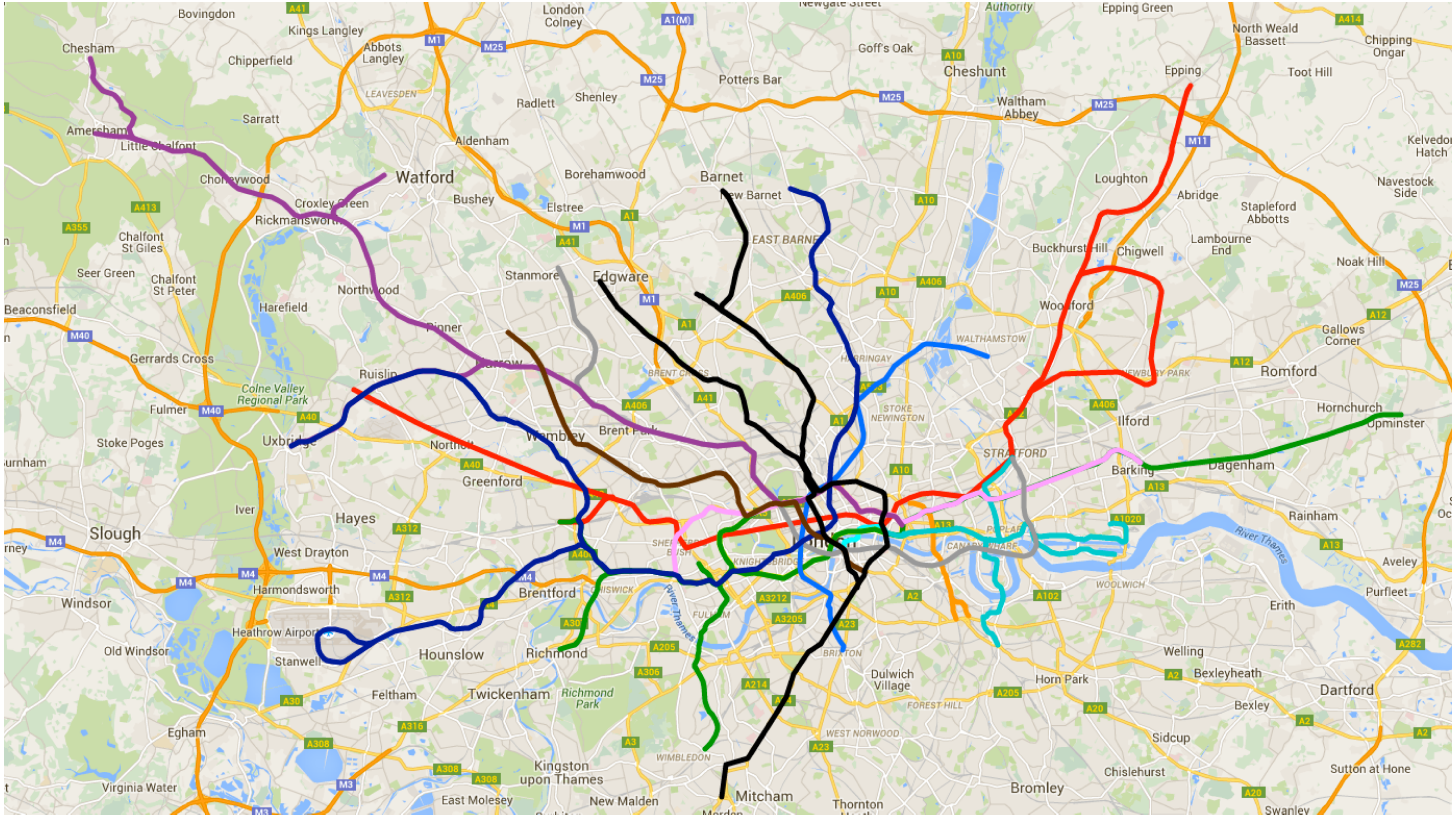
A355
A406
A413
A414
A501
A503
A1020
A3205
A3212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Epping
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Sarratt
Amersham
Aldenham
Watford
Bushey
Borehamwood
Barnet
New Barnet
Loughton
Abridge
Kelvedon Hatch
Stapleford Abbotts
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Buckhurst Hill
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Lambourne End
Chalfont St Giles
Seer Green
Chalfont St Peter
Northwood
Stanmore
Edgware
Noak Hill
Woodford
Beaconsfield
Harefield
Pinner
Gallows Corner
Gerrards Cross
Romford
Ruislip
Harrow
Colne Valley Regional Park
Fulmer
Hornchurch
Ilford
Upminster
Uxbridge
Stoke Poges
Northolt
Wembley
Brent Park
Stratford
Barking
Dagenham
Greenford
Iver
Hayes
Rainham
Slough
West Drayton
Aveley
Windsor
Harmondsworth
Brentford
Purfleet
Erith
Heathrow Airport
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Stanwell
Hounslow
Richmond
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Dulwich Village
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Feltham
Twickenham
Richmond Park
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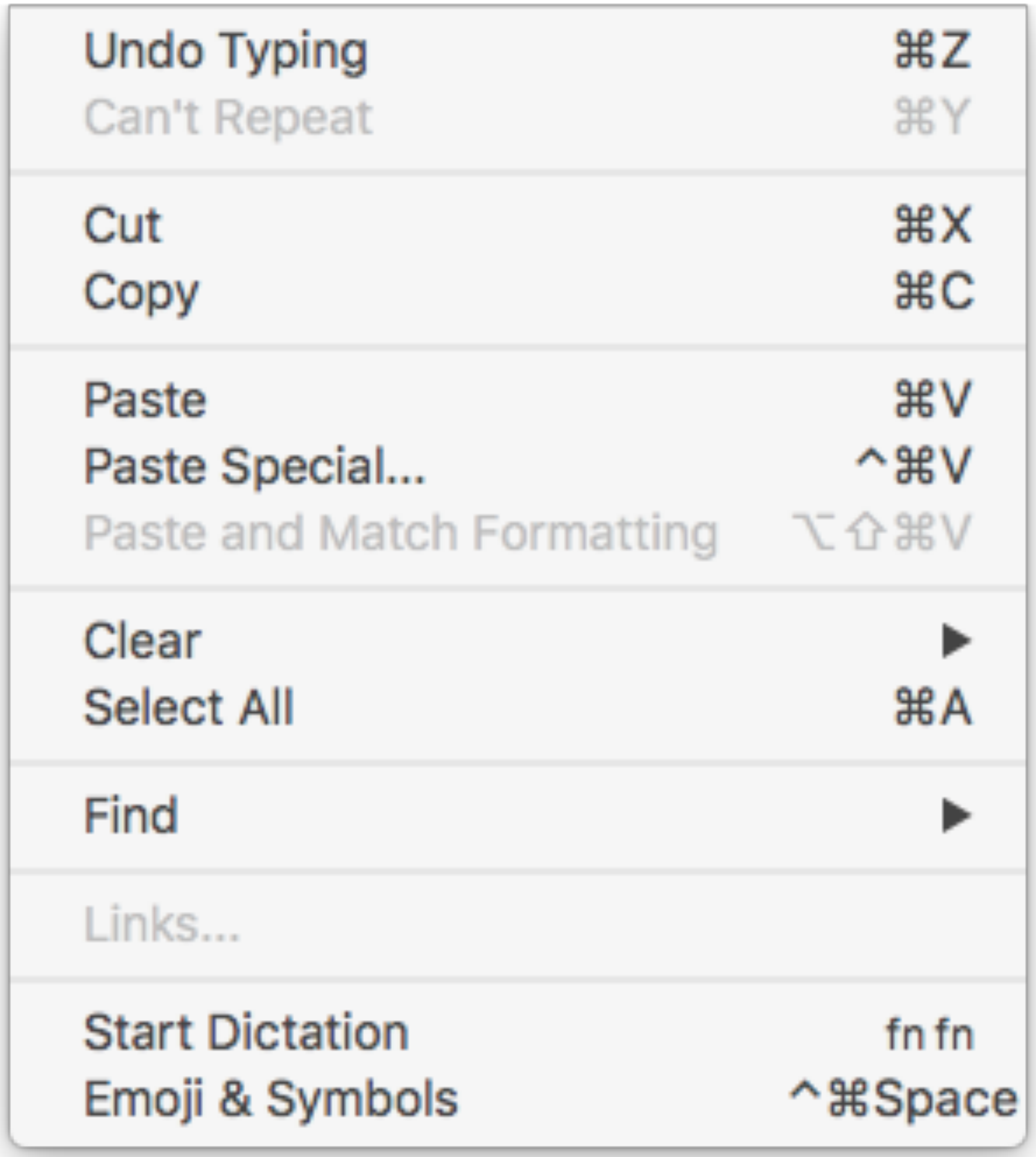
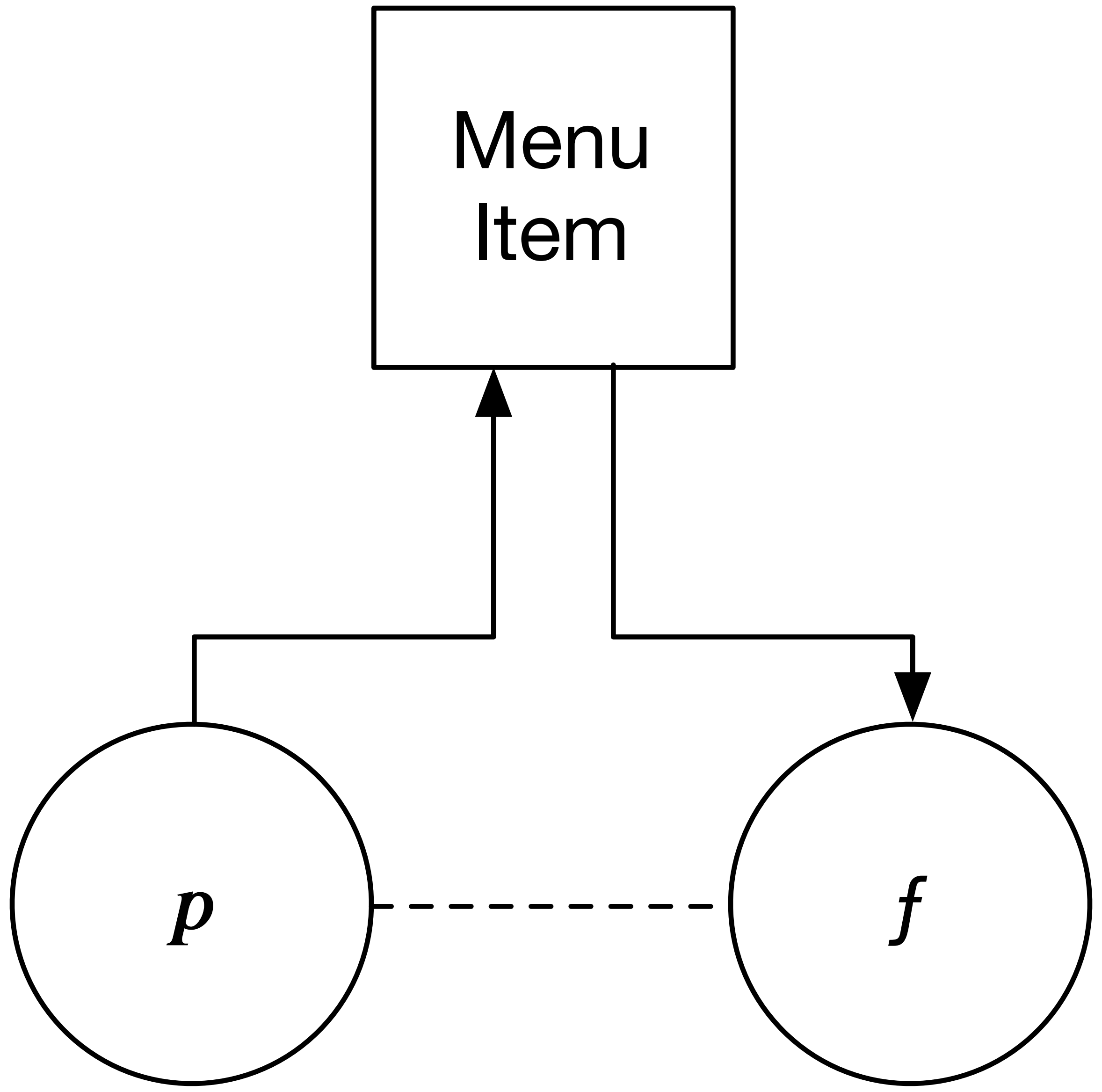
Dartford
Egham
Sidcup
Kingston upon Thames
Chislehurst
Sutton at Hone
Virginia Water
East Molesey
New Malden
Mitcham
Thornton
Bromley
Swanley
River Thames

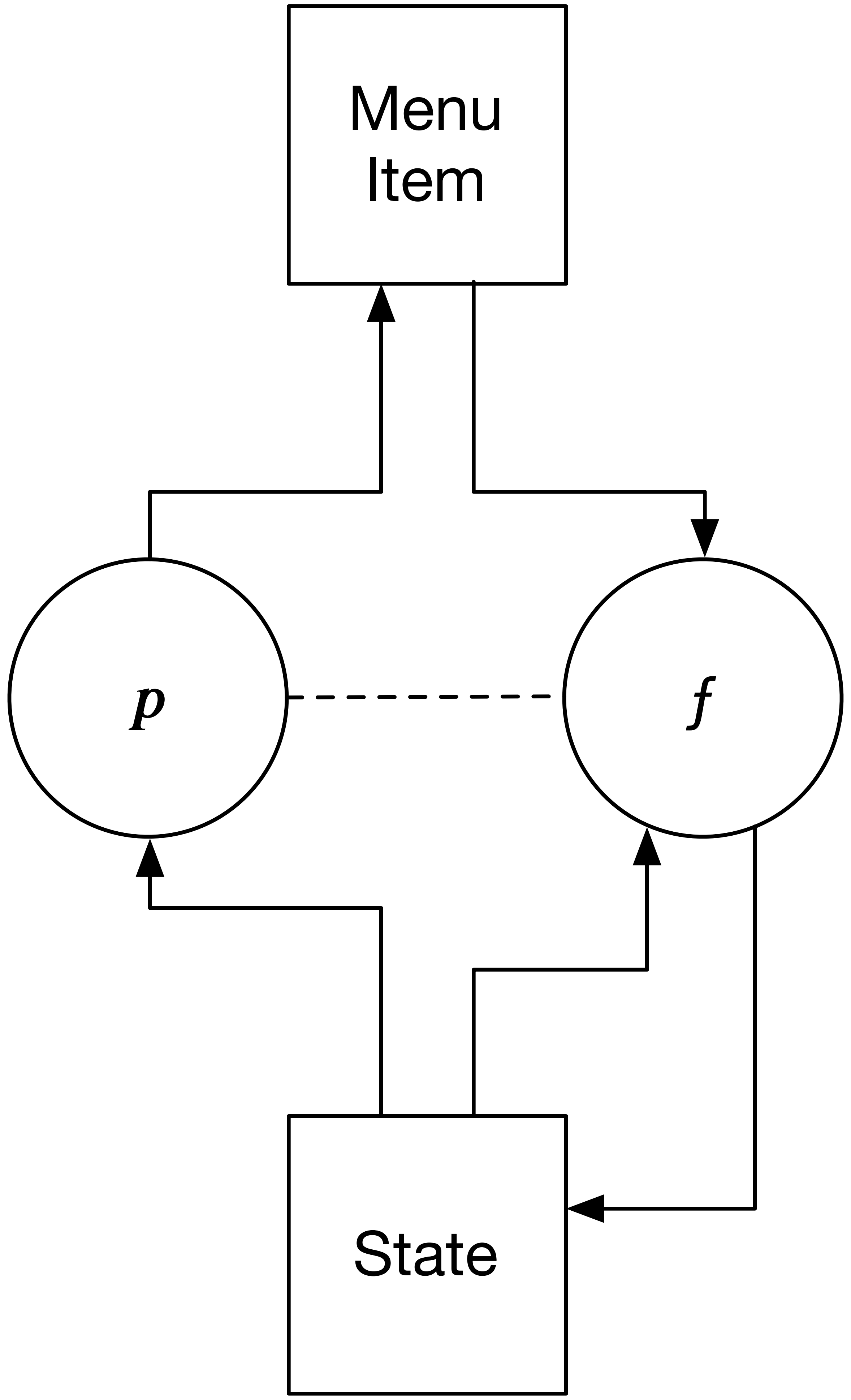

"There are rules!"
– The Big Lebowski
GMUNK

Lower Bound

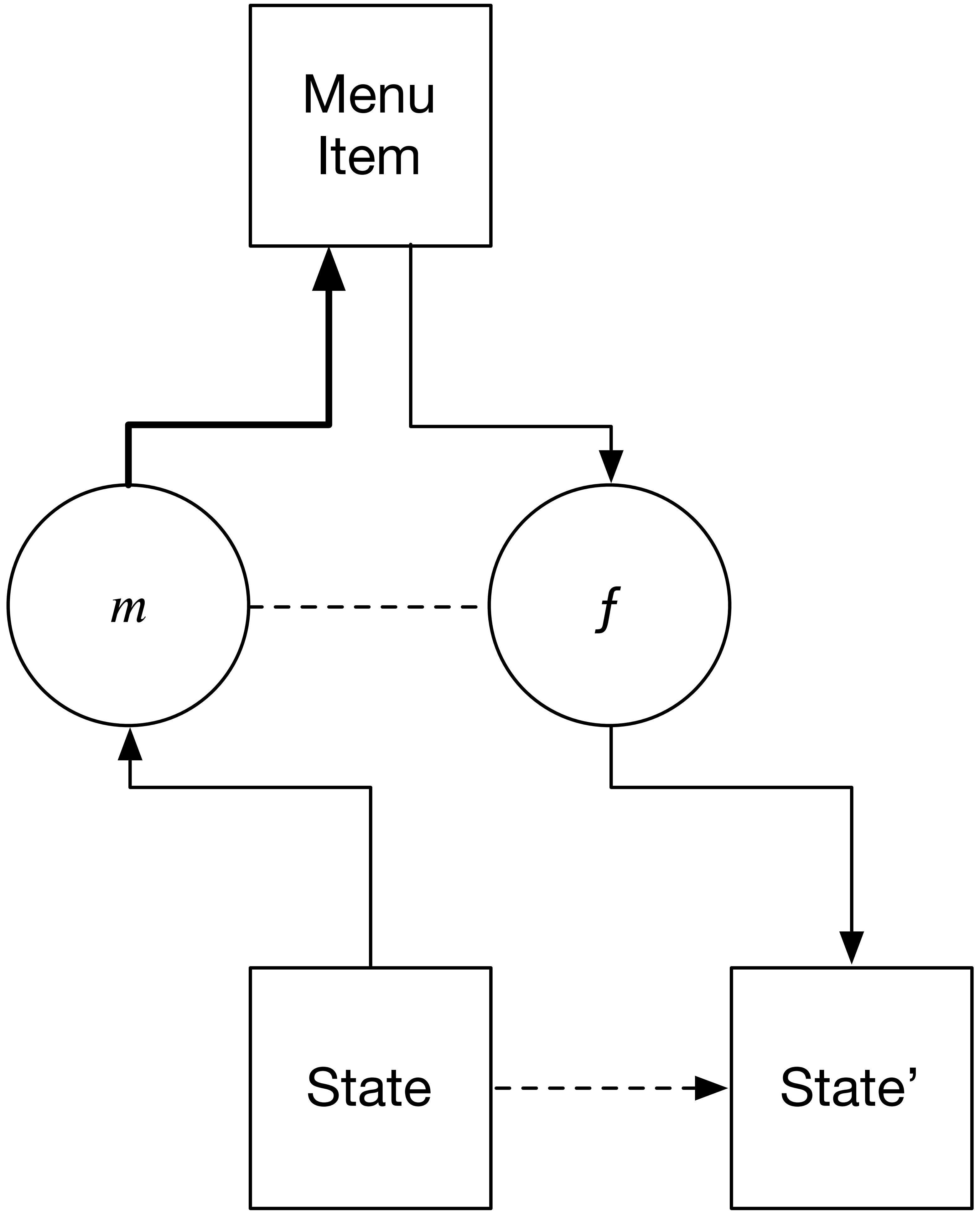
```
template <class ForwardIterator, class T, class Compare>
ForwardIterator lower_bound(ForwardIterator first, ForwardIterator last,
        const T& value, Compare comp)
{
    auto n = distance(first, last);

    while (n != 0)  {
        auto h = n / 2;
        auto m = next(first, h);

        if (comp(*m, value)) {
            first = next(m);
            n -= h + 1;
        } else { n = h; }
    }

    return first;
}
```

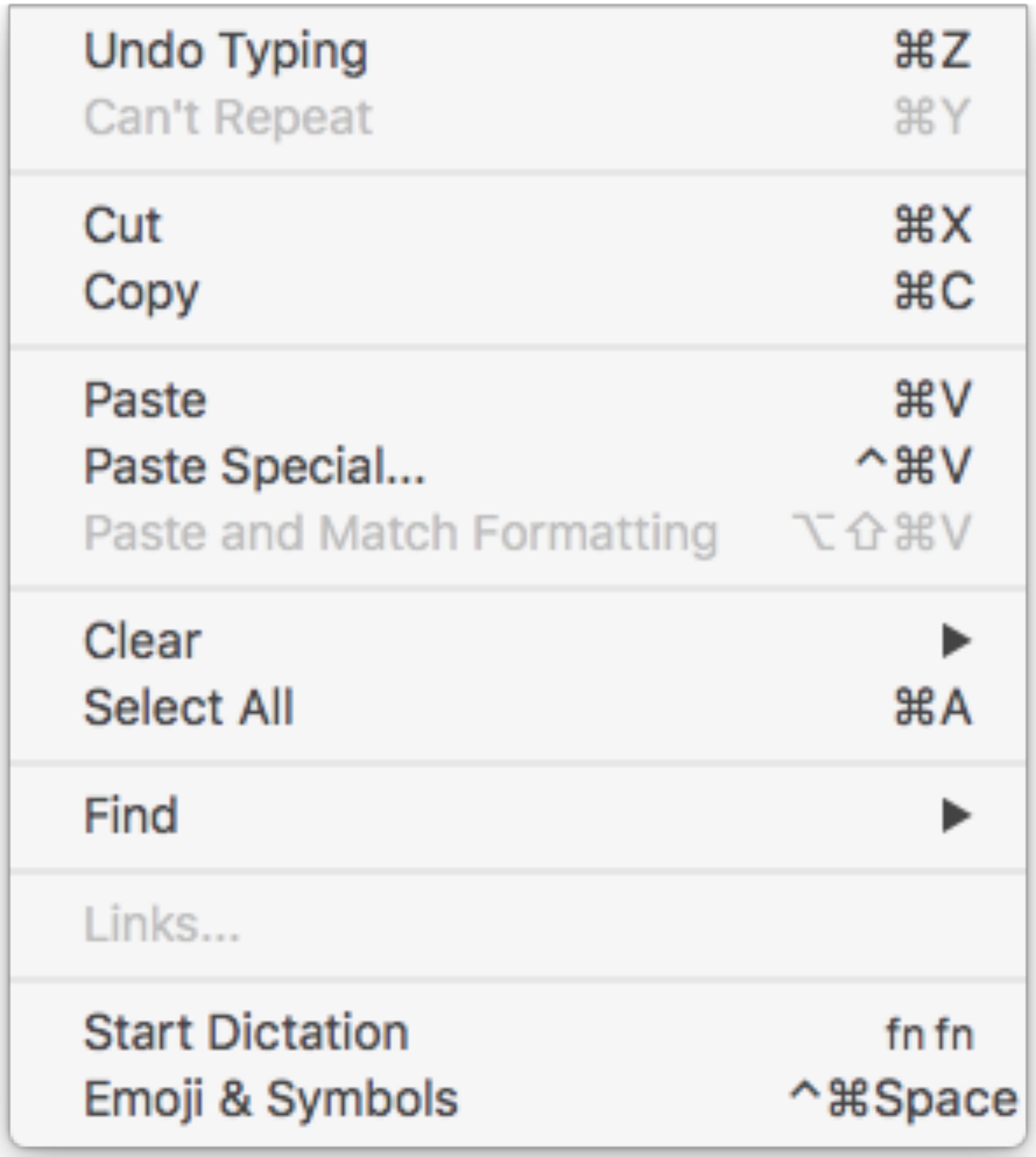

Undo Typing ⌘Z
Can't Repeat ⌘Y
Cut ⌘X
Copy ⌘C
Paste ⌘V
Paste Special... ^⌘V
Paste and Match Formatting ⌥⇧⌘V
Clear
Select All ⌘A
Find
Links...
Start Dictation fn fn
Emoji & Symbols ^⌘Space


Menu
Item
p
f



Menu Item
p
f
State


Menu
Item
m
f
State
State’


Undo Typing ⌘Z
Can't Repeat ⌘Y
Cut ⌘X
Copy ⌘C
Paste ⌘V
Paste Special... ^⌘V
Paste and Match Formatting ⌥⇧⌘V
Clear
Select All ⌘A
Find
Links...
Start Dictation fn fn
Emoji & Symbols ^⌘Space

Good Code

Good code is *correct*

Good Code

Good code is *correct*

- Consistent; without contradiction

Simple Bug

```
void print_string(const char* s) {
    while (*s != '\0') {
        cout << *s++;
    }
}

int main() {
    print_string(nullptr);
}
```

Simple Bug

```
void print_string(const char* s) {
    while (*s != '\0') {                    Thread 1: EXC_BAD_ACCESS (code=1, address=0x0)
        cout << *s++;
    }
}

int main() {
    print_string(nullptr);
}
```

Simple Bug

```
void print_string(const char* s) {
    while (*s != '\0') {
        cout << *s++;
    }
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int main() {
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```

Simple Bug

```
void print_string(const char* s) {
    while (*s != '\0') {
        cout << *s++;
    }
}

int main() {
    print_string(nullptr); // FORCE CRASH!
}
```

Subtle defects

Subtle defects

Consistency requires context

Subtle defects

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```
template<class T> const T& min(const T& a, const T& b);
```

Returns: The smaller value.

Remarks: Returns the first argument when the arguments are equivalent.

Subtle defects

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```
template<class T> const T& max(const T& a, const T& b);
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Returns: The larger value.

Remarks: Returns the first argument when the arguments are equivalent.

Subtle defects

Subtle defects

```
template<typename T>
const T& clamp(const T& a, const T& lo, const T& hi)
{
    return min(max(lo, a), hi);
}
```

Subtle defects

```
template<typename T>
const T& clamp(const T& a, const T& lo, const T& hi)
{
    return min(max(lo, a), hi);
}

template<typename T, typename Compare>
const T& clamp(const T& a, const T& lo, const T& hi, Compare comp)
{
    return min(max(lo, a, comp), hi, comp);
}
```

Subtle defects

Subtle defects

```
int main() {
    using pair = pair<int, string>;

    pair a = { 1, "OK" };

    pair lo = { 1, "FAIL: LO" };
    pair hi = { 2, "FAIL: HI" };

    a = clamp(a, lo, hi, [](const auto& a, const auto& b) {
        return a.first < b.first;
    });

    cout << a.second << endl;
};
```

Subtle defects

```
int main() {
    using pair = pair<int, string>;

    pair a = { 1, "OK" };

    pair lo = { 1, "FAIL: LO" };
    pair hi = { 2, "FAIL: HI" };

    a = clamp(a, lo, hi, [](const auto& a, const auto& b) {
        return a.first < b.first;
    });

    cout << a.second << endl;
};
```

```
FAIL: LO
```

Subtle defects

Subtle defects

```
template<typename T>
const T& clamp(const T& a, const T& lo, const T& hi)
{
    return min(max(a, lo), hi);
}
```

Subtle defects

```
template<typename T>
const T& clamp(const T& a, const T& lo, const T& hi)
{
    return min(max(a, lo), hi);
}

template<typename T, typename Compare>
const T& clamp(const T& a, const T& lo, const T& hi, Compare comp)
{
    return min(max(a, lo, comp), hi, comp);
}
```

Subtle defects

Subtle defects

```
template<class T> const T& min(const T& a, const T& b);
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Returns: The smaller value.

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```
template<class T> const T& max(const T& a, const T& b);
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Remarks: Returns the **second** argument when the arguments are equivalent.

Subtle defects

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template<class T> const T& min(const T& a, const T& b);
```

Returns: The smaller value.

Remarks: Returns the first argument when the arguments are equivalent.

```
template<class T> const T& max(const T& a, const T& b);
```

Returns: The larger value.

Remarks: Returns the **second** argument when the arguments are equivalent.

```
template <class T> const T& max(const T& a, const T& b, const T& c);
```

Returns: The larger value.

Remarks: **???**

Rules are Contentious

Rules are Contentious

"Names should not be associated with semantics because everybody has their own hidden assumptions about what semantics are, and they clash, causing comprehension problems without knowing why. This is why it's valuable to write code to reflect what code is actually doing, rather than what code 'means': it's hard to have conceptual clashes about what code actually does."

– Craig Silverstein, Google

"There is no spoon."

– The Matrix

How can nothing be something?

How can nothing be something?

```
int x;
```

How can nothing be something?

```
int x;
 // indeterminate value
```

How can nothing be something?

```
int x;
 // indeterminate value

int x = 1 / 0;
```

How can nothing be something?

```
int x;
 // indeterminate value

int x = 1 / 0;
 // undefined behavior
```

How can nothing be something?

```
int x;
 // indeterminate value

int x = 1 / 0;
 // undefined behavior

double x = 1.0 / 0.0;
```

How can nothing be something?

```
int x;
 // indeterminate value

int x = 1 / 0;
 // undefined behavior

double x = 1.0 / 0.0;
 // inf
```

How can nothing be something?

```
int x;
 // indeterminate value

int x = 1 / 0;
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double x = 1.0 / 0.0;
 // inf

double x = 0.0 / 0.0;
```

How can nothing be something?

```
int x;
 // indeterminate value

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 // undefined behavior

double x = 1.0 / 0.0;
 // inf

double x = 0.0 / 0.0;
 // NaN
```

How can nothing be something?

```
int x;
 // indeterminate value

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double x = 1.0 / 0.0;
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double x = 0.0 / 0.0;
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struct empty { };
```

How can nothing be something?

```
int x;
 // indeterminate value

int x = 1 / 0;
 // undefined behavior

double x = 1.0 / 0.0;
 // inf

double x = 0.0 / 0.0;
 // NaN

struct empty { };
 // sizeof(empty) == 1
```

How can nothing be something?

How can nothing be something?

```
int a[0];
```

How can nothing be something?

```
int a[0];
 // Error
```

How can nothing be something?

```
int a[0];
 // Error
 // but common extension
```

How can nothing be something?

```
int a[0];
 // Error
 // but common extension
 using empty = int[0];
```

How can nothing be something?

```
int a[0];
 // Error
 // but common extension
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
```

How can nothing be something?

```
int a[0];
 // Error
 // but common extension
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
 // &a[0] == &a[1]
```

How can nothing be something?

```
int a[0];
 // Error
 // but common extension
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
 // &a[0] == &a[1]

void f() { return void(); }
```

How can nothing be something?

```
int a[0];
 // Error
 // but common extension
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
 // &a[0] == &a[1]

void f() { return void(); }
 // OK
```

How can nothing be something?

```
int a[0];
 // Error
 // but common extension
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
 // &a[0] == &a[1]

void f() { return void(); }
 // OK

void x = f();
```

How can nothing be something?

```
int a[0];
 // Error
 // but common extension
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
 // &a[0] == &a[1]

void f() { return void(); }
 // OK

void x = f();
 // Error
```

How can nothing be something?

```
int a[0];
 // Error
 // but common extension
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
 // &a[0] == &a[1]

void f() { return void(); }
 // OK

void x = f();
 // Error
 // but void* is a pointer to anything…
```

How can nothing be something?

How can nothing be something?

```
std::vector<int> x = { 1, 2, 3 };
try {
    x.insert(x.begin(), 0);
} catch (...) {
    std::cout << x.size() << std::endl;
}
```

How can nothing be something?

```
std::vector<int> x = { 1, 2, 3 };
try {
    x.insert(x.begin(), 0);
} catch (...) {
    std::cout << x.size() << std::endl;
}
 // Basic Exception Guarantee:
 // Valid but unspecified
```

How can nothing be something?

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std::vector<int> x = { 1, 2, 3 };
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    x.insert(x.begin(), 0);
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    std::cout << x.size() << std::endl;
}
 // Basic Exception Guarantee:
 // Valid but unspecified

std::vector<int> y = std::move(x);
```

How can nothing be something?

```
std::vector<int> x = { 1, 2, 3 };
try {
    x.insert(x.begin(), 0);
} catch (...) {
    std::cout << x.size() << std::endl;
}
 // Basic Exception Guarantee:
 // Valid but unspecified

std::vector<int> y = std::move(x);
 // Moved from object, x, is valid but unspecified
```

Good Code

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Good code is *correct*

- Consistent; without contradiction

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Good code has *meaning*

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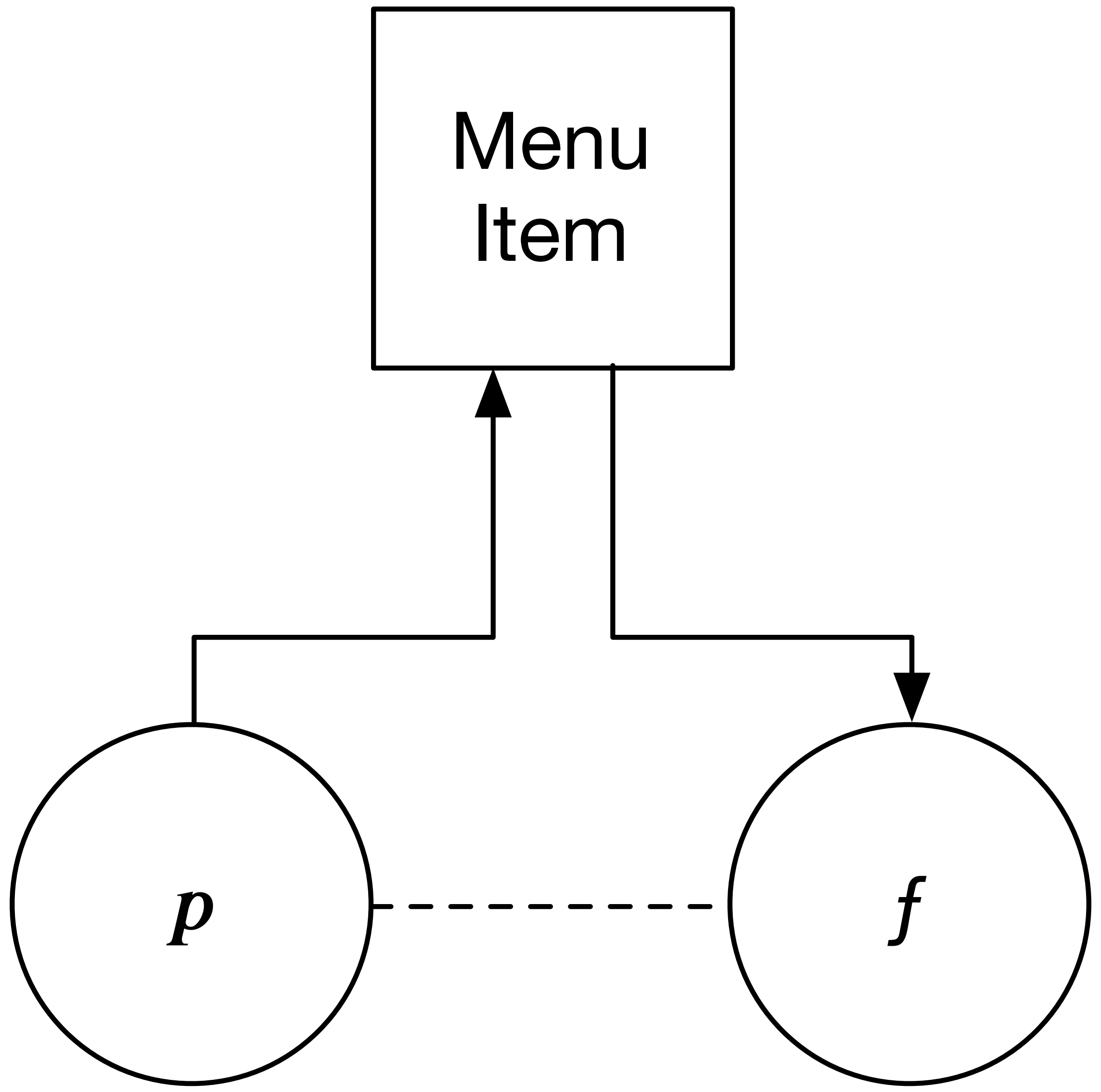
Consistent; without contradiction

Good code has *meaning*

Correspondence to an entity; specified, defined


Menu
Item
p
f

Categories of nothing

Categories of nothing

Absence of *something*

0, Ø, [p, p), void

Categories of nothing

Absence of *something*

0, Ø, [p, p), void

Absence of *meaning*

NaN, undefined, indeterminate

How can nothing be something?

How can nothing be something?

```
int x;
```

How can nothing be something?

```
int x;
 // Partially formed; assign value or destruct
```

How can nothing be something?

```
int x;
 // Partially formed; assign value or destruct

int x = 1 / 0;
```

How can nothing be something?

```
int x;
 // Partially formed; assign value or destruct

int x = 1 / 0;
 // undefined behavior; reading from meaningless value
```

How can nothing be something?

```
int x;
 // Partially formed; assign value or destruct

int x = 1 / 0;
 // undefined behavior; reading from meaningless value

double x = 1.0 / 0.0;
```

How can nothing be something?

```
int x;
 // Partially formed; assign value or destruct

int x = 1 / 0;
 // undefined behavior; reading from meaningless value

double x = 1.0 / 0.0;
 // inf; OK, approximation for underflow
```

How can nothing be something?

```
int x;
 // Partially formed; assign value or destruct

int x = 1 / 0;
 // undefined behavior; reading from meaningless value

double x = 1.0 / 0.0;
 // inf; OK, approximation for underflow

double x = 0.0 / 0.0;
```

How can nothing be something?

```
int x;
 // Partially formed; assign value or destruct

int x = 1 / 0;
 // undefined behavior; reading from meaningless value

double x = 1.0 / 0.0;
 // inf; OK, approximation for underflow

double x = 0.0 / 0.0;
 // NaN; OK, though undefined behavior would also be
```

How can nothing be something?

```
int x;
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double x = 1.0 / 0.0;
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double x = 0.0 / 0.0;
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struct empty : void { };
```

How can nothing be something?

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double x = 1.0 / 0.0;
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struct empty : void { };
 // sizeof(empty) == 0;
```

How can nothing be something?

How can nothing be something?

```
int a[0];
```

How can nothing be something?

```
int a[0];
 // OK
```

How can nothing be something?

```
int a[0];
 // OK
 using empty = int[0];
```

How can nothing be something?

```
int a[0];
 // OK
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
```

How can nothing be something?

```
int a[0];
 // OK
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
 // &a[0] == &a[1]
```

How can nothing be something?

```
int a[0];
 // OK
 using empty = int[0];
 // sizeof(empty) == 0
 empty a[2];
 // &a[0] == &a[1]

void f() { return void(); }
```

How can nothing be something?

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void x = f();
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 using empty = int[0];
 // sizeof(empty) == 0
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 // &a[0] == &a[1]

void f() { return void(); }
 // OK

void x = f();
 // OK
 // void* is OK
```

How can nothing be something?

How can nothing be something?

```
std::vector<int> x = { 1, 2, 3 };
try {
    x.insert(x.begin(), 0);
} catch (...) {
    std::cout << x.size() << std::endl;
}
```

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std::vector<int> x = { 1, 2, 3 };
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 // Basic Exception Guarantee:
 // Partially formed object. Reading is undefined behavior
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std::vector<int> y = std::move(x);
```

How can nothing be something?

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try {
    x.insert(x.begin(), 0);
} catch (...) {
    std::cout << x.size() << std::endl;
}
 // Basic Exception Guarantee:
 // Partially formed object. Reading is undefined behavior

std::vector<int> y = std::move(x);
 // Moved from object, x, is partially formed
```

"That makes you wonder. Take chicken, for example."

– Matrix

Specification

Specification

- `clone_ptr<T>` is like `std::unique_ptr<T>` but with two additional operations, copy and assignment that copy the object pointed to.

- Example implementation of new operations:

```
clone_ptr(const clone_ptr& x) : _ptr(new T(*x)) { }
clone_ptr& operator=(const clone_ptr& x) { return *this = clone_ptr(x); }
```

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```

- copy-assignment written in terms of copy and move-assignment

What is copy?

- *Copying* an object creates a new object which is equal-to and logically disjoint from the original.

```
T a = b; ⇒ a == b;
T a = b; modify(b); ⇒ a != b;
```

“copy” of clone_ptr

```
clone_ptr<T> a = b; ⇒ a != b;
```

- *“Copying”* a clone pointer creates an object that is not equal to the original
- Contradiction

- Defining a copy-constructor that doesn’t copy is dangerous
  - The compiler may elide copies
  - Programmers will assume they are substitutable

Specification: Amendment 1

- Two `clone_ptrs` are considered equal if the value they point to is equal. Because we don't want to require that the pointed to types are equal `operator==()` and `operator!=()` are not implemented. i.e.:

```
clone_ptr<T> a = b; ⇒ a == b;
```

However, == is not implemented.

What is a pointer?

- A *pointer* is an object that refers to another object via a dereference operation. Two pointers are equal if they refer to the same instance of an object.

```
a == b; ⇒ &*a == &*b;
```

“equality” of clone_ptr

```
clone_ptr<T> a = b; ⇒ a == b;
```

- Because `clone_ptr` is a pointer this would imply:

```
assert(&*a == &*b);
```

- But that is false - contradiction.

Specification: Amendment 2

- Because `clone_ptr<>` is not a pointer it is to be renamed `indirect<>`.

What is a const?

- *const* is a type qualifier. An object accessed through a *const* reference may not be modified.

```
const T a = b; read(a); ⇒ a == b;
modify(a); is not allowed
```

“const” of indirect

```
const indirect<T> a = b; read(a); ⇏ a == b;
```

- Because const does not propagate (from unique_ptr):

```
void read(const indirect<T>& x) {
    modify(*x);
}
```

- Contradiction!

Specification: Amendment 3

- Because copy of remote part implies const propagation, get(), operator*() and operator->() must be overloaded:

```
T* get();
const T* get() const;

T& operator*();
const T& operator*() const;

T* operator->();
const T* operator->() const;
```

Alternative Specification:

Alternative Specification:

- clone_ptr<T> is like std::unique_ptr<T> but with one additional operation, clone() that works by copying the object pointed to.

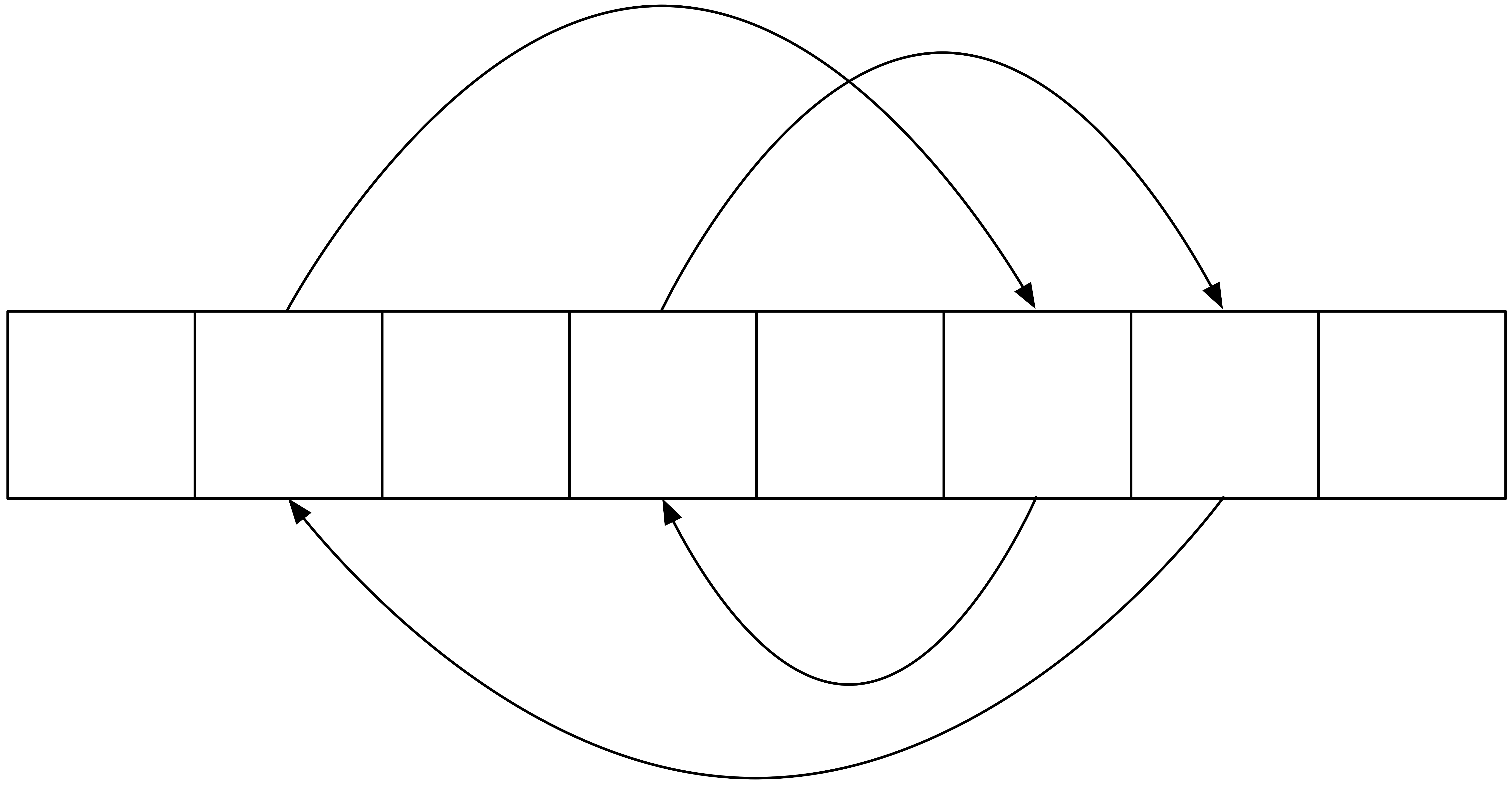
- Example implementation of clone operation:

```
clone_ptr clone() const { return make_clone<T>(**this); }
```

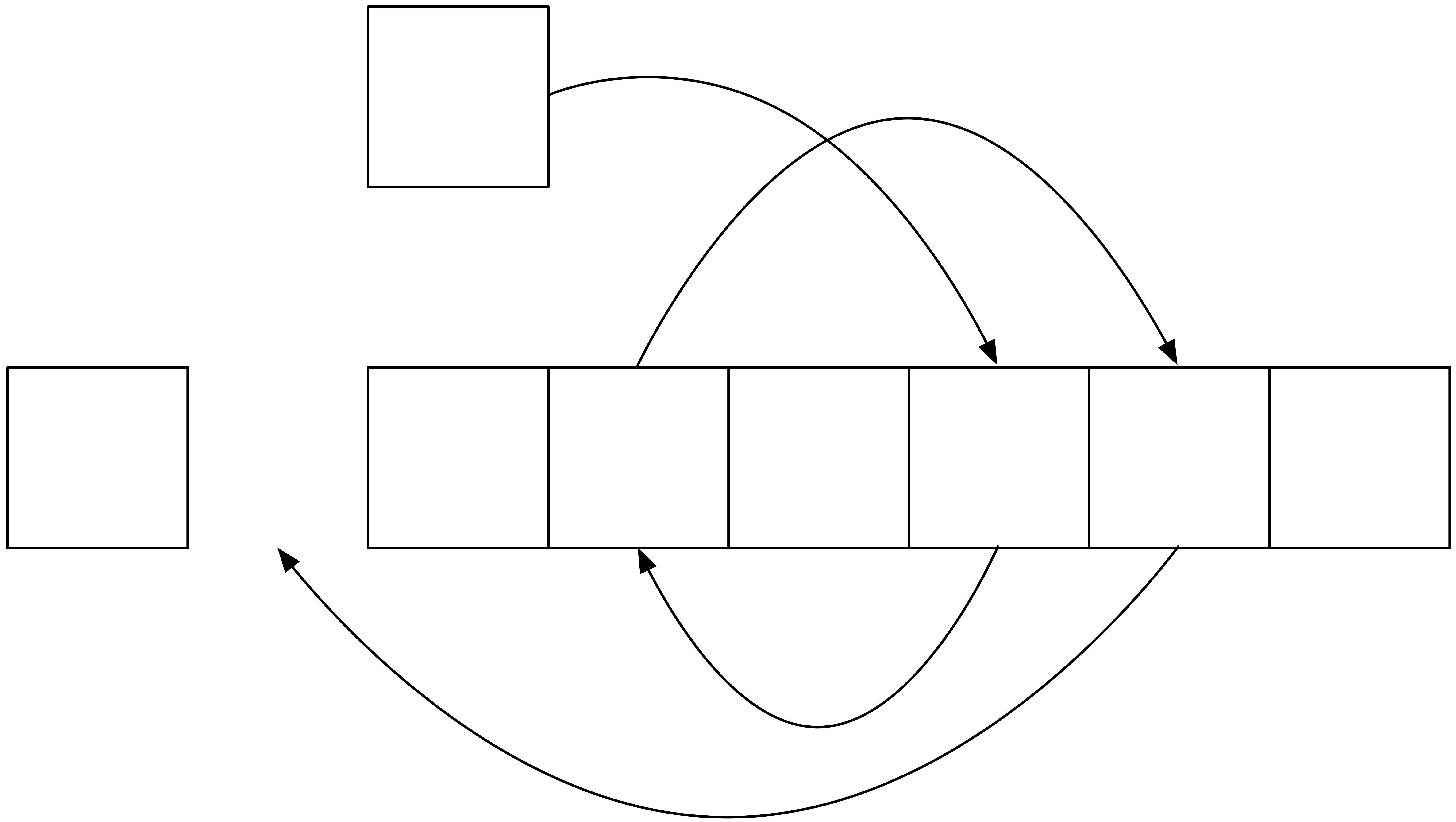
"What's in the box?"

– Seven

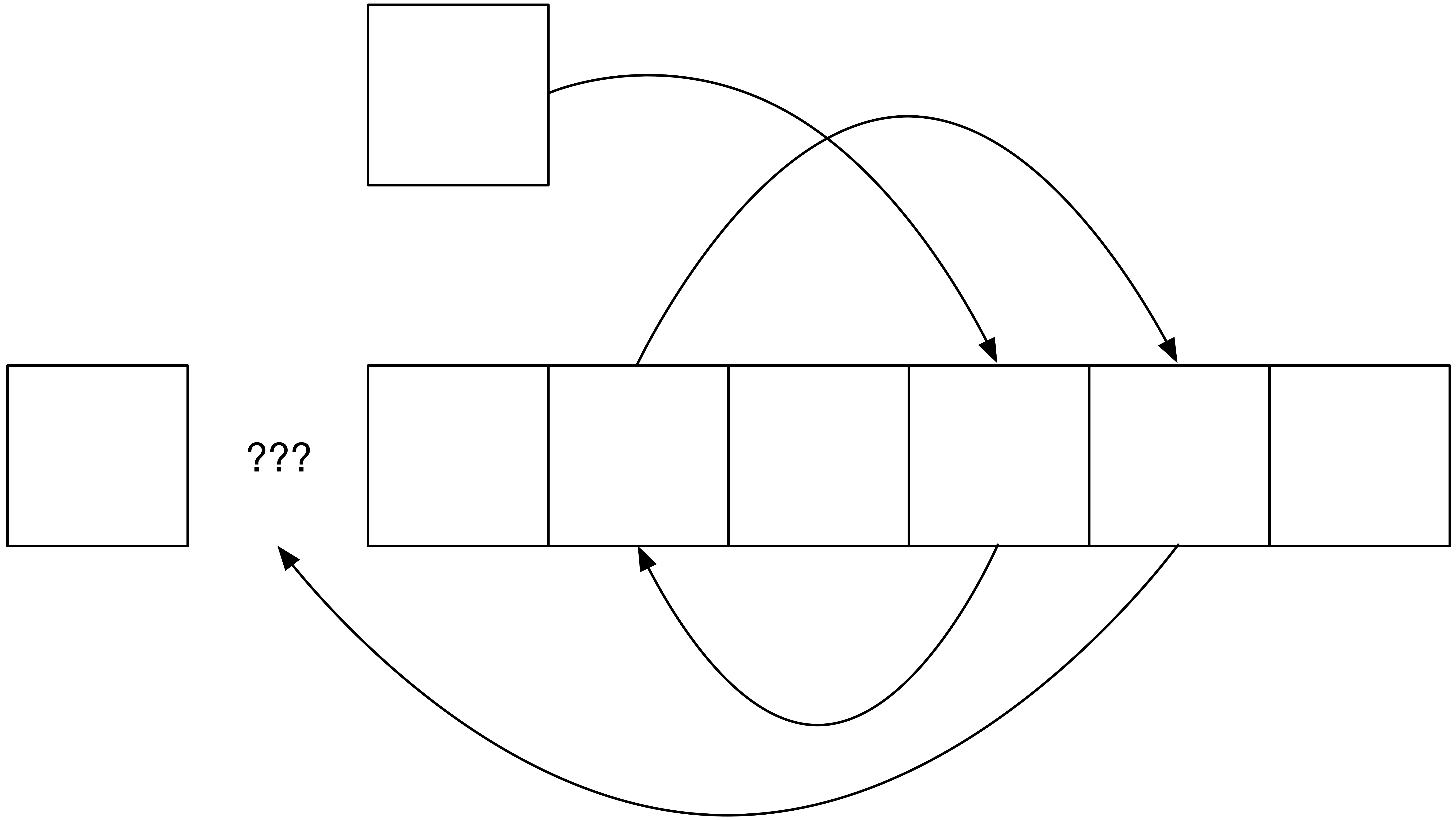
The Permutation Paradox



The Permutation Paradox

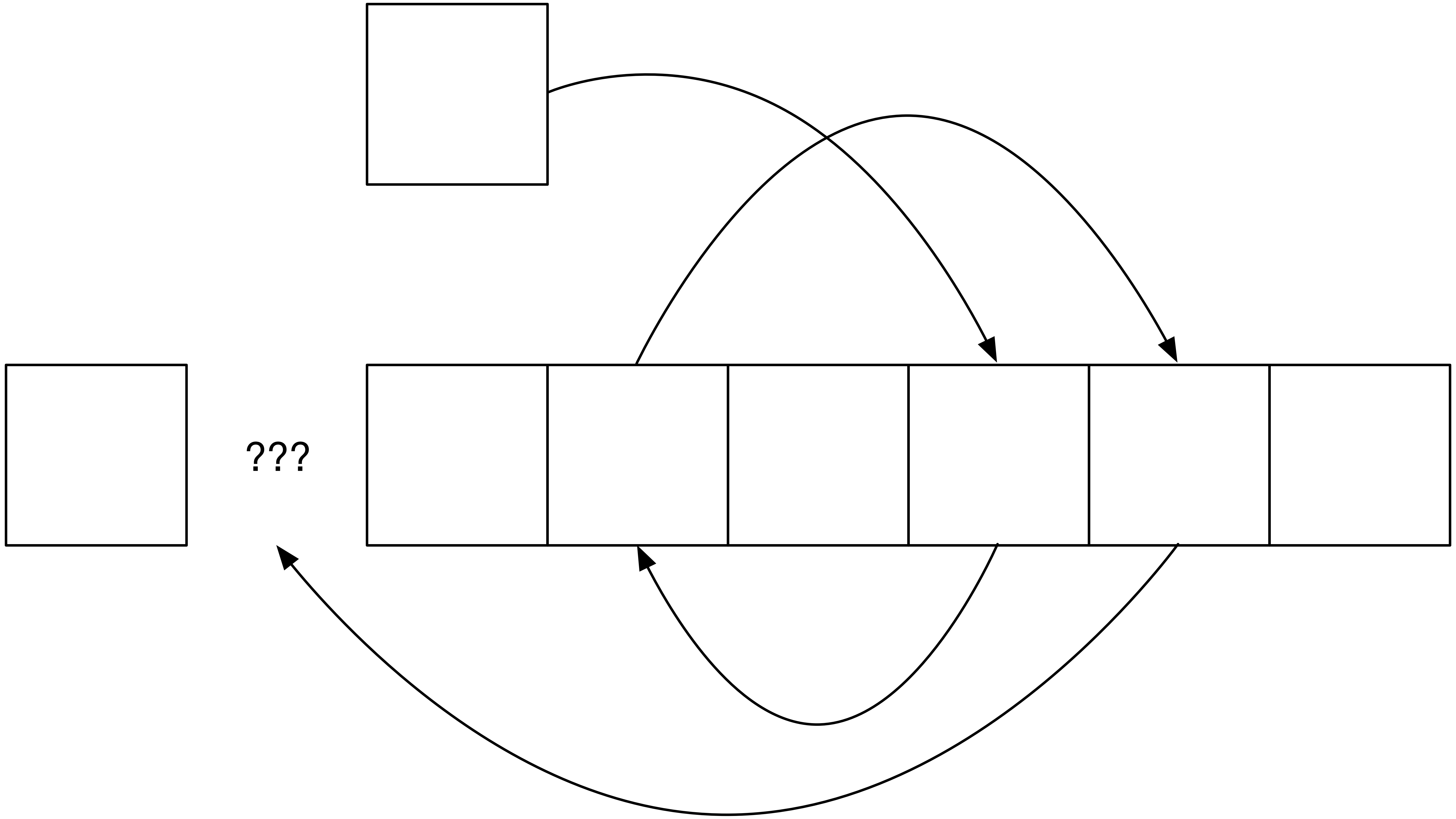


The Permutation Paradox



The Permutation Paradox

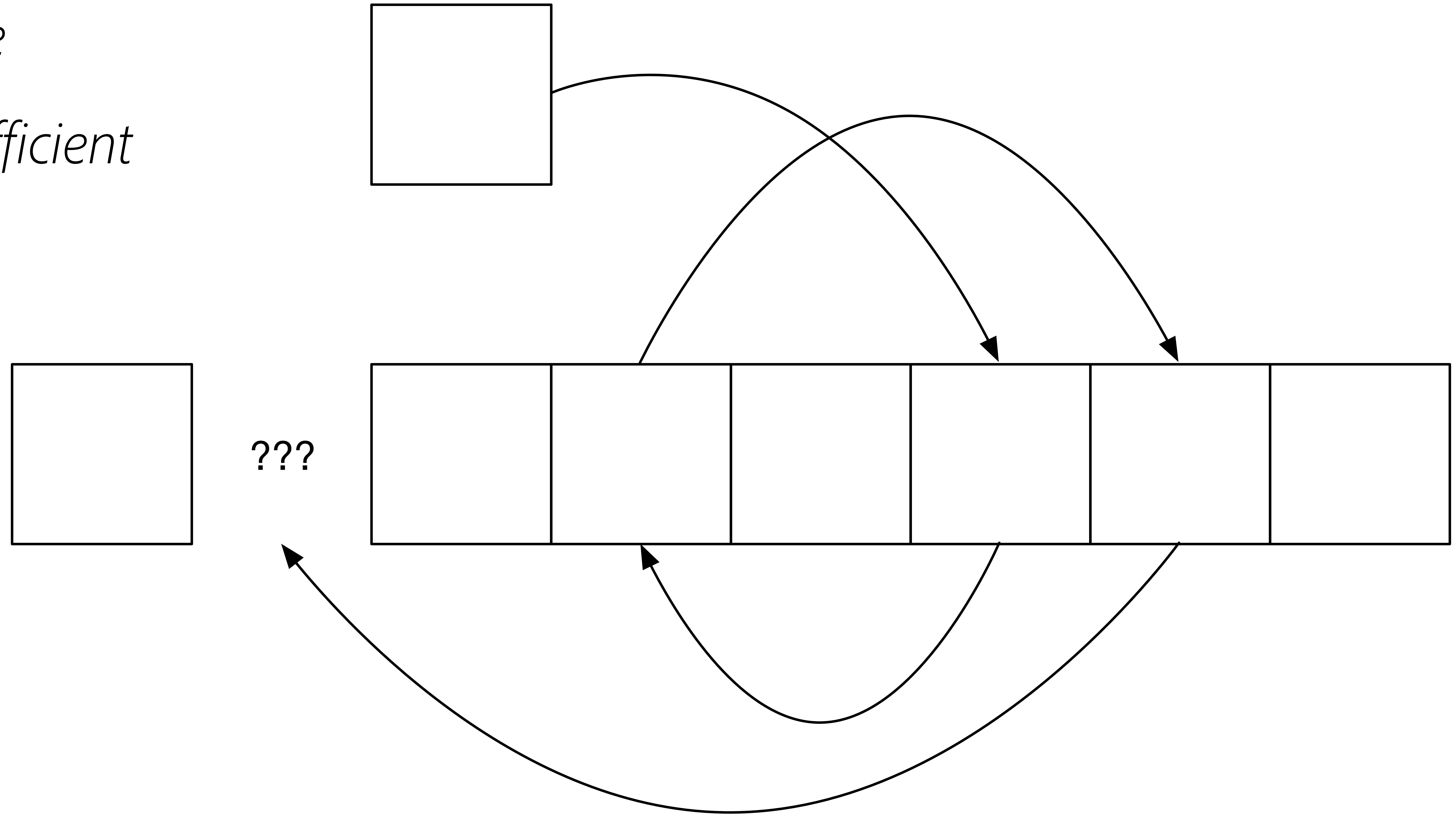
nothing ⇒ unsafe



The Permutation Paradox

nothing ⇒ unsafe

something ⇒ inefficient



The Permutation Paradox

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"There is a duality between transformations and the corresponding actions: An action is definable in terms of a transformation and vice versa:

The Permutation Paradox

“There is a duality between transformations and the corresponding actions: An action is definable in terms of a transformation and vice versa:

```
void a(T& x) { x = f(x); } // action from transformation
```

and

```
T f(T x) { a(x); return x; } // transformation from action
```

The Permutation Paradox

"There is a duality between transformations and the corresponding actions: An action is definable in terms of a transformation and vice versa:

```
void a(T& x) { x = f(x); } // action from transformation
```

and

```
T f(T x) { a(x); return x; } // transformation from action
```

Despite this duality, independent implementations are sometimes more efficient, in which case both action and transformation need to be provided."

– *Elements of Programming (section 2.5)*


Adobe
"It's not that I'm lazy, it's that I just don't care."
– Office Space
Bé
GMUNK

Good Code

Good code is *correct*

Consistent; without contradiction

Good code has *meaning*

Correspondence to an entity; specified, defined

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Maximum effect with minimum resources

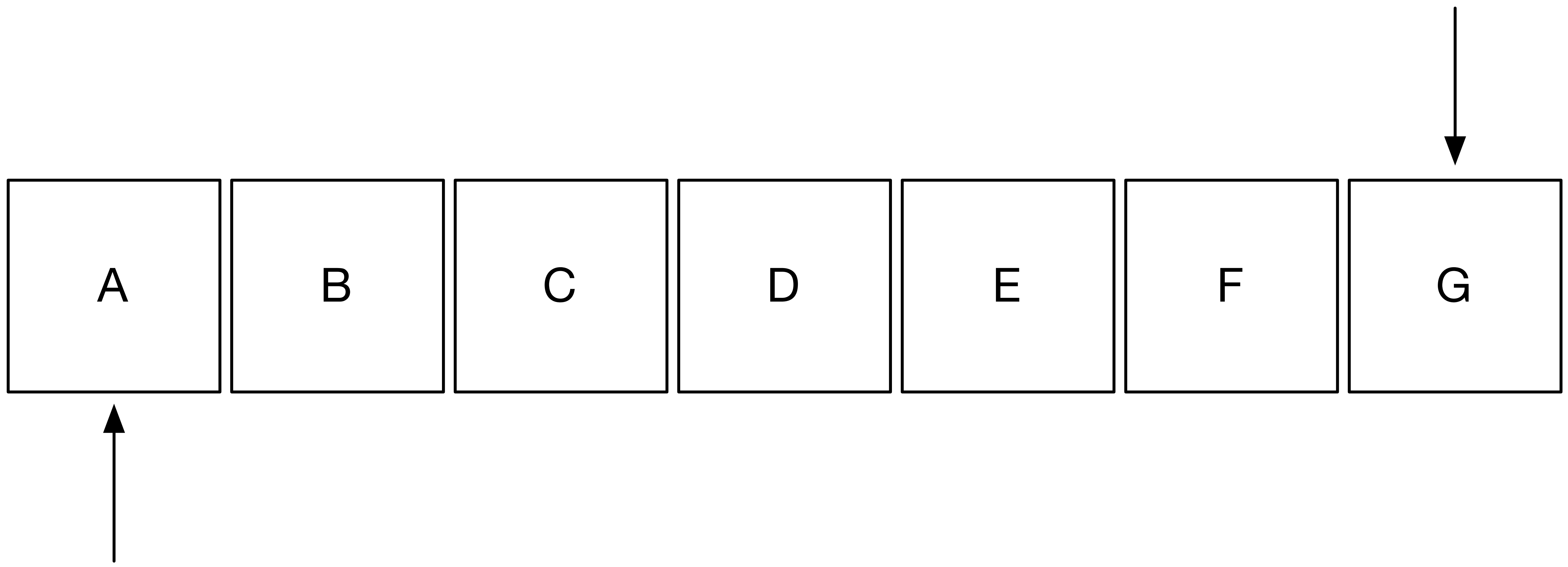
Efficiency

Efficiency

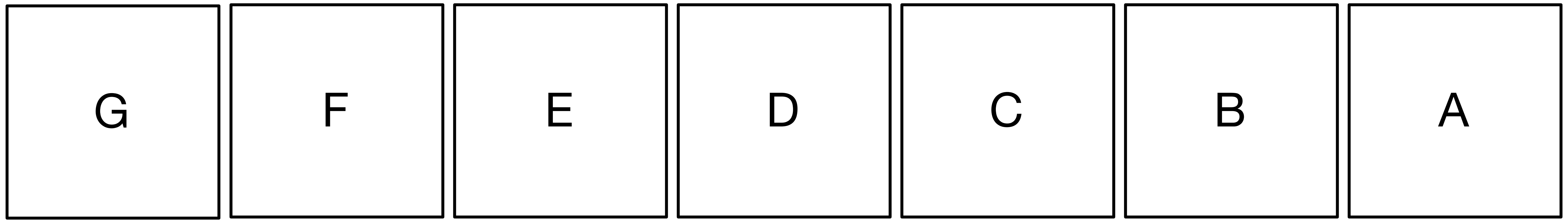
Choice of data structures and algorithms

Choice of what to optimize for

Efficiency



Efficiency



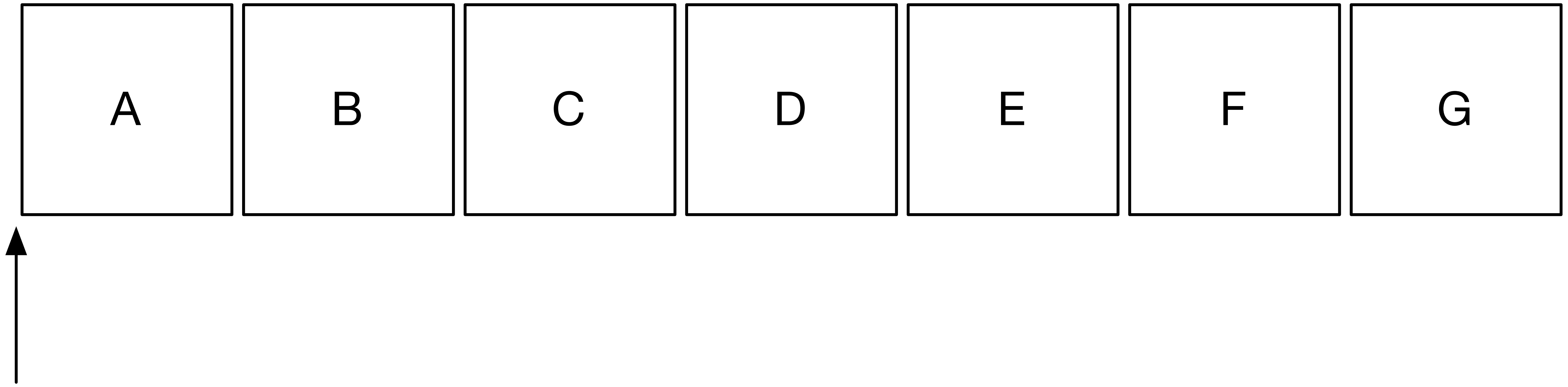
Efficiency

```
template <class ForwardIterator, class N>
auto reverse_n(ForwardIterator f, N n) {
    if (n < 2) return next(f, n);

    auto h = n / 2;
    auto m1 = reverse_n(f, h);
    auto m2 = next(m1, n % 2);
    auto l = reverse_n(m2, h);
    swap_ranges(f, m1, m2);
    return l;
}

template <class ForwardIterator>
void reverse(ForwardIterator f, ForwardIterator l) {
    reverse_n(f, distance(f, l));
}
```

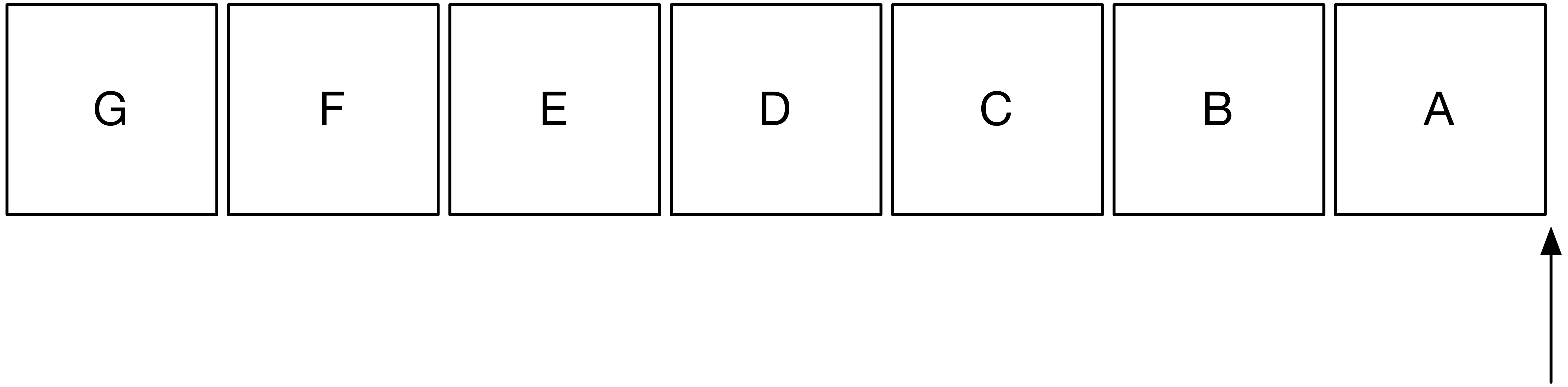
$O(n \log n)$

Elements of Programming, 10.3

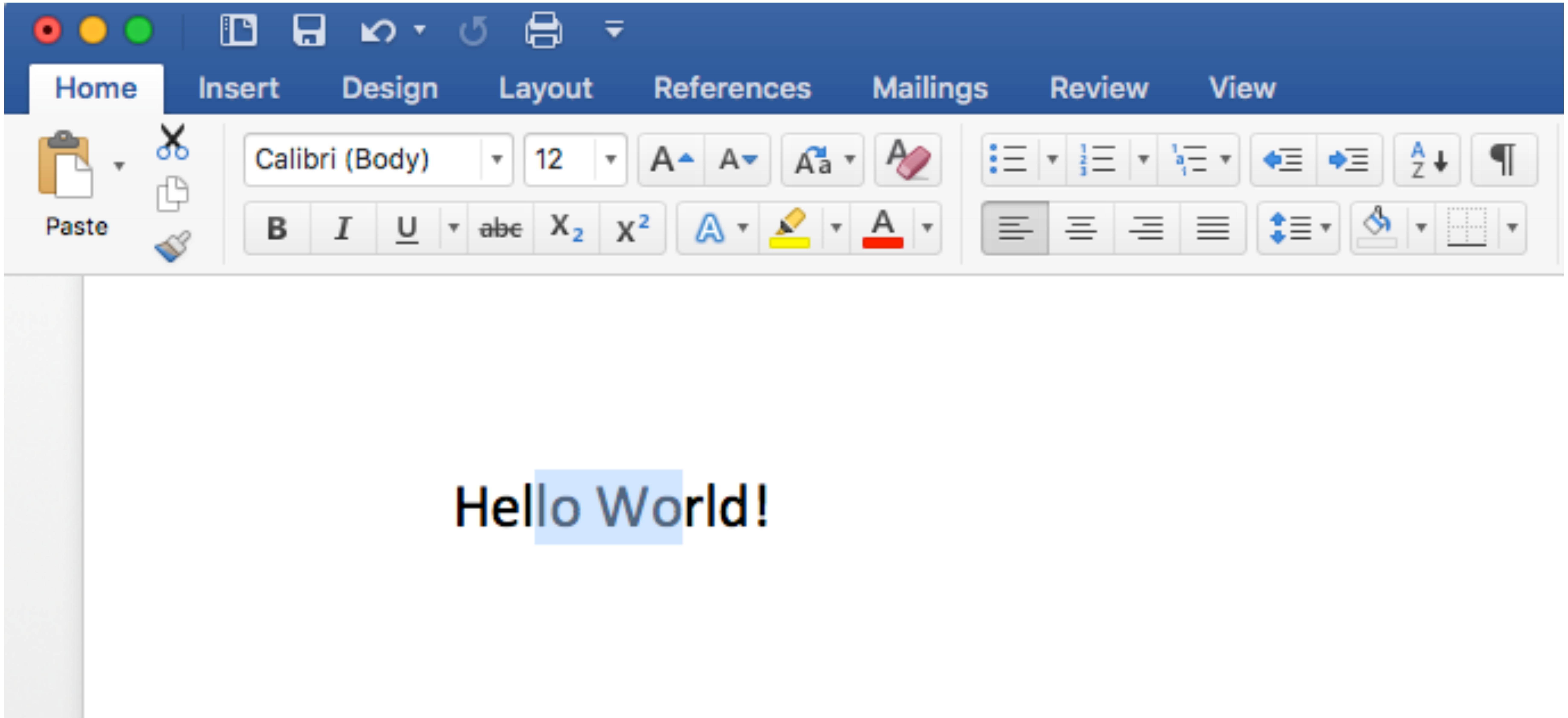
Efficiency



Efficiency

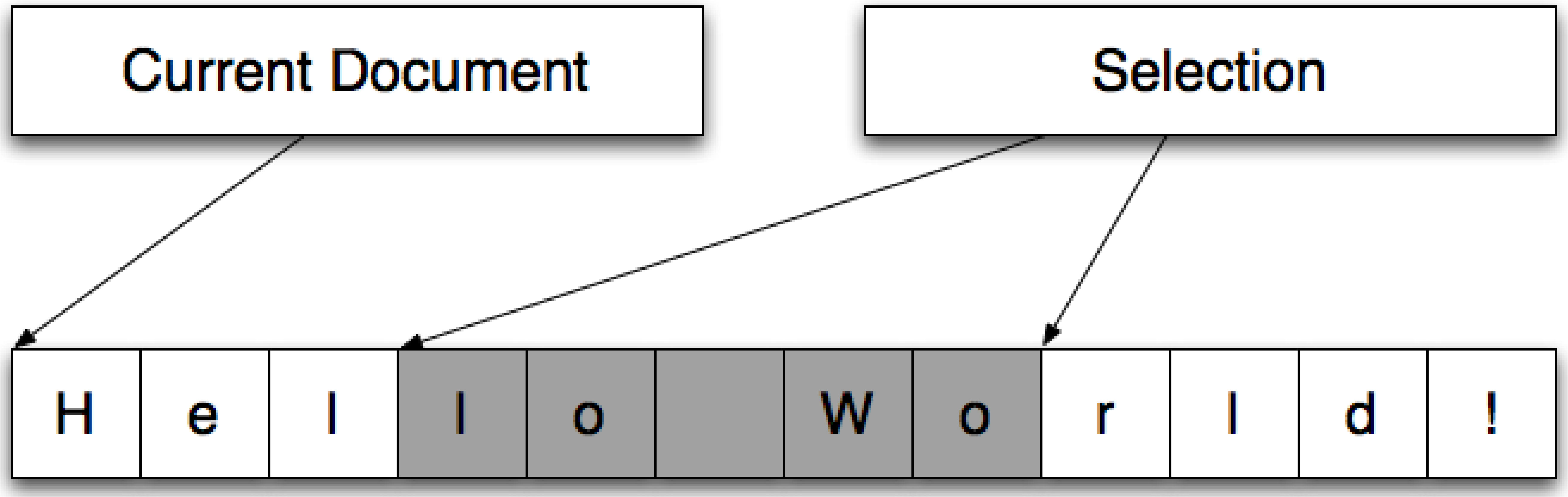


Simple Word Model



Simple Word Model

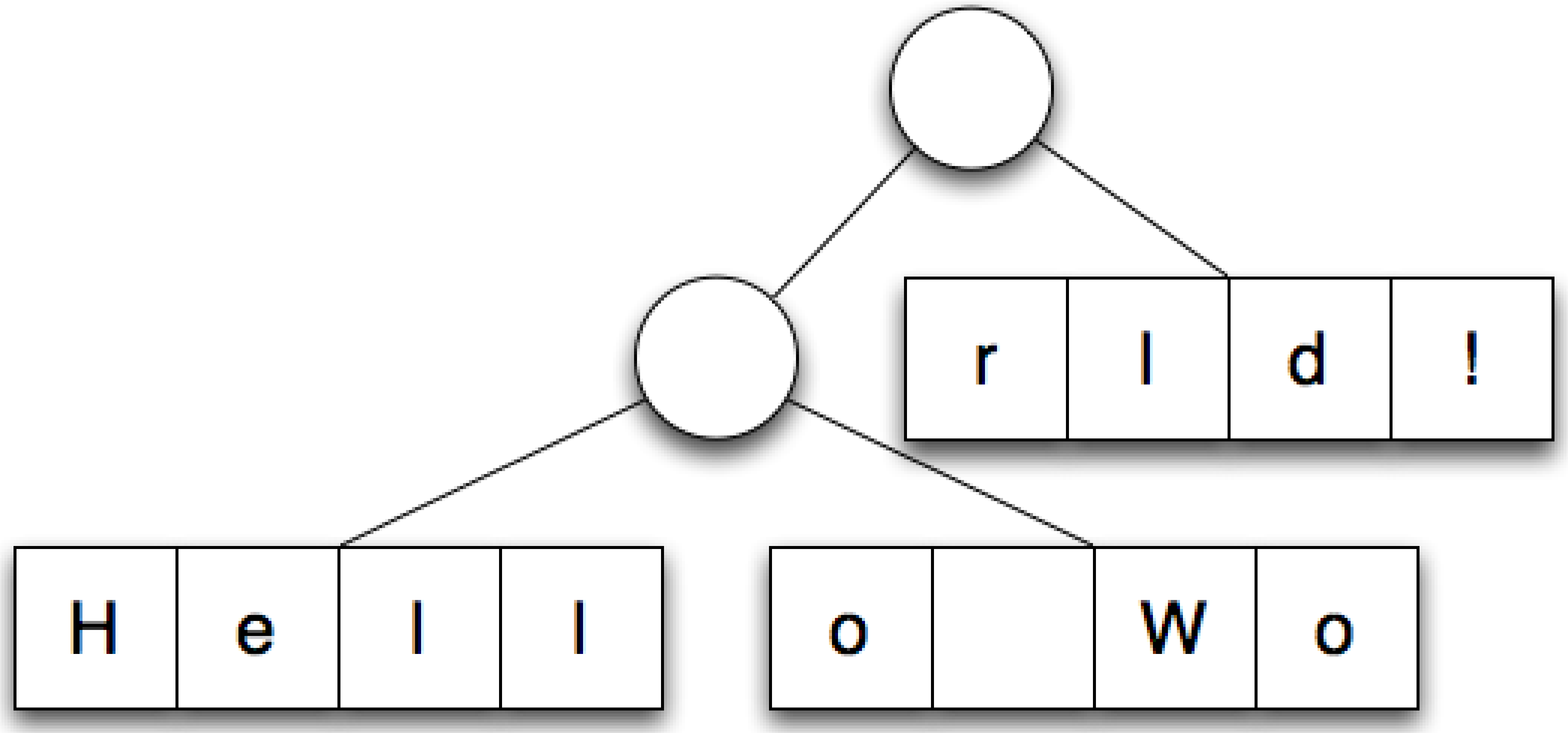
- Current Document
- Selection
  - Provides a range; an empty range denotes a location



More Complex Word Model

- Need to be able to set the selection in “constant” time
  - This would imply a vector data structure
- Also need constant time insert and erase
  - This would imply a list data structure

- Solution: a more complex data structure such as a rope



What is an efficient type?

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- A type is *complete* if the set of provided basis operations allow us to construct and operate on any valid, representable value
- A type is *efficient* if the set of basis operations allow for any valid operation to be performed in the most efficient way possible for the chosen representation

What is an efficient type?

- A type is *complete* if the set of provided basis operations allow us to construct and operate on any valid, representable value
- A type is *efficient* if the set of basis operations allow for any valid operation to be performed in the most efficient way possible for the chosen representation

- By simply making all data members public, you provide, by definition, an efficient basis
- However, you may fail to protect the invariants of the type, making the approach unsafe

- std::move is both unsafe an inefficient.

"I don't smoke, I don't drink… I recycle…"

– 50/50

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Good code has *meaning*

Correspondence to an entity; specified, defined

Good code is *efficient*

Maximum effect with minimum resources

Good code is r*eusable*

Applicable to multiple problems; general in purpose

Reusable

Reusable

Concrete but of general use, i.e. numeric algorithms, utf conversions, …

Generic when algorithm is useful with different models

- Sometimes faster to convert one model to another

Runtime dispatched when types not known at compile time

Reusable

Reusable

Minimize client dependencies and intrusive requirements

Separate data structures from algorithms

Reusable

Reusable

```
template <class T, class InputIterator, class OutputIterator>
OutputIterator copy_utf(InputIterator first, InputIterator last,
        OutputIterator result);


const char str[] = u8"Hello World!";
vector<uint16_t> out;
copy_utf<uint16_t>(begin(str), end(str), back_inserter(out));
```


"You mean we're in the future."
– Back to the Future Part II
Bē
GMUNK

Why Status Quo Will Fail

Why Status Quo Will Fail

"I've assigned this problem [binary search] in courses at Bell Labs and IBM. Professional programmers had a *couple of hours* to convert the description into a programming language of their choice; a high-level pseudo code was fine... Ninety percent of the programmers found bugs in their programs (and I wasn't always convinced of the correctness of the code in which no bugs were found)."

– Jon Bentley, Programming Pearls, 1986

Why Status Quo Will Fail

```
int* lower_bound(int* first, int* last, int value)
{
    while (first != last)
    {
        int* middle = first + (last - first) / 2;

        if (*middle < value) first = middle + 1;
        else last = middle;
    }

    return first;
}
```

Signs of Hope

Elements of Programming

Concepts aren't dead yet in C++

Increased interest in new languages and formalisms

Renewed interest in Communication Sequential Processes

Renewed interest in Functional Programming ideas

Rise of Reactive Programming & Functional Reactive Programming

Work Continues

Work Continues

Generating Reactive Programs for Graphical User Interfaces from Multi-way Dataflow Constraint Systems, GPCE 2015, Gabriel Foust, Jaakko Järvi, Sean Parent

One Way To Select Many, ECOOP 2016, Jaakko Järvi, Sean Parent

http://sean-parent.stlab.cc/papers-and-presentations

https://github.com/stlab

Write Better Code

Adobe