Better Code

Sean Parent | Principal Scientist

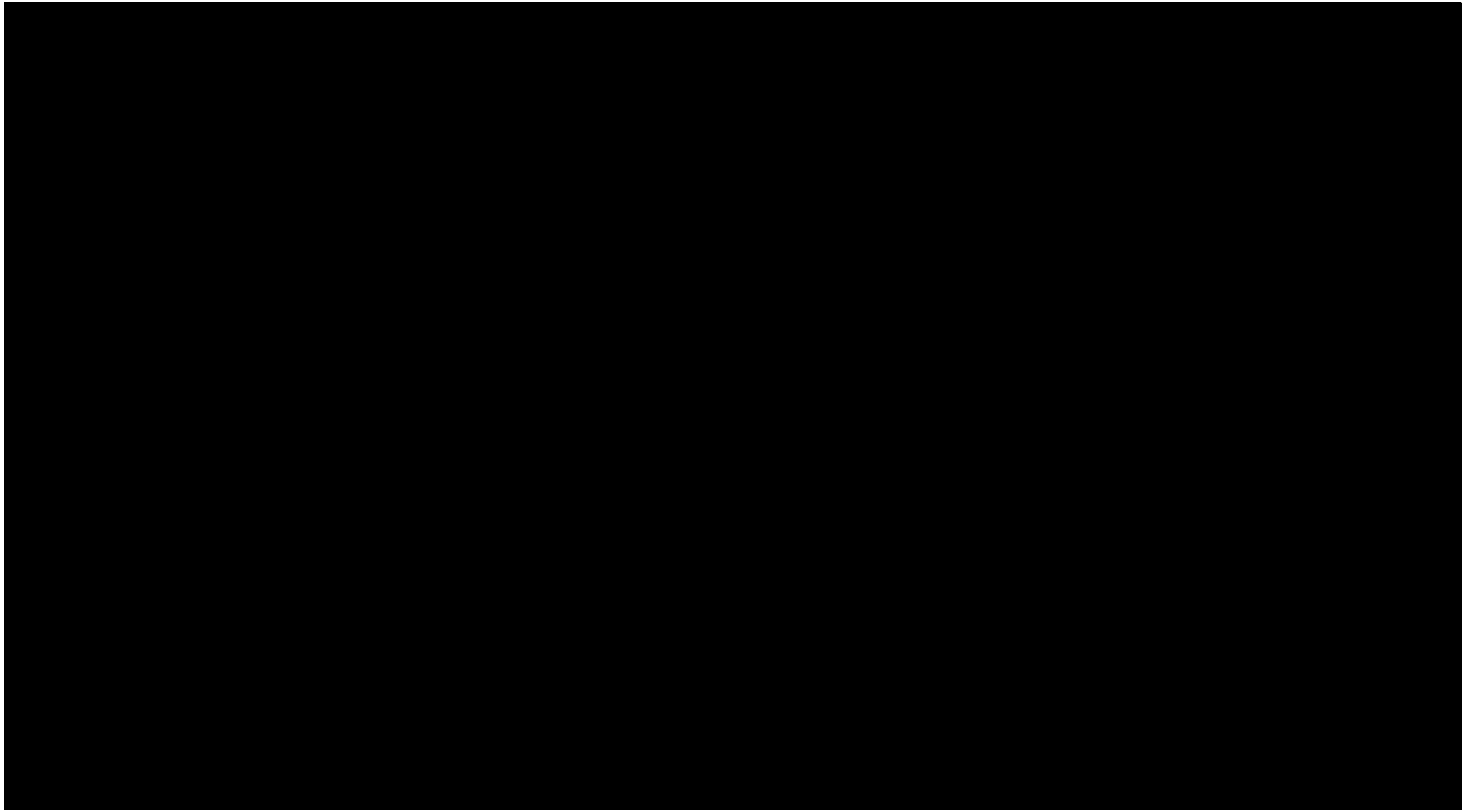
Bē
GMUNK

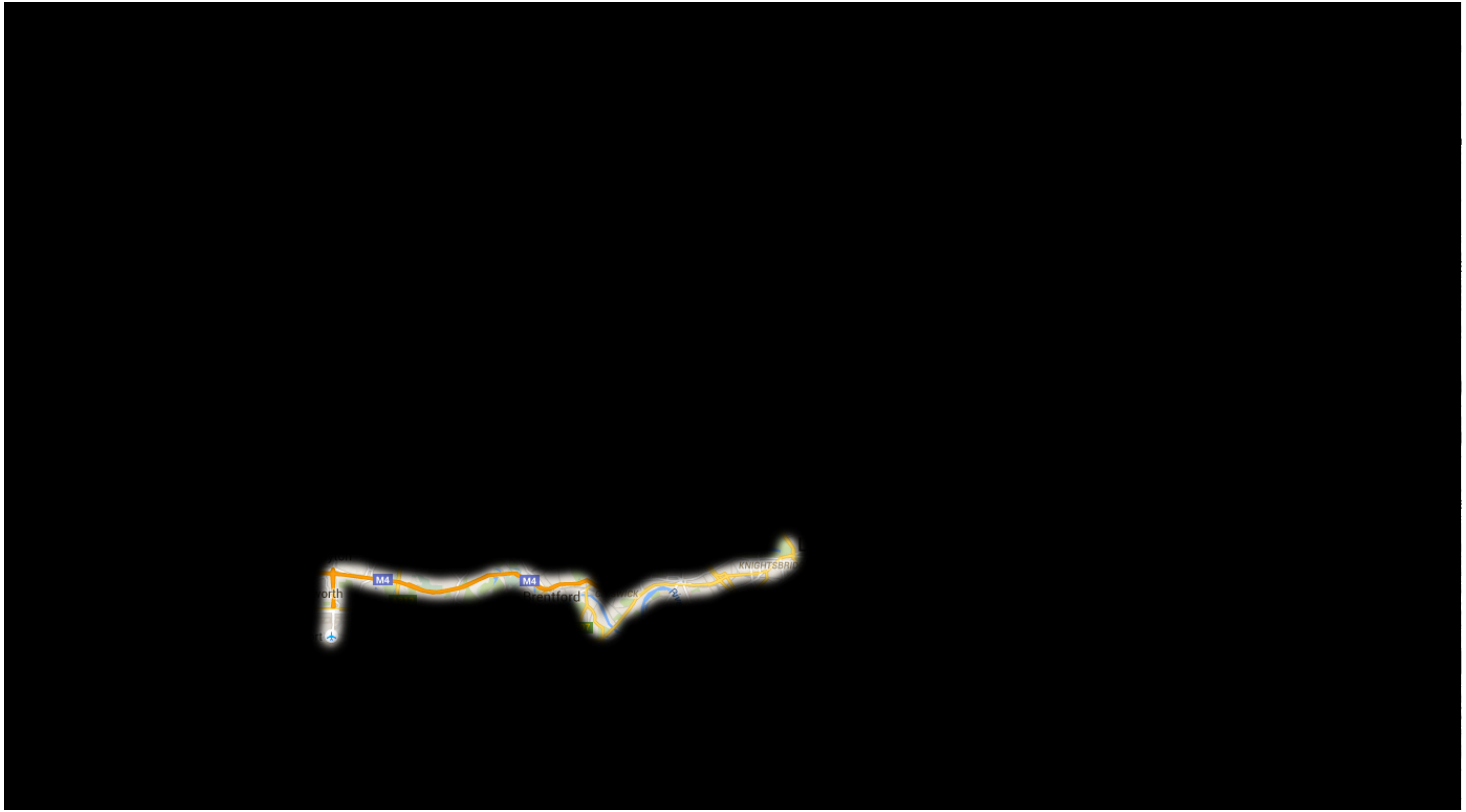
Better Code

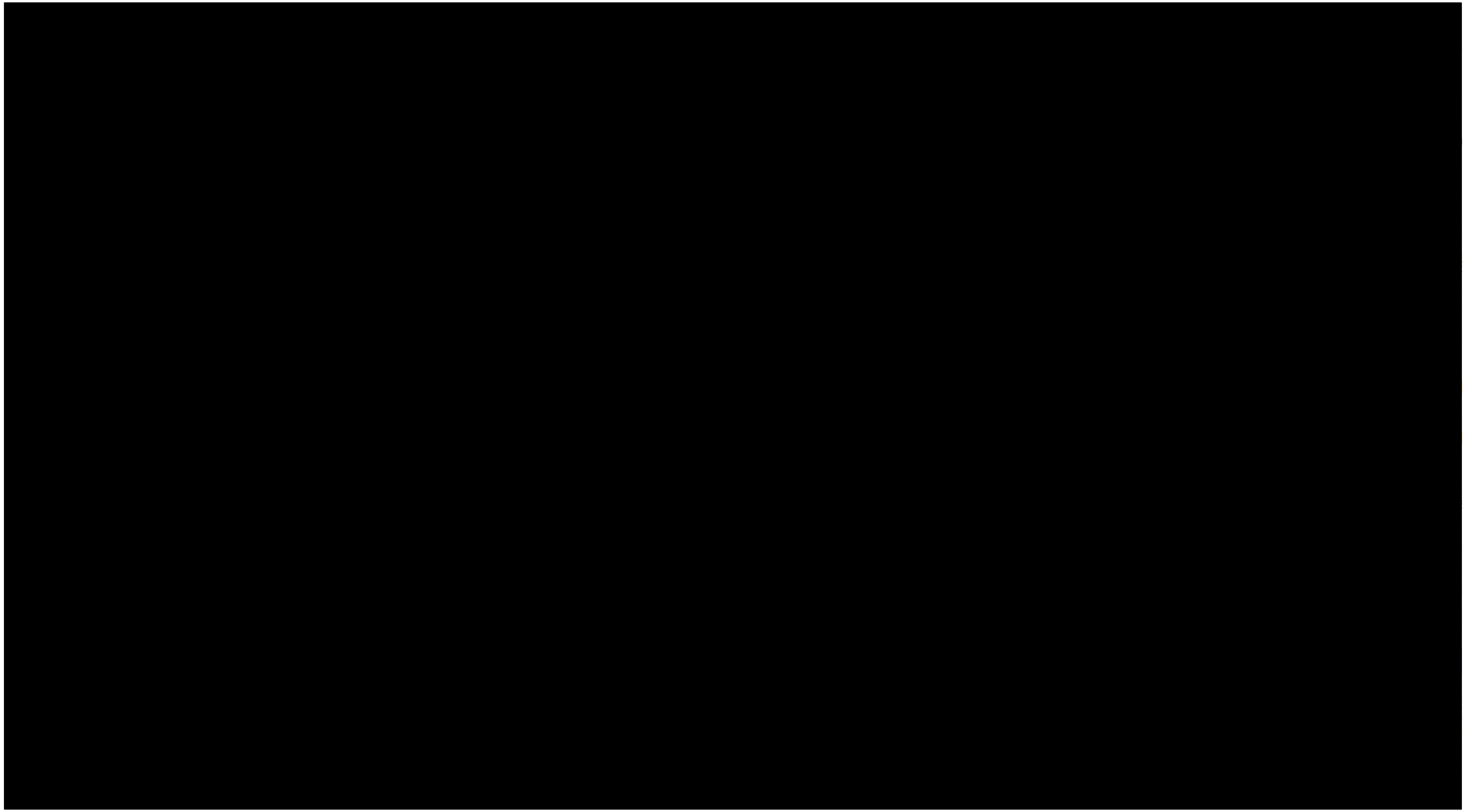
- Regular Types
  - Goal: No Incomplete Types
- Algorithms
  - Goal: No Raw Loops
- Data Structures
  - Goal: No Incidental Data Structures
- Runtime Polymorphism
  - Goal: No Inheritance
- Concurrency
  - Goal: No Raw Synchronization Primitives

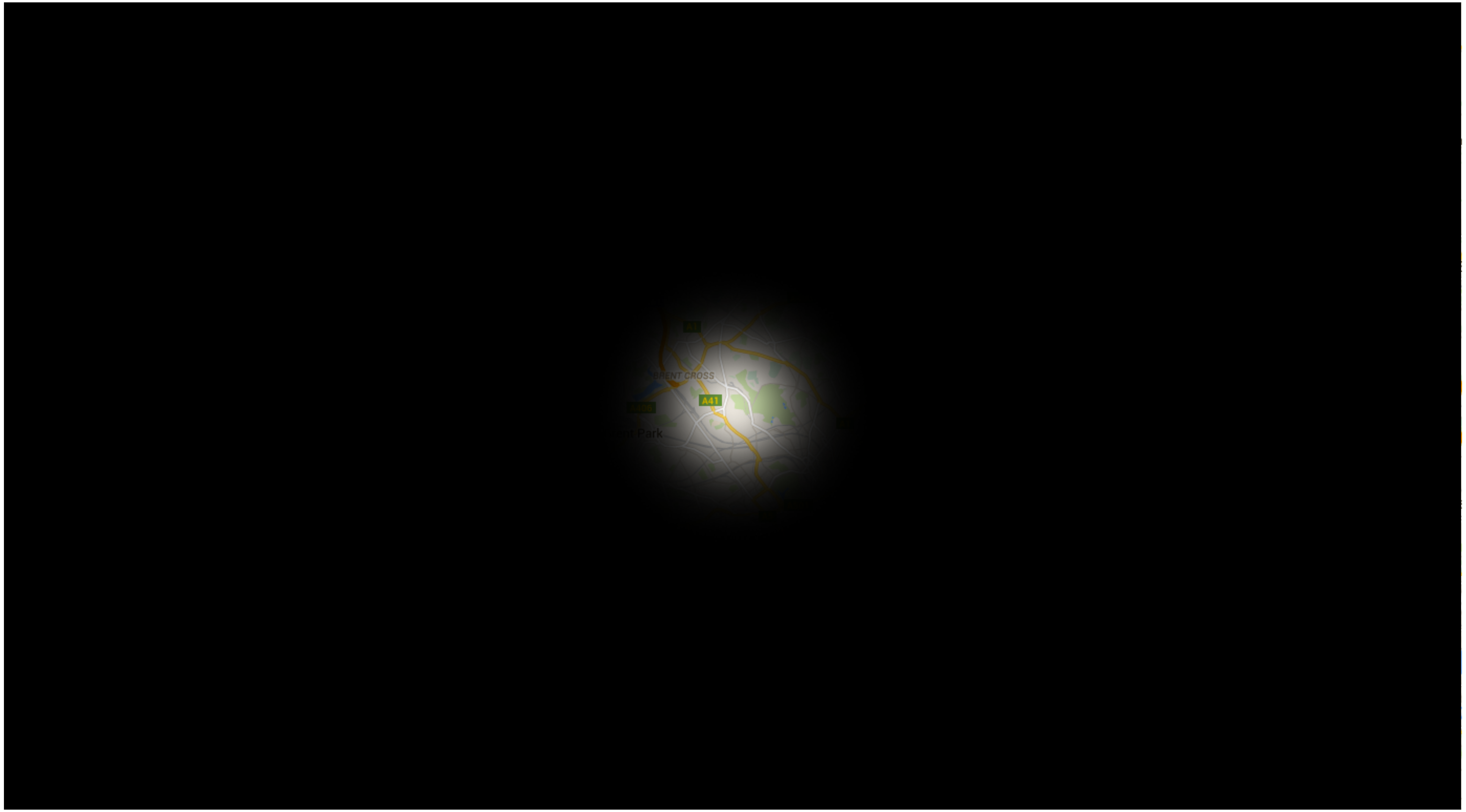
http://sean-parent.stlab.cc/papers-and-presentations

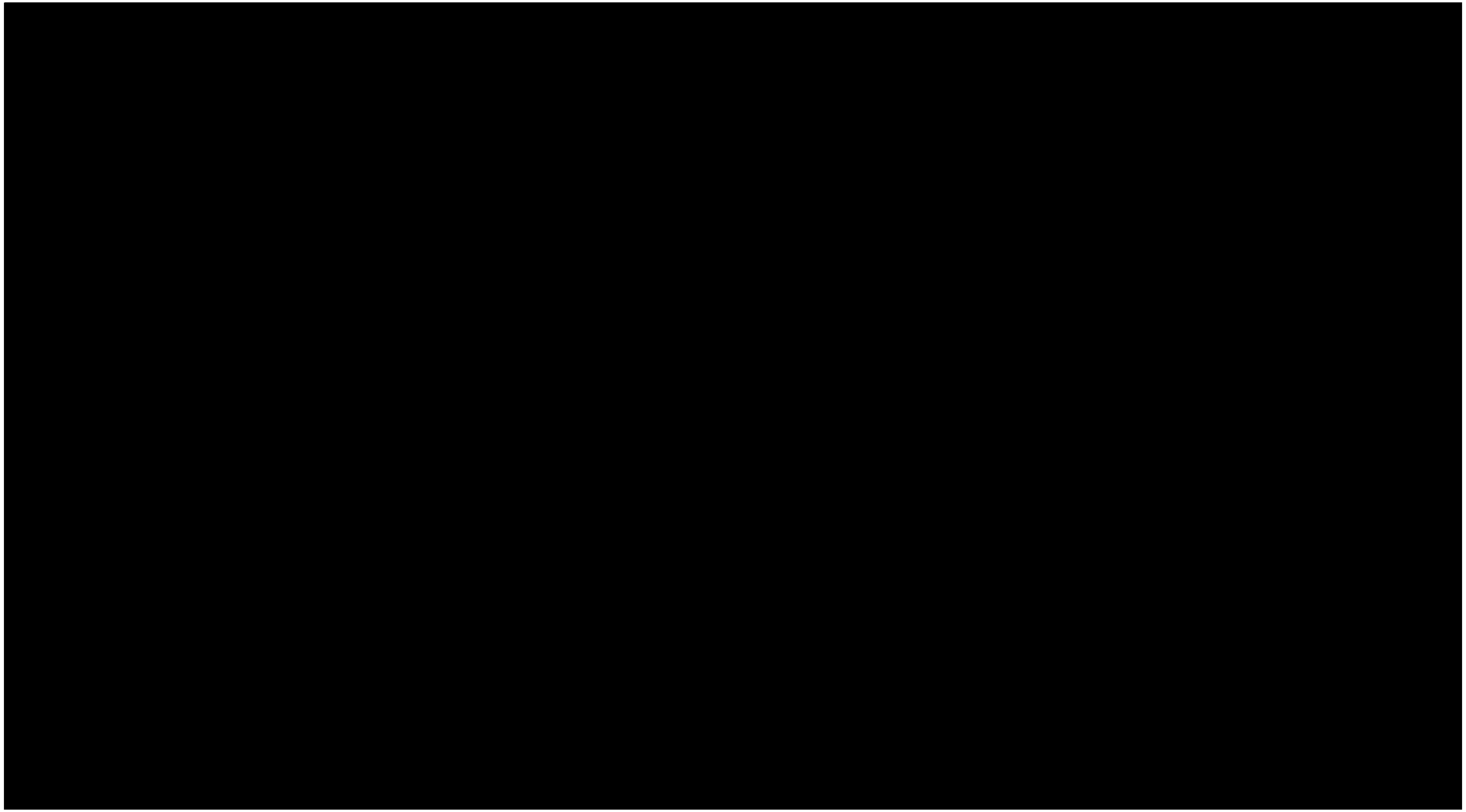
The Knowledge

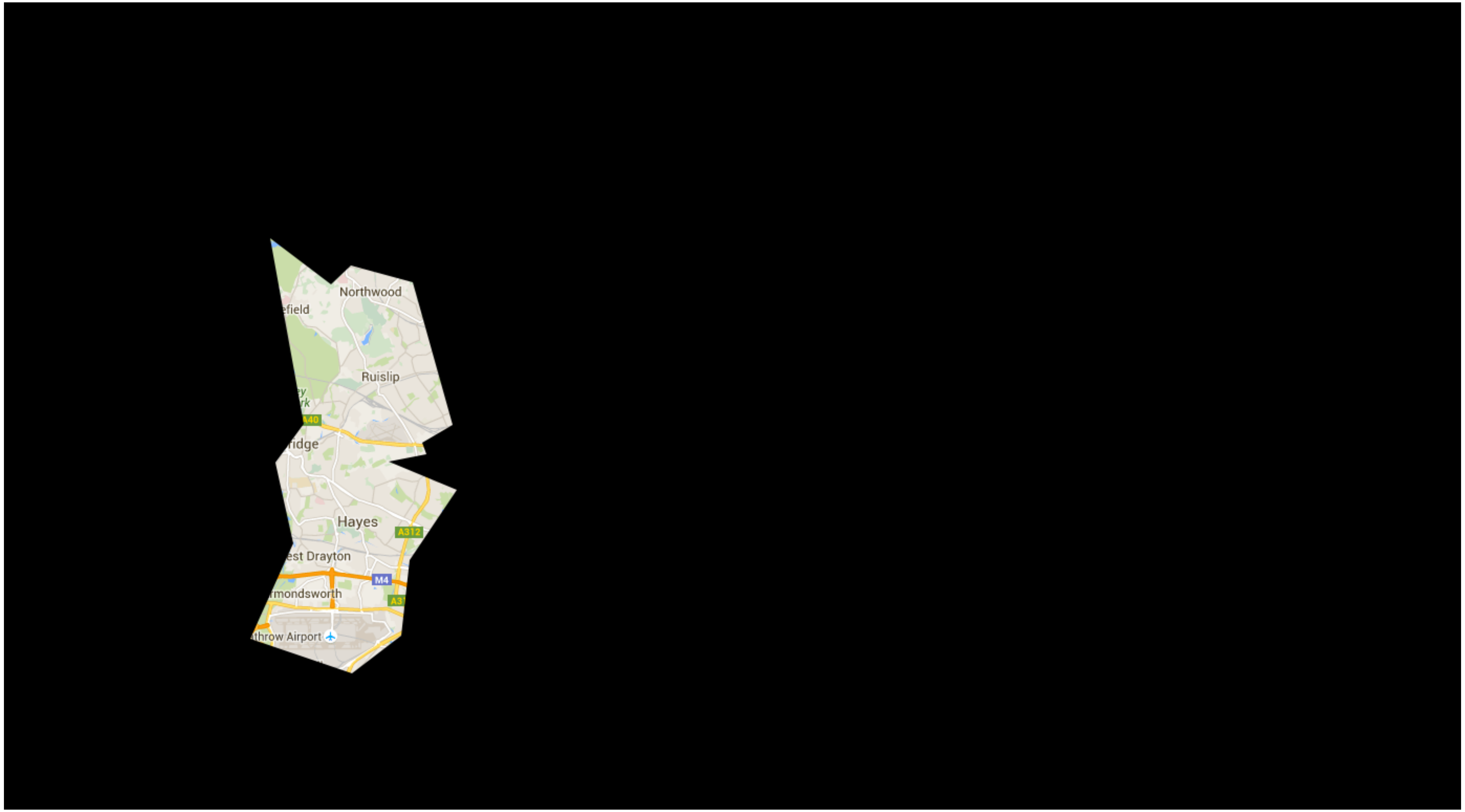


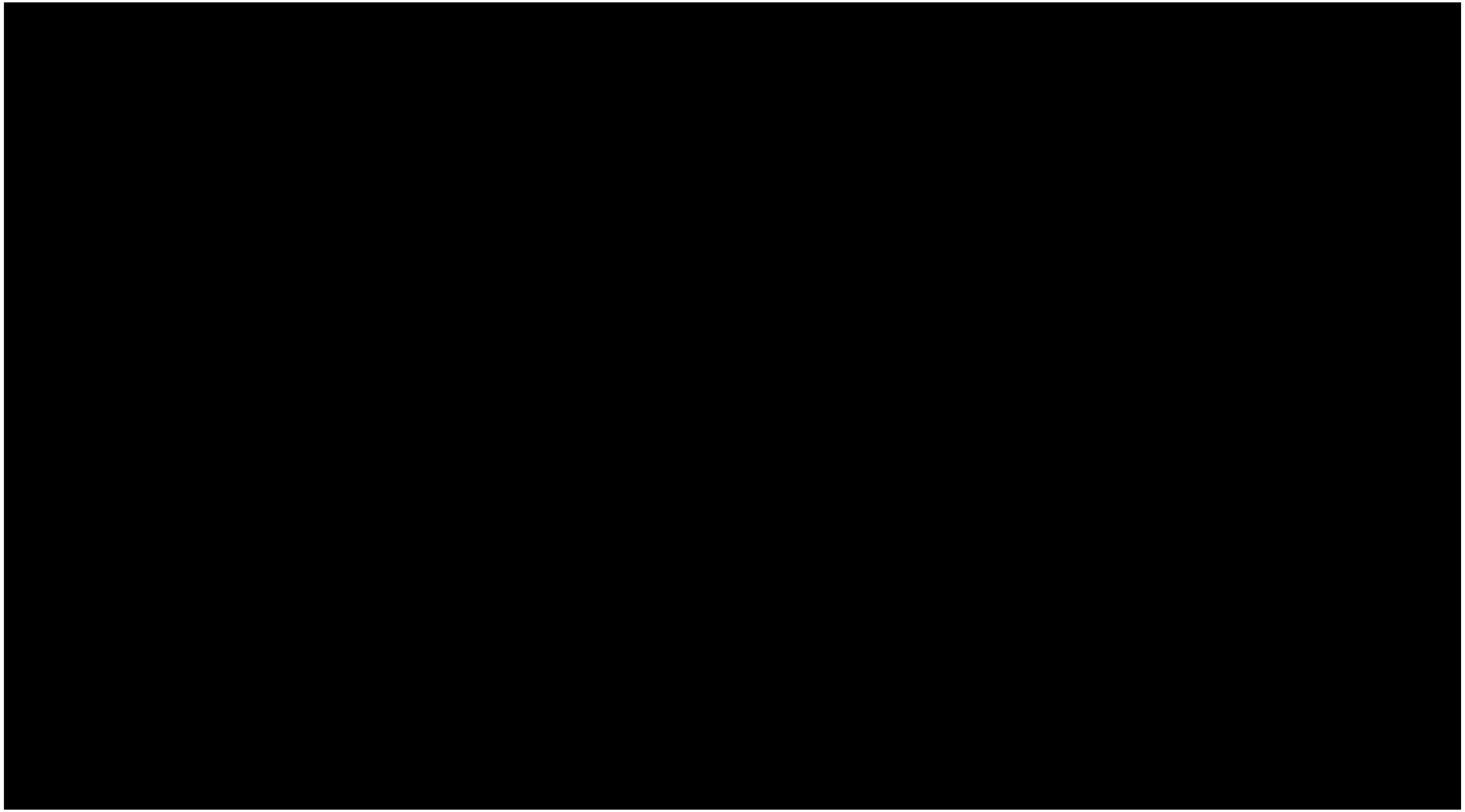

M4
M4
Brentford

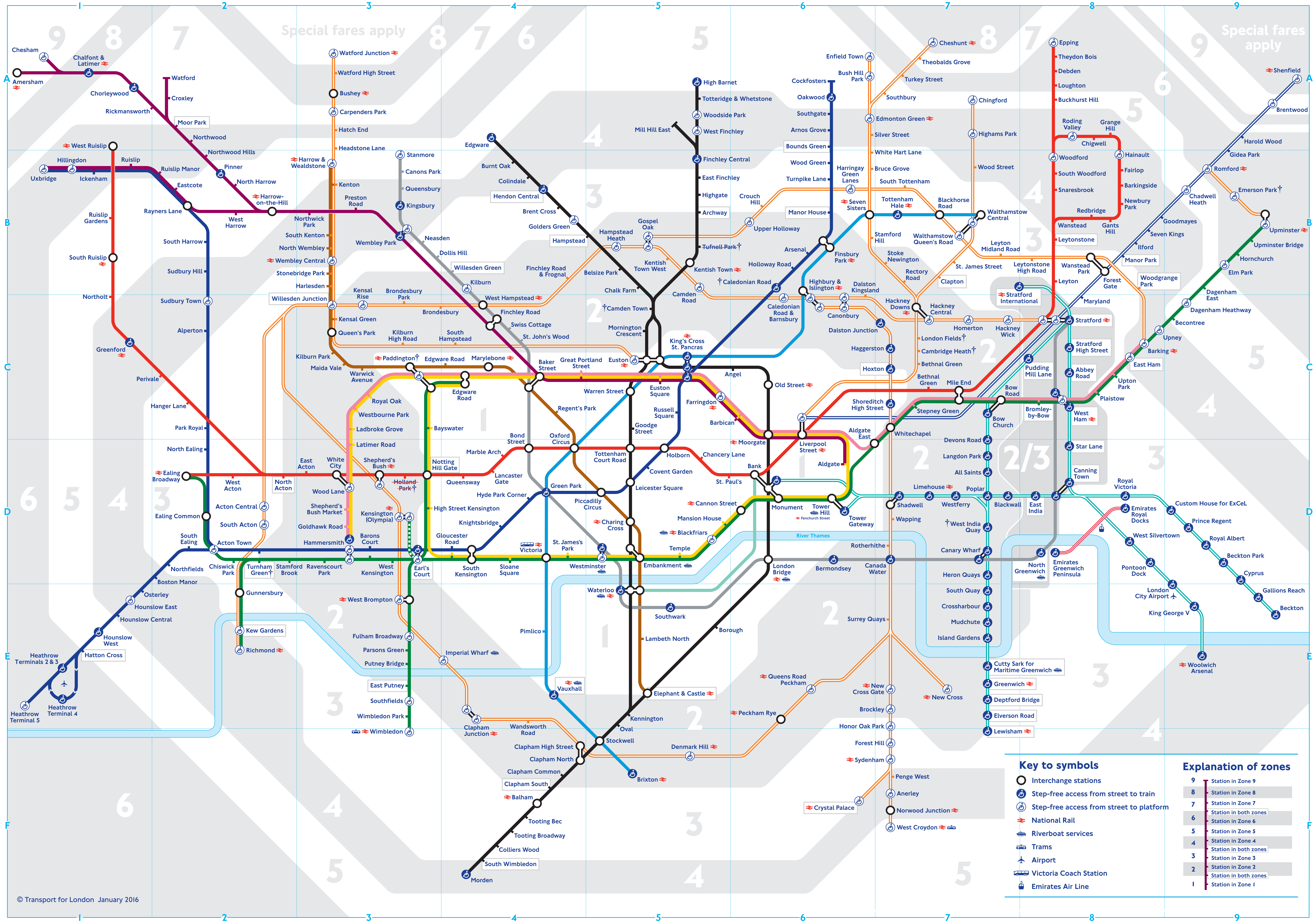



A1
BRENT CROSS
A41
A406




Northwood
Ruislip
A40
Hayes
A312
Drayton
M4
Airport





Special fares apply
Special fares apply
Chesham
Amersham
Chalfont & Latimer
Chorleywood
Rickmansworth
Watford
Croxley
Moor Park
Northwood
Northwood Hills
Pinner
North Harrow
Harrow-on-the-Hill
West Harrow
West Ruislip
Ruislip
Ruislip Manor
Eastcote
Hillingdon
Uxbridge
Ickenham
Rayners Lane
Ruislip Gardens
South Harrow
South Ruislip
Sudbury Hill
Northolt
Sudbury Town
Alperton
Greenford
Perivale
Hanger Lane
Park Royal
North Ealing
Ealing Broadway
West Acton
North Acton
East Acton
White City
Ealing Common
Acton Central
South Acton
South Ealing
Acton Town
Northfields
Chiswick Park
Turnham Green
Stamford Brook
Ravenscourt Park
Boston Manor
Osterley
Hounslow East
Hounslow Central
Hounslow West
Hatton Cross
Heathrow Terminals 2 & 3
Heathrow Terminal 5
Heathrow Terminal 4
Gunnersbury
Kew Gardens
Richmond
Watford Junction
Watford High Street
Bushey
Carpenders Park
Hatch End
Headstone Lane
Harrow & Wealdstone
Kenton
Preston Road
Northwick Park
South Kenton
North Wembley
Wembley Central
Stonebridge Park
Harlesden
Willesden Junction
Kensal Green
Queen's Park
Kilburn Park
Maida Vale
Warwick Avenue
Stanmore
Canons Park
Queensbury
Kingsbury
Wembley Park
Neasden
Dollis Hill
Willesden Green
Kilburn
West Hampstead
Finchley Road
Swiss Cottage
St. John's Wood
Kensal Rise
Brondesbury Park
Brondesbury
Kilburn High Road
South Hampstead
Edgware
Burnt Oak
Colindale
Hendon Central
Brent Cross
Golders Green
Hampstead
Hampstead Heath
Finchley Road & Frognal
Belsize Park
Chalk Farm
Camden Town
Mornington Crescent
Gospel Oak
Kentish Town West
Kentish Town
Camden Road
Mill Hill East
High Barnet
Totteridge & Whetstone
Woodside Park
West Finchley
Finchley Central
East Finchley
Highgate
Archway
Crouch Hill
Tufnell Park
Upper Holloway
Holloway Road
Caledonian Road
Caledonian Road & Barnsbury
Highbury & Islington
Canonbury
Dalston Kingsland
Dalston Junction
Haggerston
Hoxton
Shoreditch High Street
Cockfosters
Oakwood
Southgate
Arnos Grove
Bounds Green
Wood Green
Turnpike Lane
Manor House
Harringay Green Lanes
Finsbury Park
Arsenal
Enfield Town
Bush Hill Park
Edmonton Green
Silver Street
White Hart Lane
Bruce Grove
South Tottenham
Seven Sisters
Stamford Hill
Stoke Newington
Rectory Road
Hackney Downs
Hackney Central
Homerton
Hackney Wick
Cheshunt
Theobalds Grove
Turkey Street
Southbury
Tottenham Hale
Blackhorse Road
Walthamstow Central
Walthamstow Queen's Road
Leyton Midland Road
Leytonstone High Road
St. James Street
Clapton
Chingford
Highams Park
Wood Street
London Fields
Cambridge Heath
Bethnal Green
Epping
Theydon Bois
Debden
Loughton
Buckhurst Hill
Roding Valley
Grange Hill
Chigwell
Hainault
Fairlop
Barkingside
Newbury Park
Woodford
South Woodford
Snaresbrook
Redbridge
Gants Hill
Wanstead
Leytonstone
Leyton
Wanstead Park
Forest Gate
Manor Park
Woodgrange Park
Maryland
Stratford
Stratford International
Stratford High Street
Shenfield
Brentwood
Harold Wood
Gidea Park
Romford
Emerson Park
Chadwell Heath
Goodmayes
Seven Kings
Ilford
Upminster
Upminster Bridge
Hornchurch
Elm Park
Dagenham East
Dagenham Heathway
Becontree
Upney
Barking
East Ham
Upton Park
Plaistow
West Ham
Abbey Road
Pudding Mill Lane
Bow Road
Bow Church
Bromley-by-Bow
Mile End
Stepney Green
Whitechapel
Paddington
Edgware Road
Marylebone
Baker Street
Great Portland Street
Euston
Euston Square
King's Cross St. Pancras
Angel
Old Street
Farringdon
Barbican
Moorgate
Liverpool Street
Aldgate
Aldgate East
Royal Oak
Westbourne Park
Ladbroke Grove
Latimer Road
Shepherd's Bush
Bayswater
Notting Hill Gate
Holland Park
Queensway
Lancaster Gate
Marble Arch
Bond Street
Oxford Circus
Regent's Park
Warren Street
Goodge Street
Russell Square
Tottenham Court Road
Holborn
Chancery Lane
Covent Garden
Leicester Square
Piccadilly Circus
Green Park
Hyde Park Corner
Knightsbridge
High Street Kensington
Kensington (Olympia)
Shepherd's Bush Market
Goldhawk Road
Hammersmith
Barons Court
West Kensington
Earl's Court
Gloucester Road
South Kensington
Sloane Square
Victoria
St. James's Park
Westminster
Embankment
Charing Cross
Temple
Blackfriars
Mansion House
Cannon Street
St. Paul's
Bank
Monument
Tower Hill
Fenchurch Street
Tower Gateway
Waterloo
Southwark
Lambeth North
Borough
London Bridge
Bermondsey
Canada Water
Rotherhithe
Wapping
Shadwell
Limehouse
Westferry
Poplar
Blackwall
East India
West India Quay
Canary Wharf
Heron Quays
South Quay
Crossharbour
Mudchute
Island Gardens
Cutty Sark for Maritime Greenwich
Greenwich
Deptford Bridge
Elverson Road
Lewisham
Devons Road
Langdon Park
All Saints
Star Lane
Canning Town
Royal Victoria
Custom House for ExCeL
Prince Regent
Royal Albert
Beckton Park
Cyprus
Gallions Reach
Beckton
Emirates Royal Docks
West Silvertown
Pontoon Dock
London City Airport
King George V
Woolwich Arsenal
North Greenwich
Emirates Greenwich Peninsula
River Thames
Surrey Quays
Queens Road Peckham
Peckham Rye
New Cross Gate
New Cross
Brockley
Honor Oak Park
Forest Hill
Sydenham
Crystal Palace
Penge West
Anerley
Norwood Junction
West Croydon
Denmark Hill
West Brompton
Fulham Broadway
Parsons Green
Putney Bridge
East Putney
Southfields
Wimbledon Park
Wimbledon
Imperial Wharf
Clapham Junction
Wandsworth Road
Pimlico
Vauxhall
Elephant & Castle
Kennington
Oval
Stockwell
Brixton
Clapham High Street
Clapham North
Clapham Common
Clapham South
Balham
Tooting Bec
Tooting Broadway
Colliers Wood
South Wimbledon
Morden
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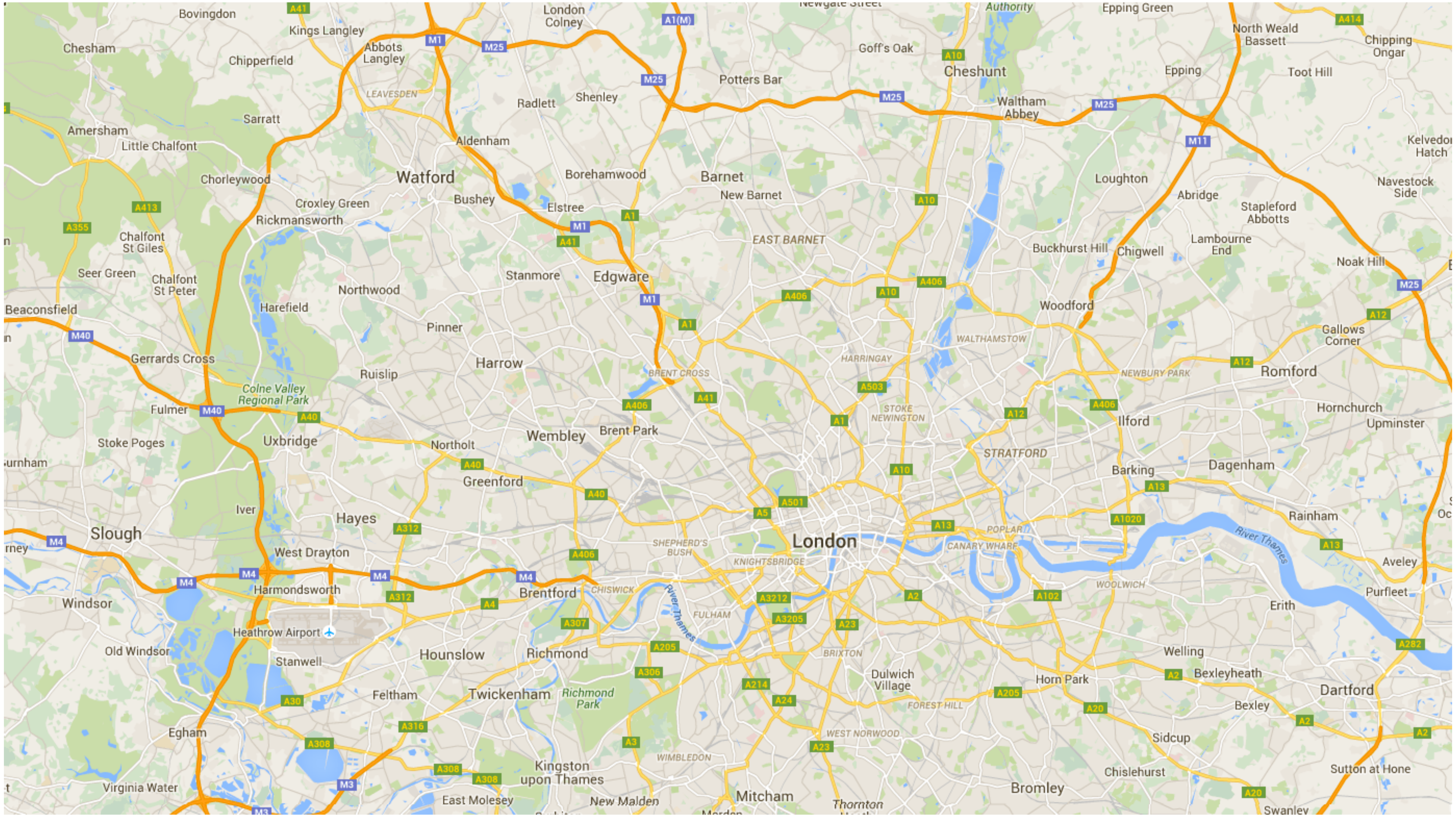
Key to symbols
Interchange stations
Step-free access from street to train
Step-free access from street to platform
National Rail
Riverboat services
Trams
Airport
Victoria Coach Station
Emirates Air Line
Explanation of zones
Station in Zone 9
Station in Zone 8
Station in Zone 7
Station in both zones
Station 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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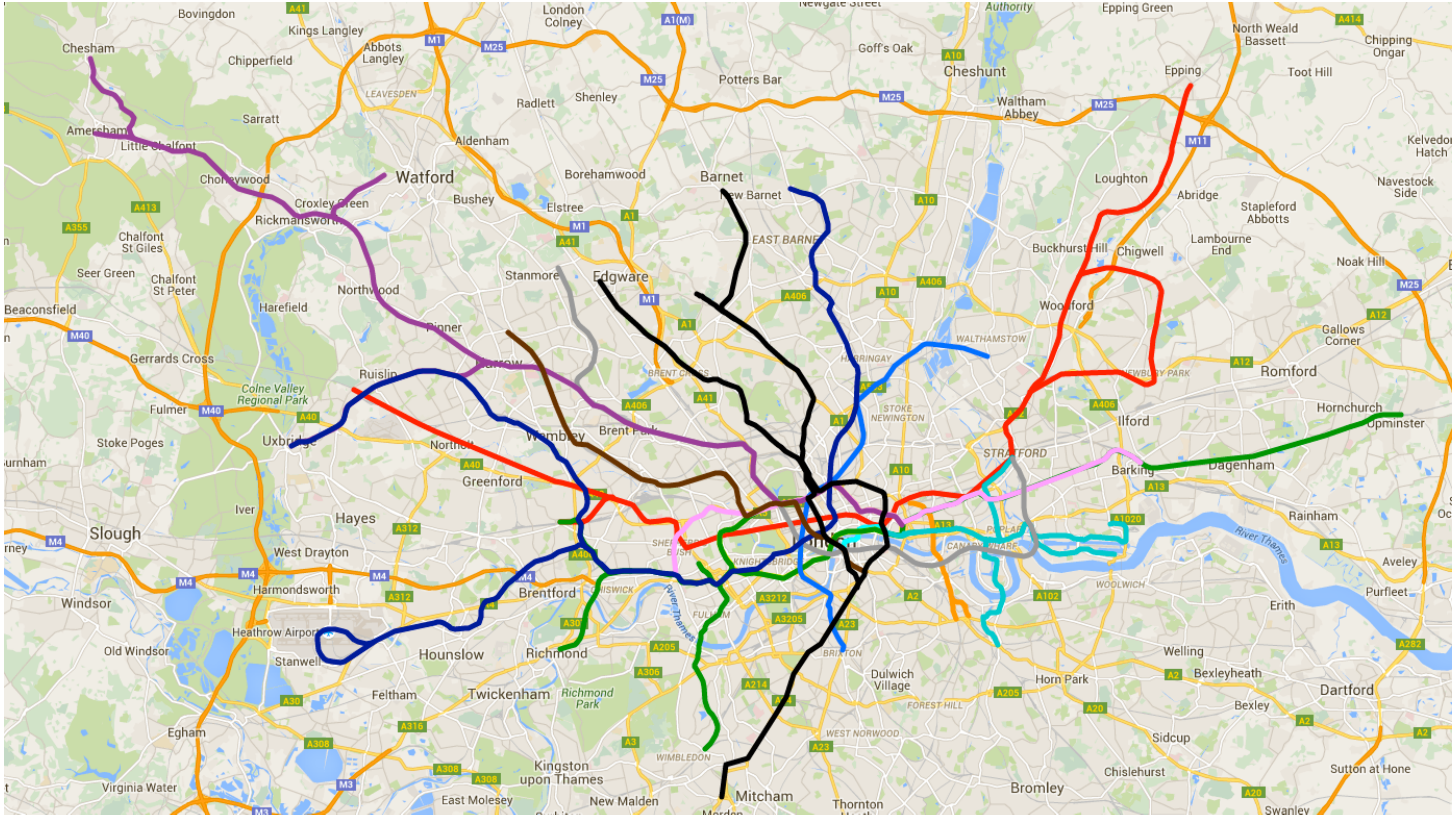
Kings Langley
London Colney
Chesham
Chipperfield
Abbots Langley
Radlett
Shenley
Potters Bar
Goff's Oak
Cheshunt
Epping Green
Epping
North Weald Bassett
Chipping Ongar
Toot Hill
Waltham Abbey
Amersham
Little Chalfont
Sarratt
Aldenham
Watford
Borehamwood
Barnet
New Barnet
Loughton
Abridge
Stapleford Abbotts
Kelvedon Hatch
Navestock Side
Chorleywood
Croxley Green
Bushey
Elstree
Rickmansworth
Chalfont St Giles
EAST BARNET
Buckhurst Hill
Chigwell
Lambourne End
Noak Hill
Seer Green
Chalfont St Peter
Stanmore
Edgware
Northwood
Harefield
Woodford
Beaconsfield
Pinner
WALTHAMSTOW
Gallows Corner
Gerrards Cross
Harrow
HARRINGAY
BRENT CROSS
NEWBURY PARK
Romford
Ruislip
Colne Valley Regional Park
Fulmer
STOKE NEWINGTON
Hornchurch
Upminster
Ilford
Uxbridge
Wembley
Brent Park
Stoke Poges
Northolt
STRATFORD
Barking
Dagenham
Greenford
Iver
Hayes
Rainham
Slough
London
SHEPHERD'S BUSH
POPLAR
CANARY WHARF
River Thames
West Drayton
KNIGHTSBRIDGE
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
Bromley
Swanley
M1
M25
M11
M40
M4
M3
A1(M)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STRATFORD
Barking
Dagenham
Greenford
Hayes
Iver
Slough
Rainham
West Drayton
Aveley
Windsor
Harmondsworth
Brentford
Purfleet
Erith
Heathrow Airport
Old Windsor
Stanwell
Hounslow
Richmond
WOOLWICH
Welling
Bexleyheath
Feltham
Twickenham
Richmond Park
Dulwich Village
Horn Park
Bexley
Dartford
Egham
FOREST HILL
WEST NORWOOD
Sidcup
Kingston upon Thames
WIMBLEDON
Chislehurst
Sutton at Hone
Virginia Water
East Molesey
New Malden
Mitcham
Thornton
Bromley
Swanley
River Thames

"There are rules!"

– The Big Lebowski

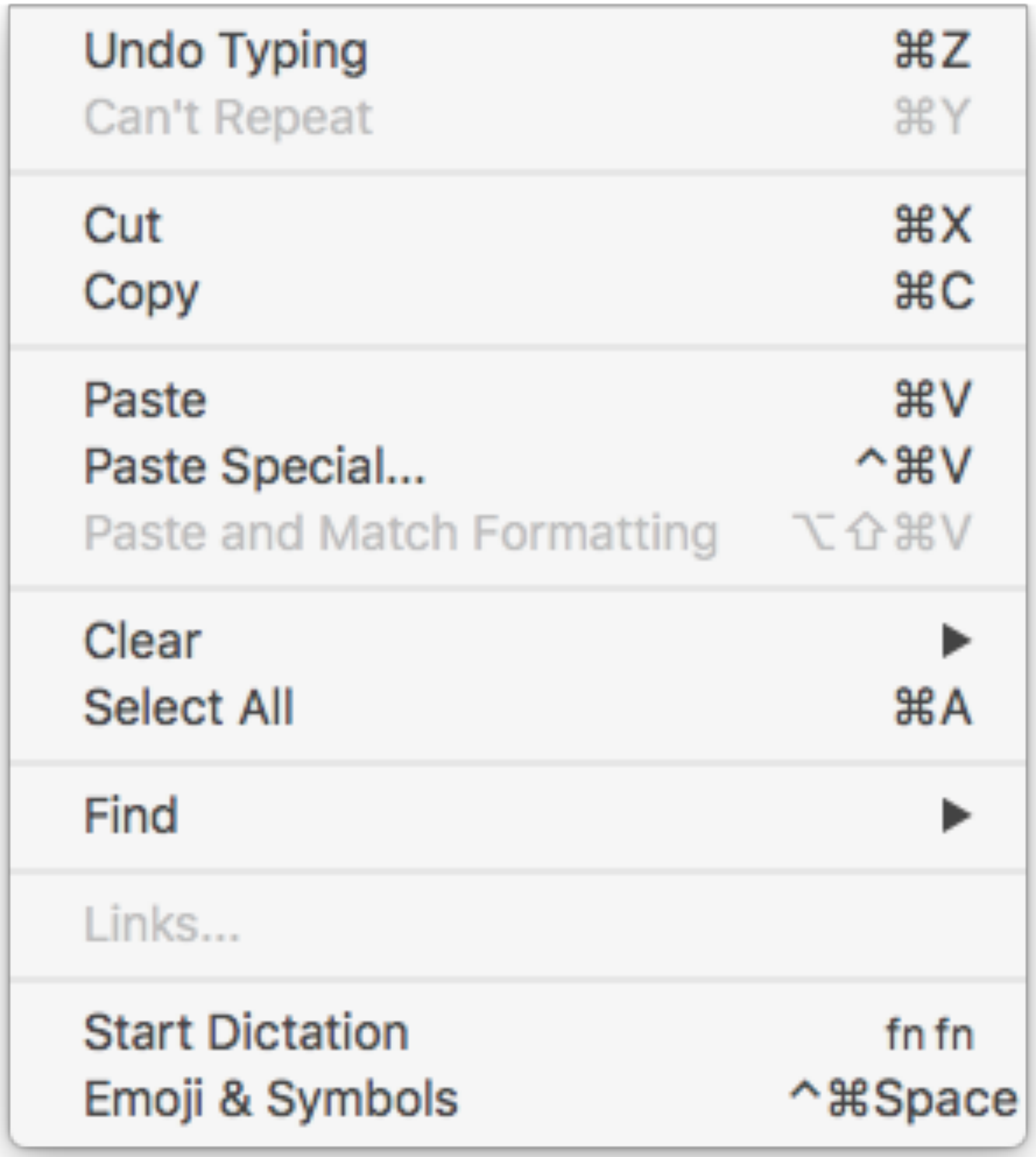
Lower Bound

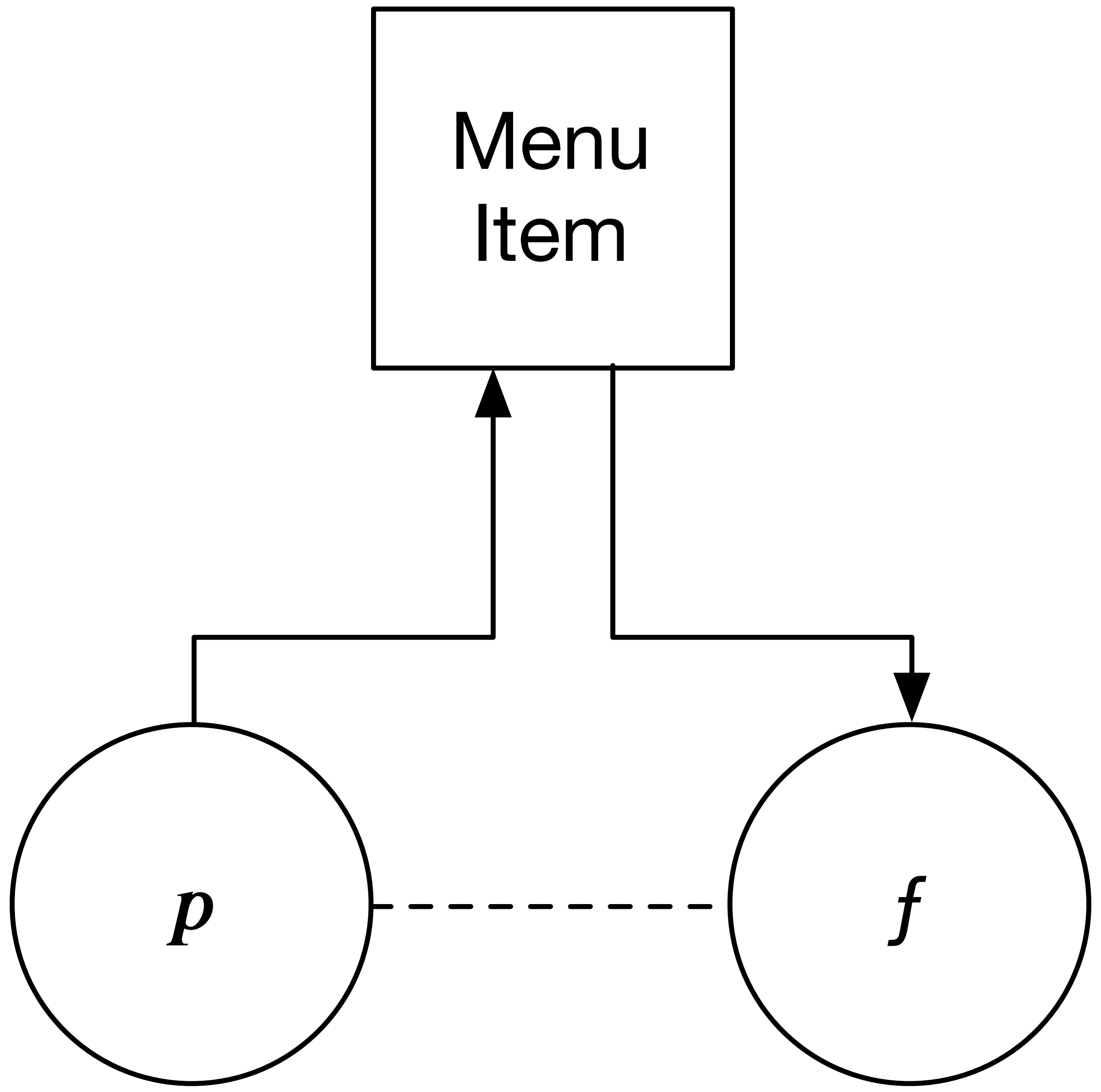
```
template <class ForwardIterator, class T, class Compare>
ForwardIterator lower_bound(ForwardIterator first, ForwardIterator last,
        const T& value, Compare comp)
{
    auto n = distance(first, last);

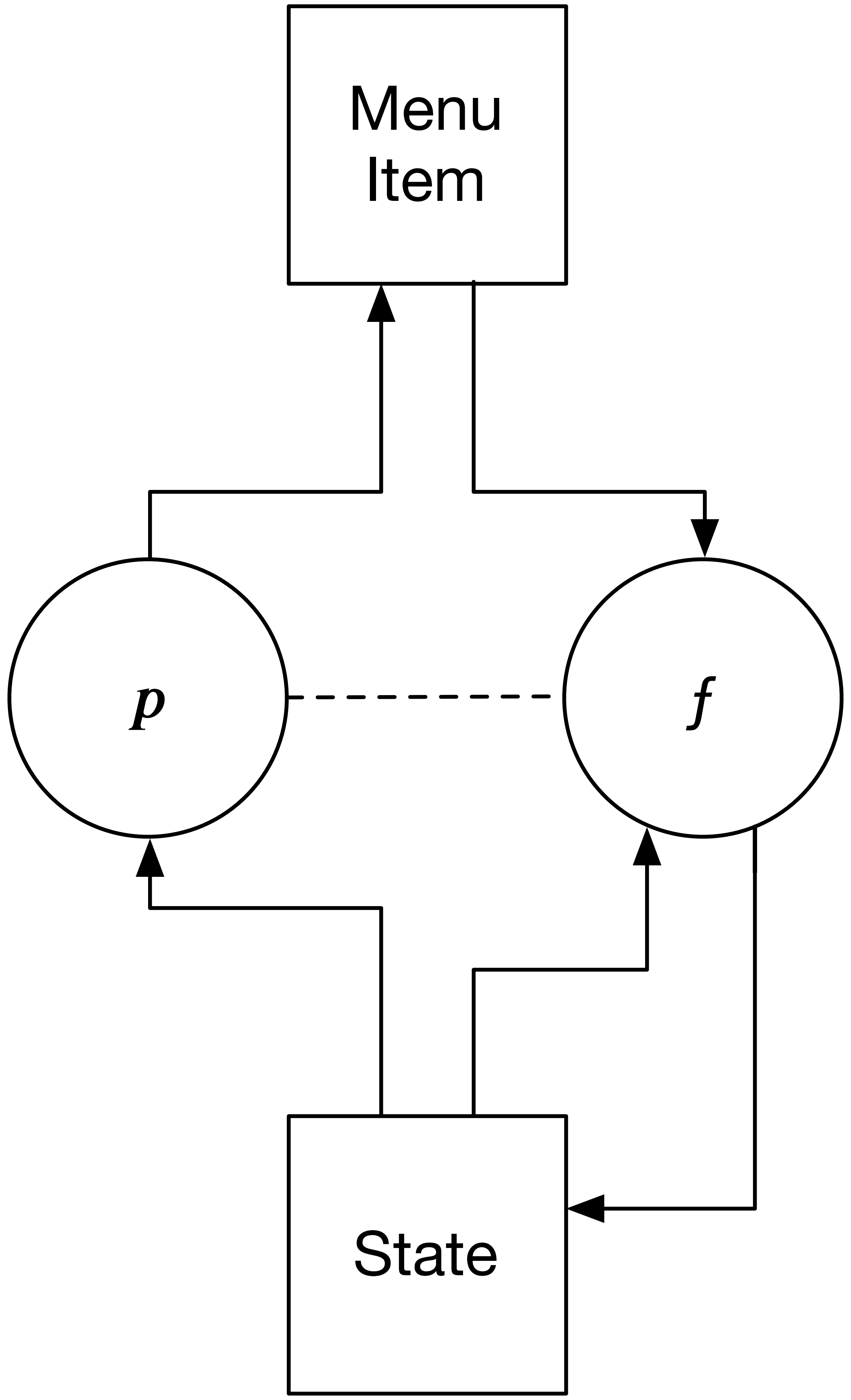
    while (n != 0)  {
        auto h = n / 2;
        auto m = next(first, h);

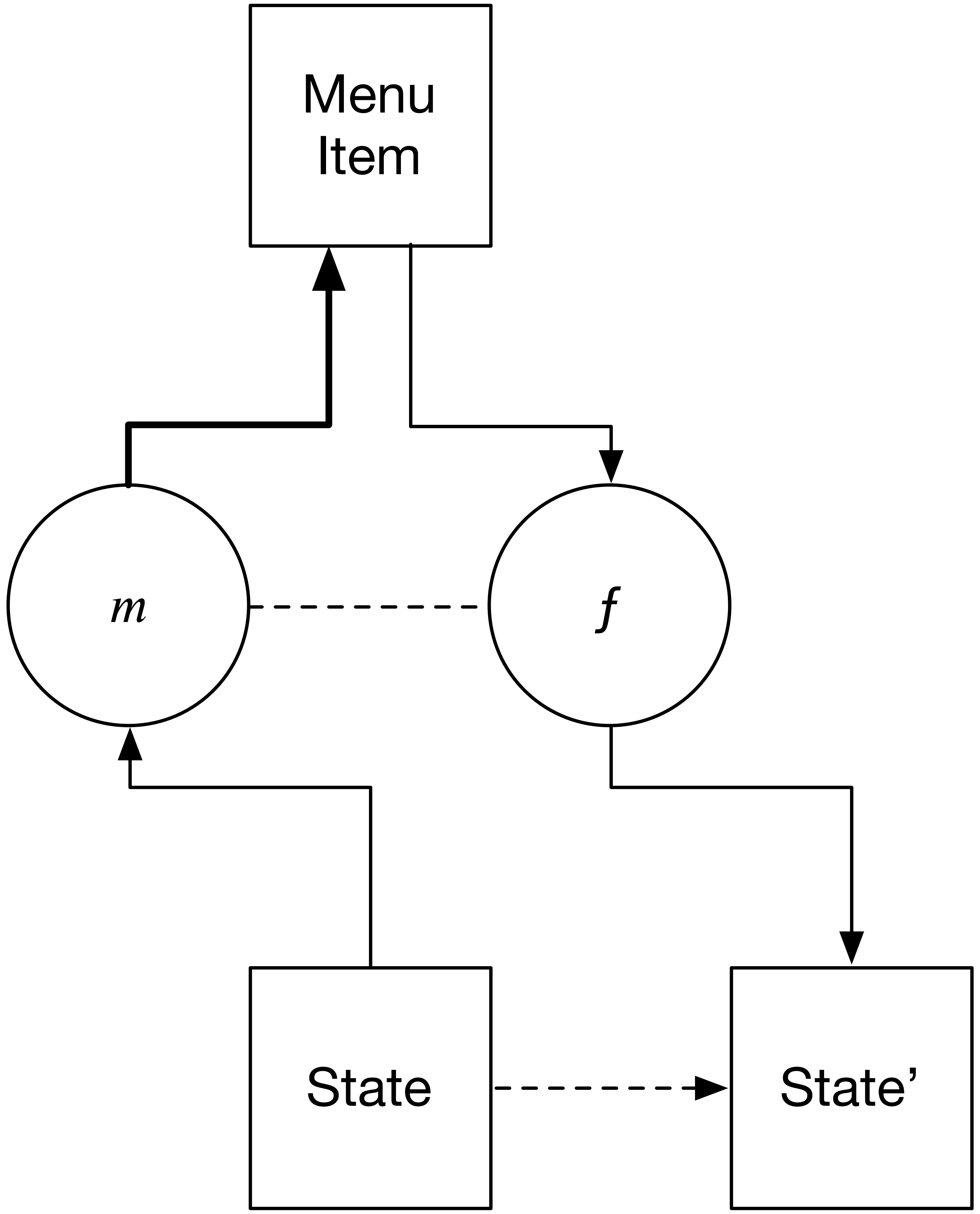
        if (comp(*m, value)) {
            first = next(m);
            n -= h + 1;
        } else { n = h; }
    }

    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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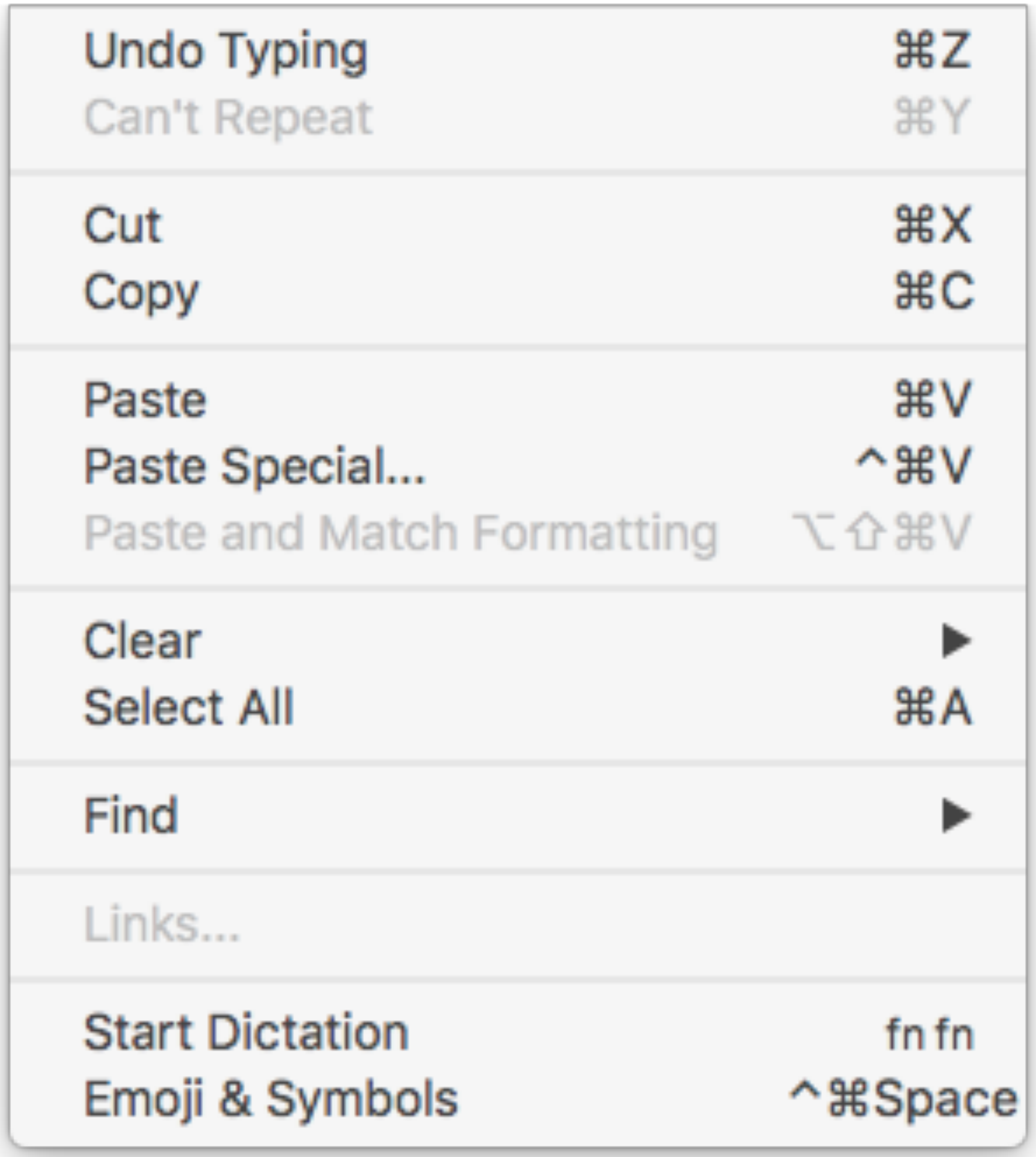
State'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Paste and Match Formatting ⌥⇧⌘V
Clear ▶
Select All ⌘A
Find ▶
Links...
Start Dictation fn fn
Emoji & Symbols ^⌘Space

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

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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') {
        cout << *s++;
    }
}

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

Subtle defects

Subtle defects

Consistency requires context

Subtle defects

Consistency requires context

```
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

Consistency requires context

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

Subtle defects

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

Subtle defects

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```
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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Returns: The larger value.

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

Subtle defects

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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
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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?

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

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
```

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 { };
```

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
```

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 // Error
 // but common extension
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 // Error
```

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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?

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std::vector<int> x = { 1, 2, 3 };
try {
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 // Basic Exception Guarantee:
 // Valid but unspecified
```

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 // Basic Exception Guarantee:
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std::vector<int> y = std::move(x);
```

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std::vector<int> x = { 1, 2, 3 };
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}
 // Basic Exception Guarantee:
 // Valid but unspecified

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

Good Code

Good Code

Good code is *correct*

- Consistent; without contradiction

Good Code

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- Consistent; without contradiction

Good code has *meaning*

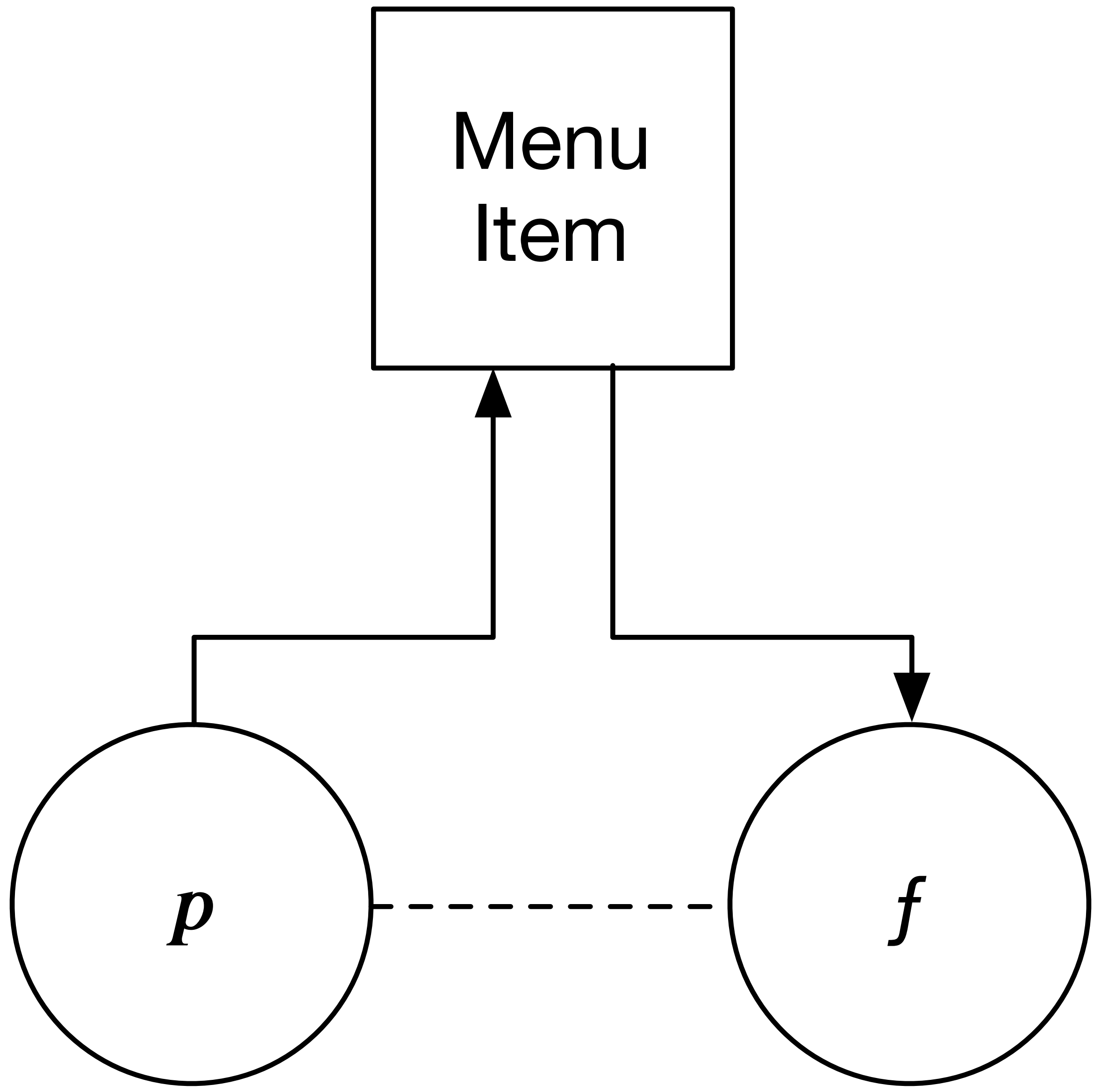
Good Code

Good code is *correct*

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, ∅, [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?

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

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

double x = 1.0 / 0.0;
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double x = 0.0 / 0.0;
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How can nothing be something?

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

double x = 1.0 / 0.0;
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double x = 0.0 / 0.0;
 // NaN; OK, though undefined behavior would also be
```

How can nothing be something?

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struct empty : void { };
```

How can nothing be something?

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

int x = 1 / 0;
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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

struct empty : void { };
 // sizeof(empty) == 0;
```

How can nothing be something?

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```
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?

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

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:
 // Partially formed object. Reading is undefined behavior
```

How can nothing be something?

```
std::vector<int> x = { 1, 2, 3 };
try {
    x.insert(x.begin(), 0);
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 // Basic Exception Guarantee:
 // Partially formed object. Reading is undefined behavior

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:
 // 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); }
```

Specification

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

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clone_ptr& operator=(const clone_ptr& x) { return *this = clone_ptr(x); }
```

- 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.

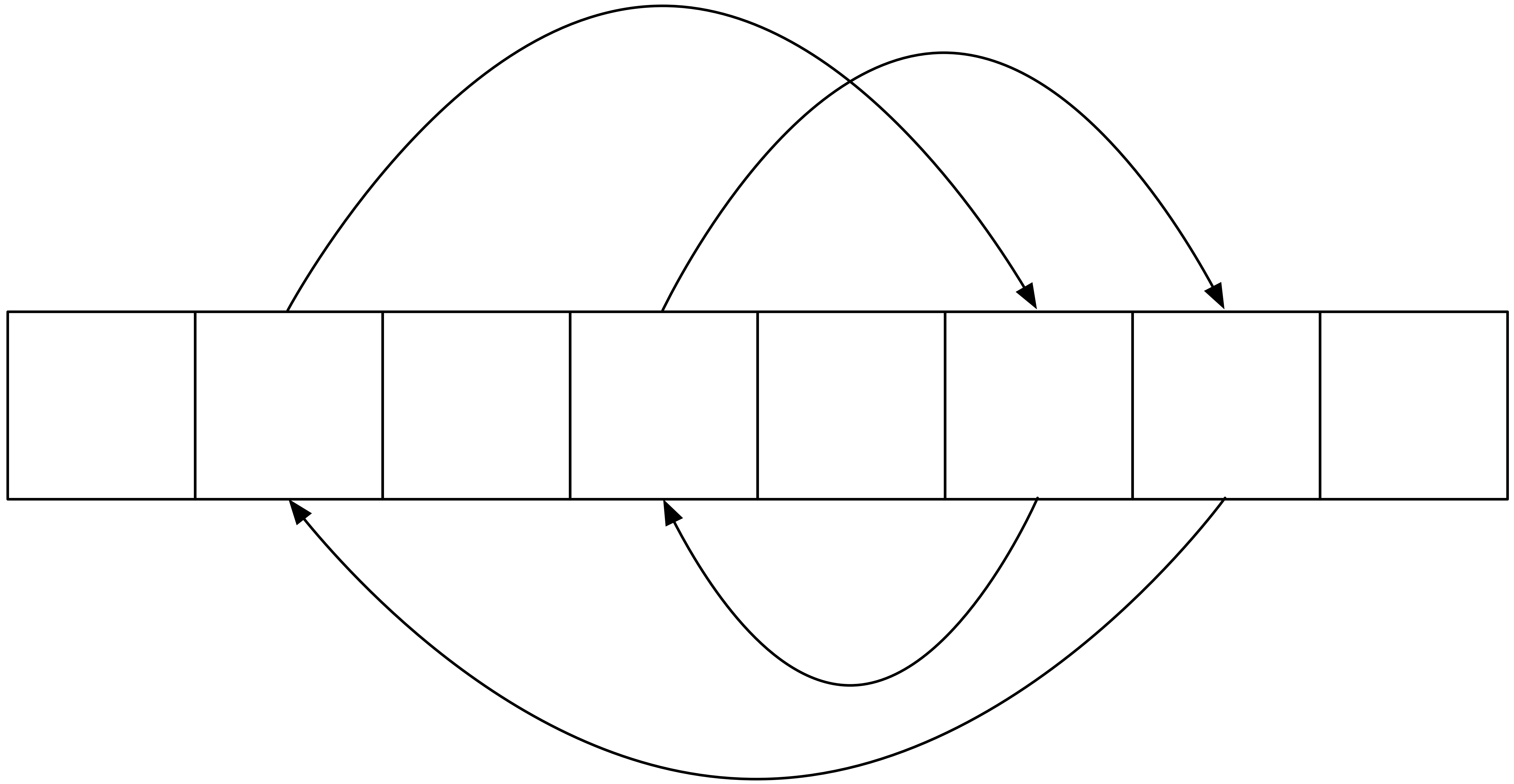
- Example implementation of clone operation:

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

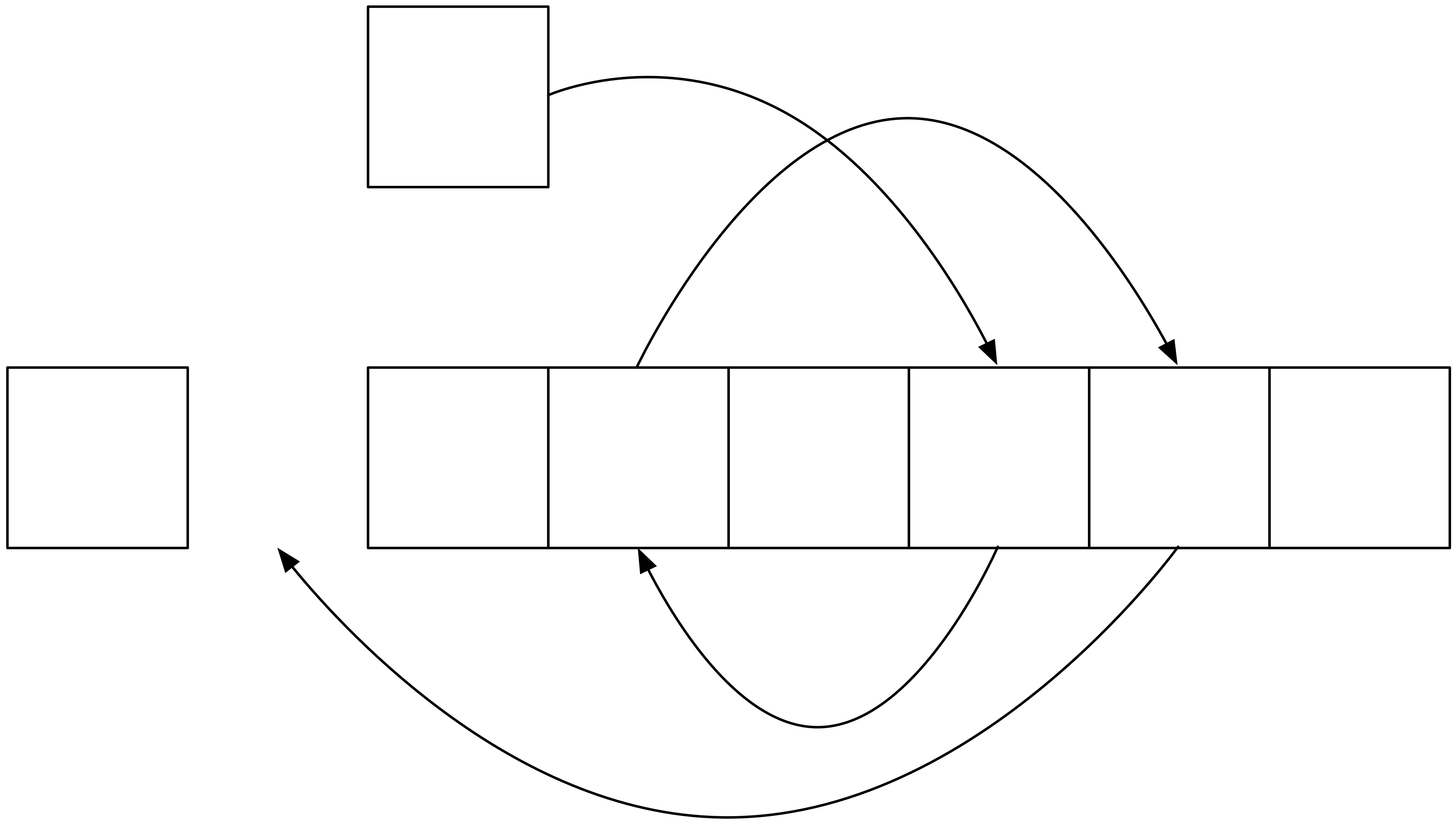
“What’s in the box?”

– Seven

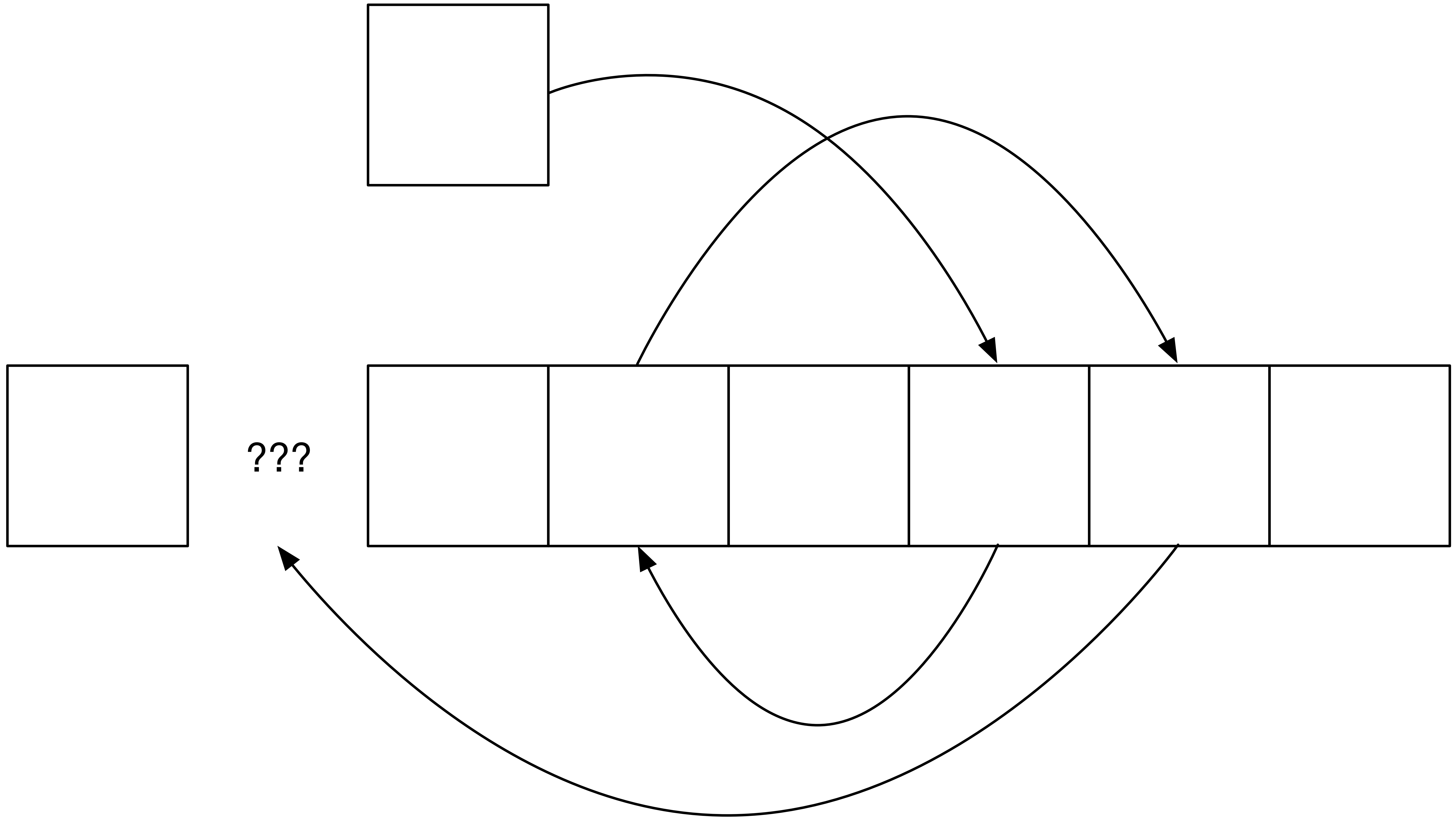
The Permutation Paradox



The Permutation Paradox

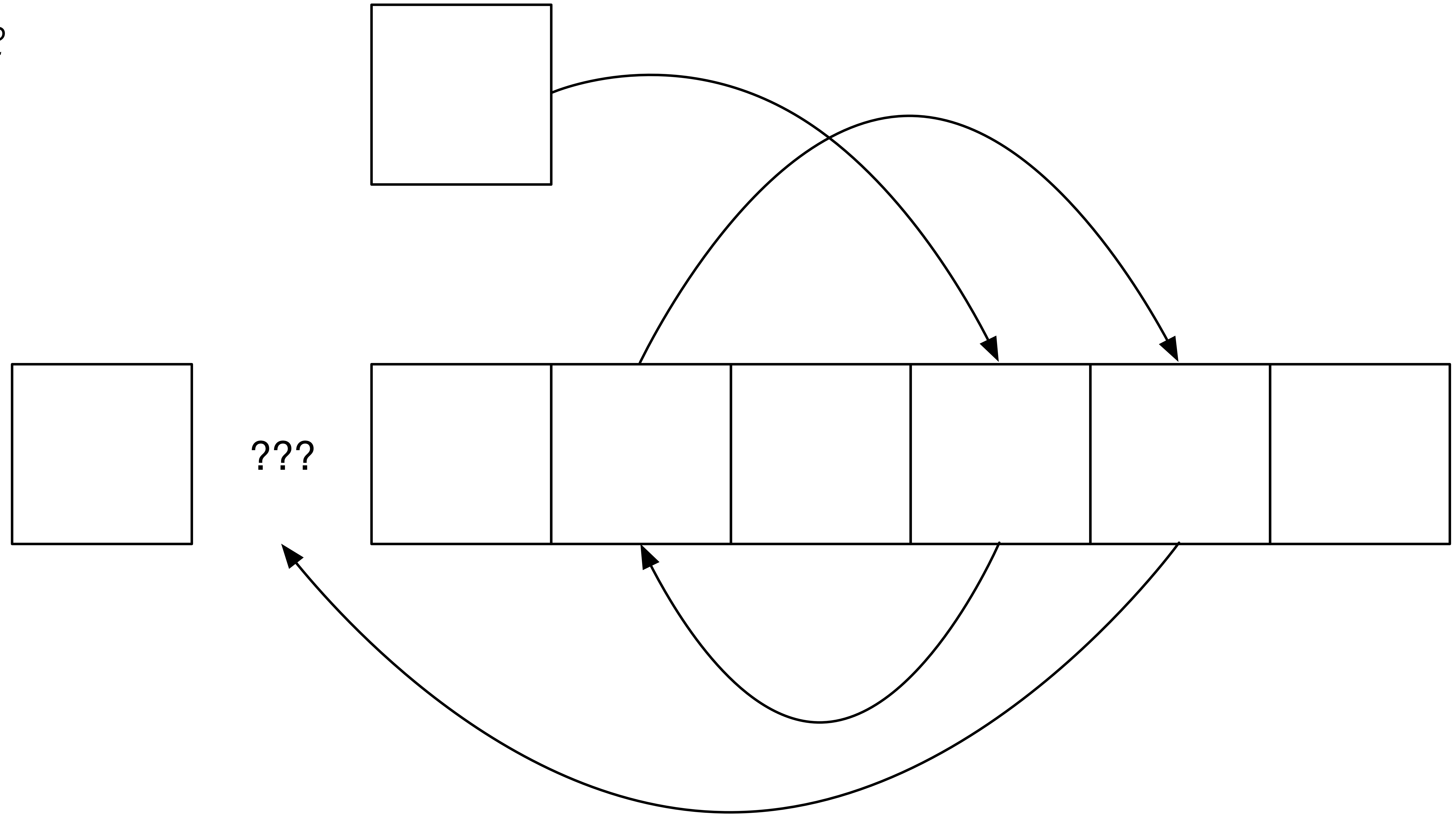


The Permutation Paradox



The Permutation Paradox

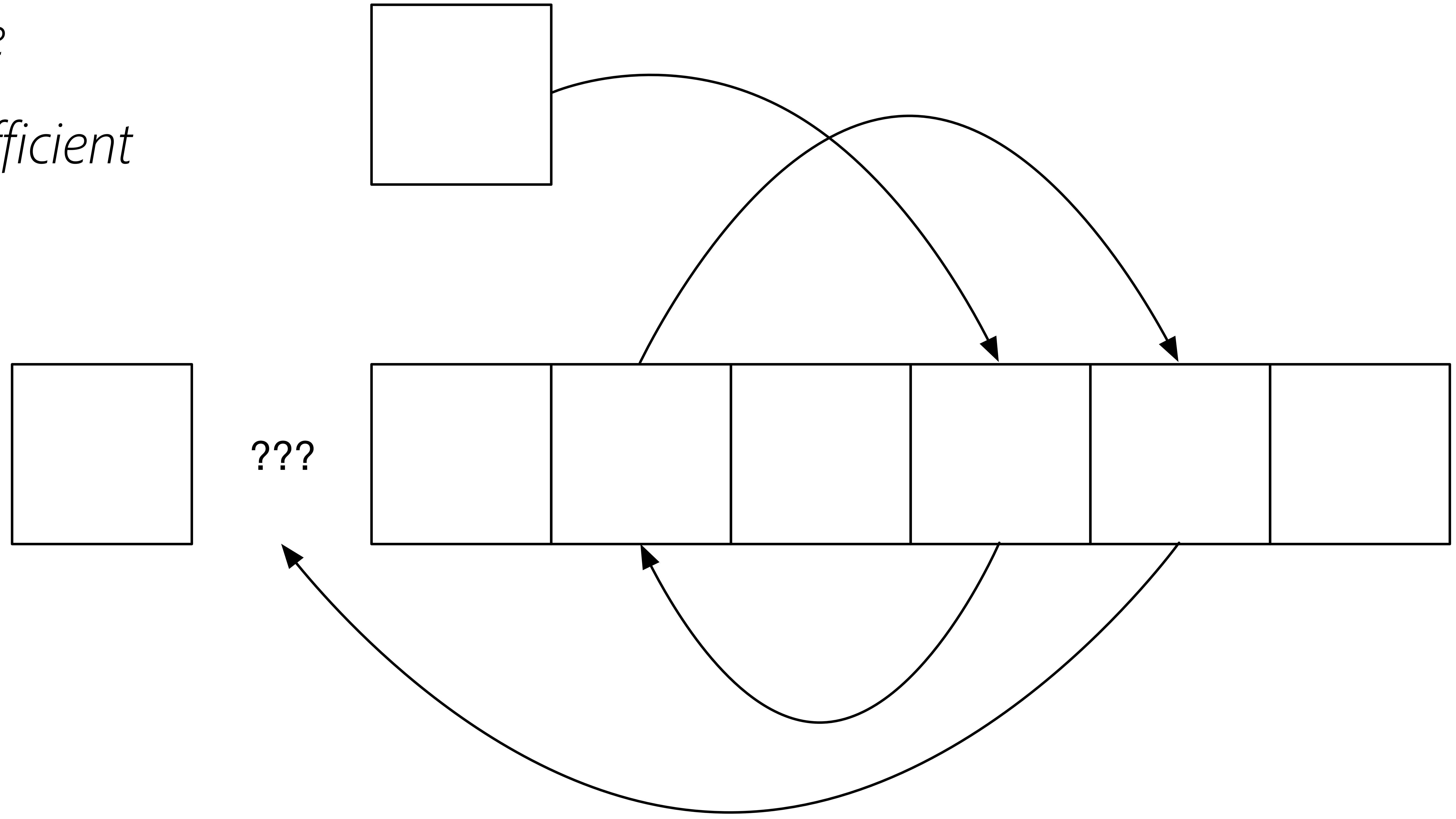
nothing ⇒ unsafe



The Permutation Paradox

nothing ⇒ *unsafe*

something ⇒ *inefficient*



The Permutation Paradox

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:

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)*

“It’s not that I’m lazy, it’s that I just don’t care.”

– Office Space

Good Code

Good code is *correct*

Consistent; without contradiction

Good code has *meaning*

Correspondence to an entity; specified, defined

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Good code is *efficient*

Maximum effect with minimum resources

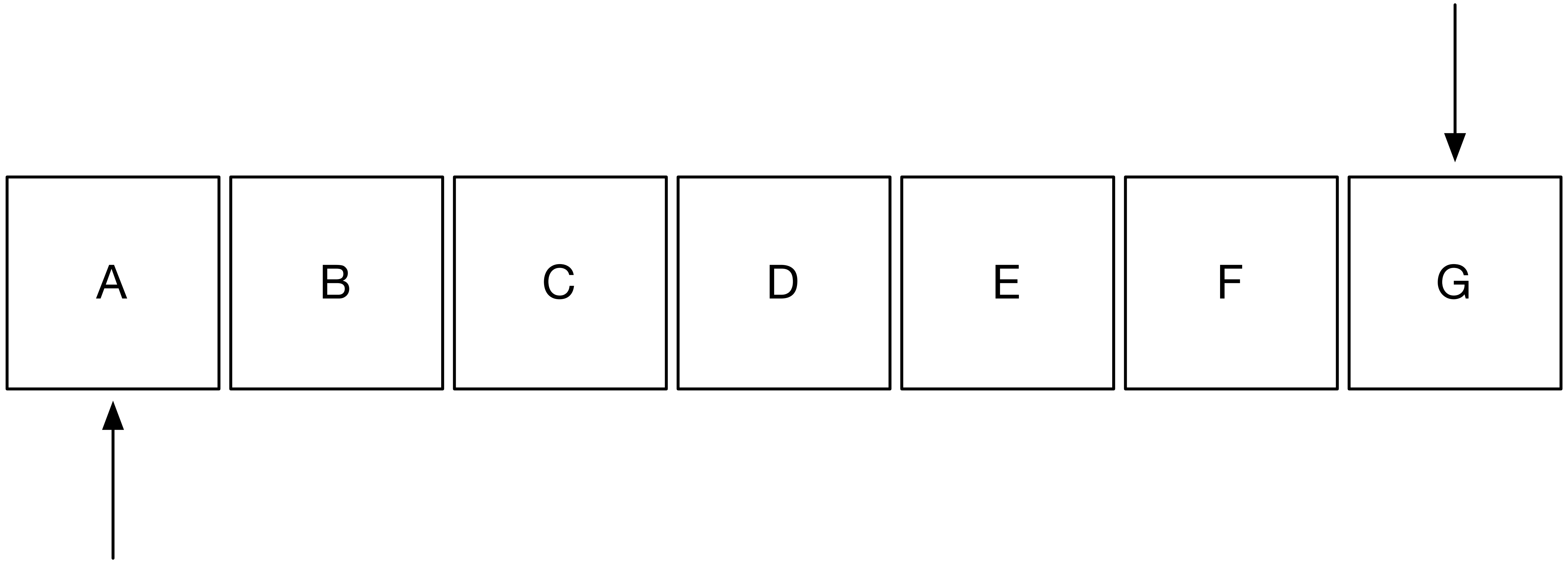
Efficiency

Efficiency

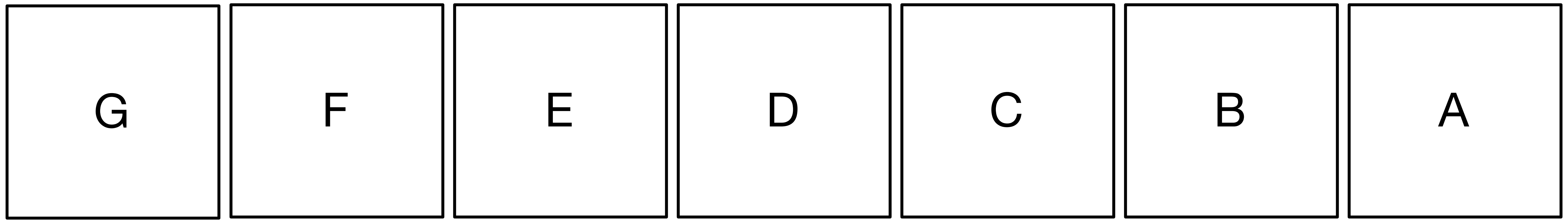
Choice of data structures and algorithms

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);

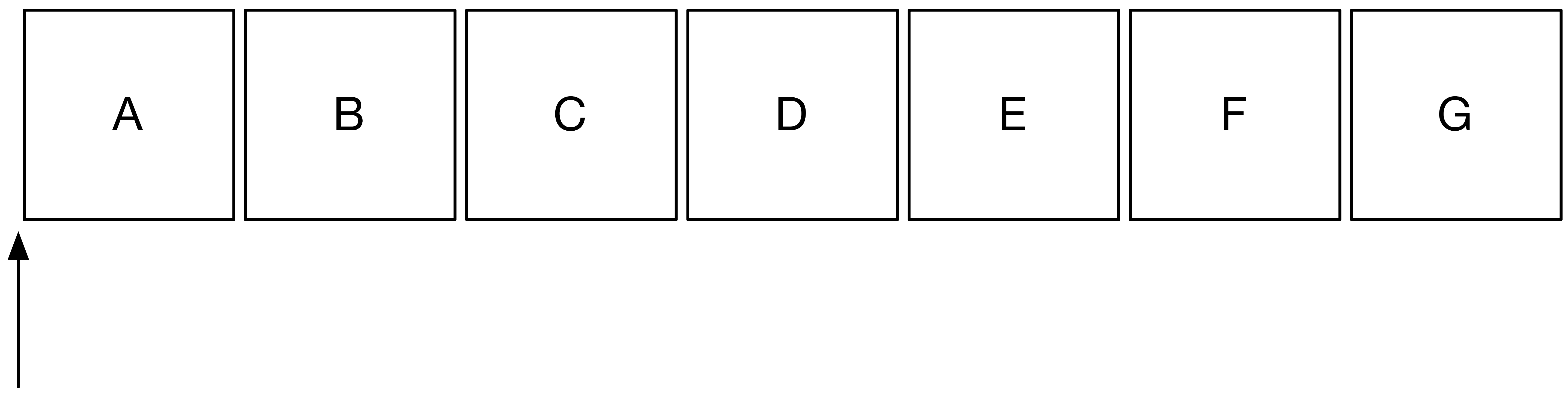
    auto h = n / 2;
    auto m1 = reverse_n(f, h);
    auto m2 = next(m1, n % 2);
    auto l = reverse_n(m2, h);
    swap_ranges(f, m1, m2);
    return l;
}

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

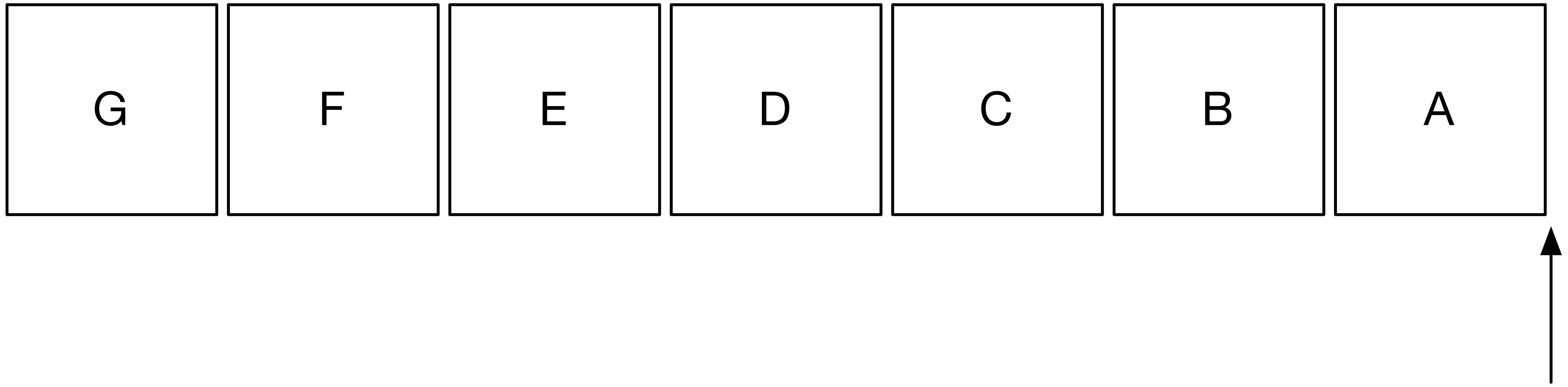
O(n log n)

Elements of Programming, 10.3

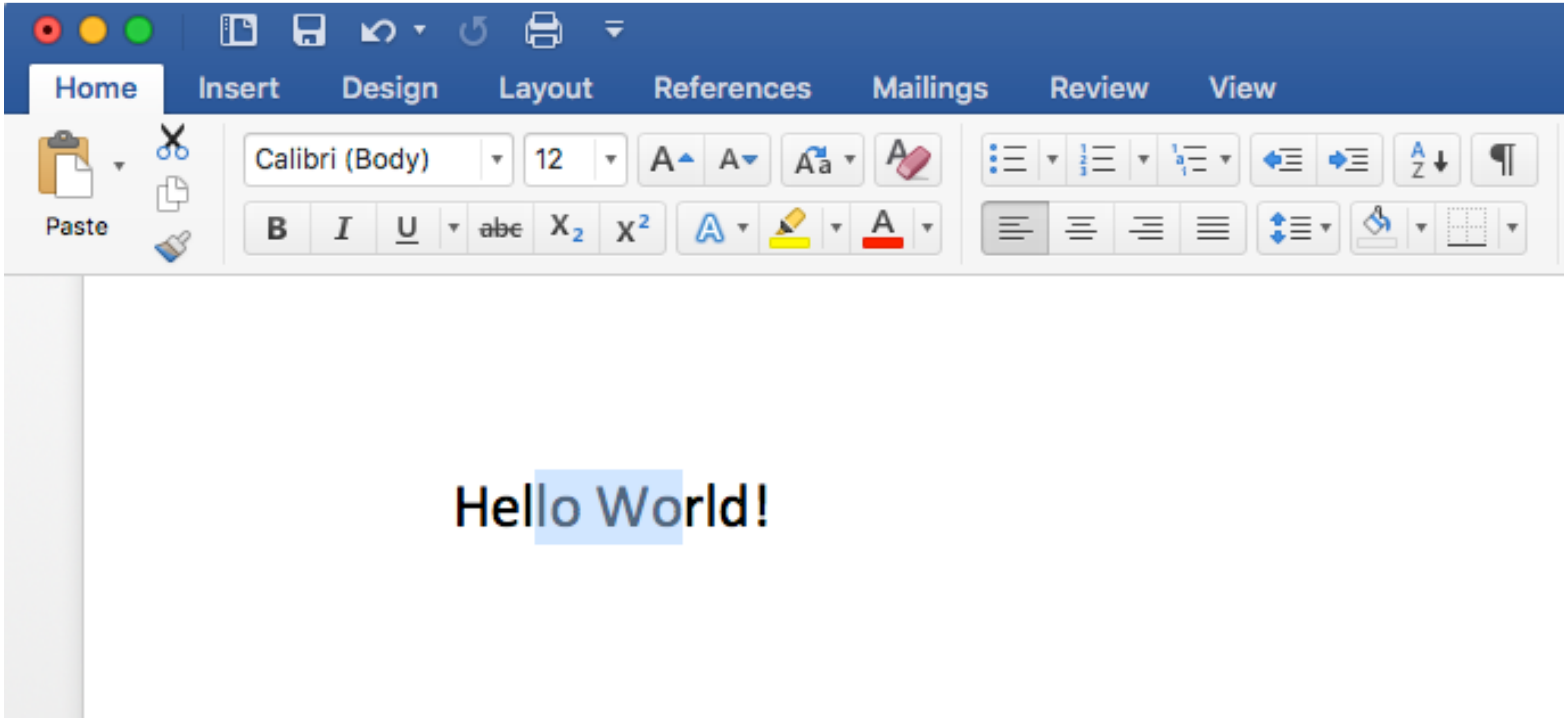
Efficiency



Efficiency

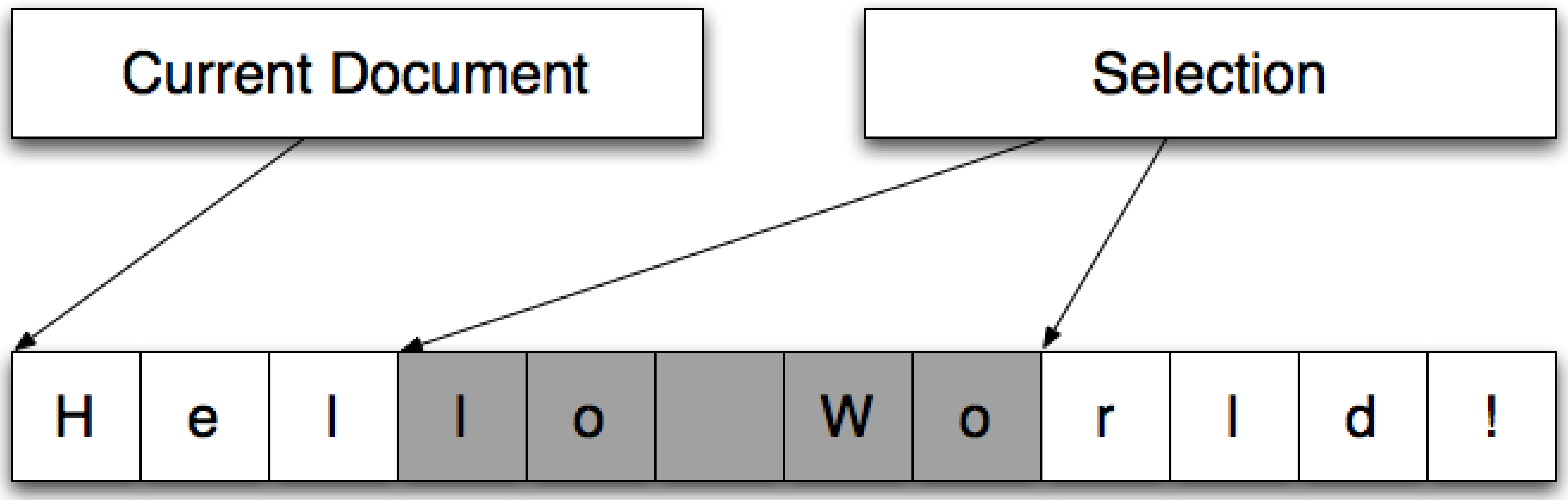


Simple Word Model



Simple Word Model

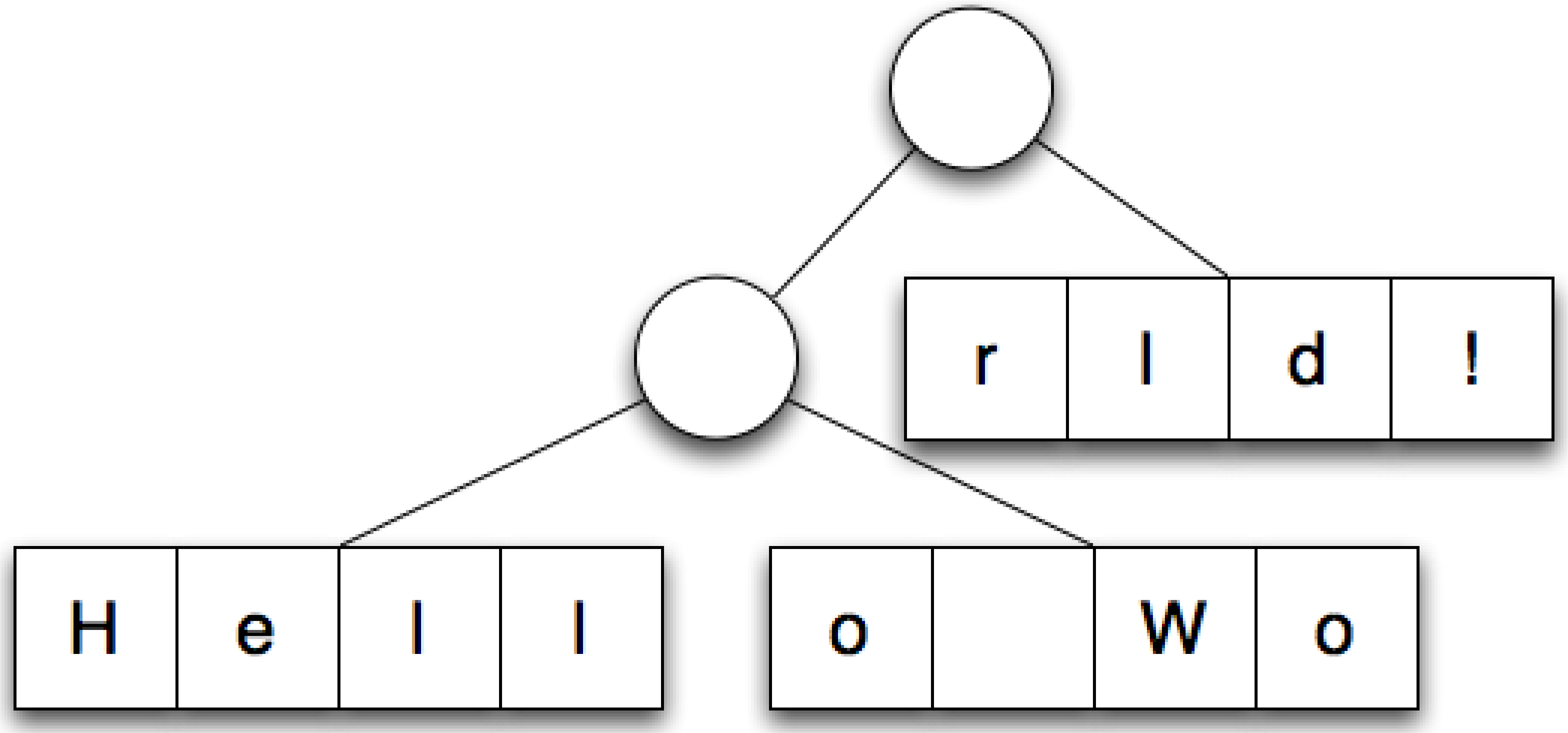
- Current Document
- Selection
  - Provides a range; an empty range denotes a location



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?

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

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
GMUNK

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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

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