ALOGRITHMS
SORTING & SEARCHING

ROWAN MEREWOOD

LET'S START WITH THE BIG PHILOSOPHICAL QUESTIONS

WHO AM I?

Software Engineer and Technical Team Lead

```
$inviqaGroup = ['Inviqa', 'Sensio Labs UK', 'Session Digital'];
```

```
$social = [
    'blog'     => 'http://merewood.org',
    'facebook' => $this->graphSearch('people i am stalking'),
    'github'   => 'https://github.com/rowan-m',
    'google+'  => 'https://plus.google.com/111813845727005160164',
    'identica' => 'http://identi.ca/rowanm',
    'imdb'     => 'http://imdb.com/name/nm1412348',
    'twitter'  => 'https://twitter.com/rowan_m',
];
```

WHY AM I HERE?

1. Because straight-up, pure computer science is **AWESOME**.
2. `^E0F`

Also, understanding the lower level detail helps you make better use of the higher level abstractions.

WHY SORT?

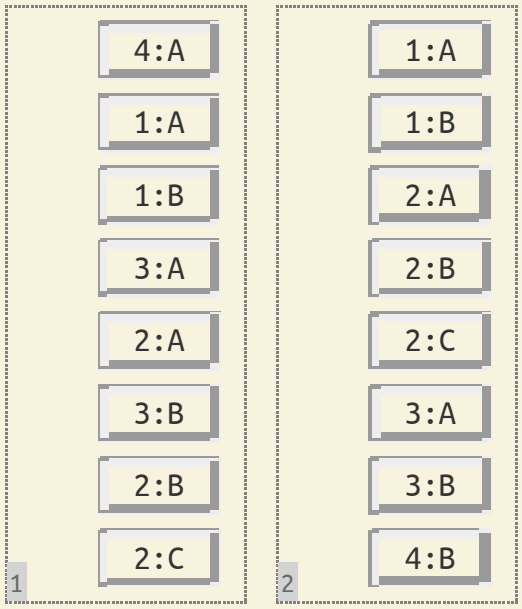
- Displaying lists to humans
- Categorising data
- Preparing data for merging
- Preparing data for searching

In general: to display or to prepare for another operation.

COMPARING ALGORITHMS

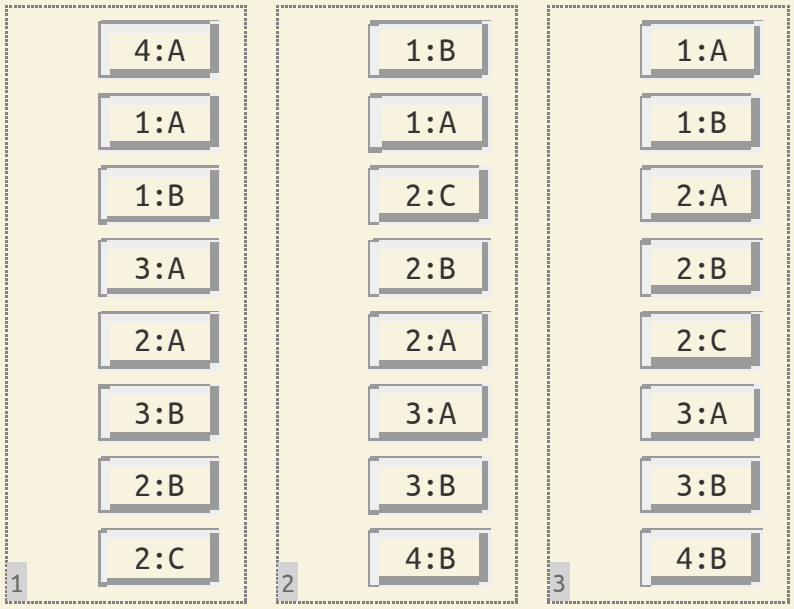
STABILITY

STABLE



Order of unsorted portion maintained

UNSTABLE



Order of unsorted portion may change

BIG O NOTATION

Rate of growth for resource usage based on the size of its input.

- Resource usage: *CPU cycles / time, memory usage*
- Size of input: *number of elements*

BIG O NOTATION *(CONT.)*

- $O(1)$: *Constant*
- $O(n)$: *Linear growth*
- $O(n \log n)$: *Logarithmic growth*
- $O(n^2)$: *Quadratic growth*

ADAPTABILITY

An adaptive algorithm has better performance when the list is already partially sorted

SORTING ALGORITHMS

INSERTION SORT

CODE

```
class InsertionSort {
    public function sort(array $elements) {
        $iterations = count($elements);
        for ($index = 1; $index < $iterations; $index++) {
            $elementToInsert = $elements[$index];
            $insertIndex = $index;

            while ($insertIndex > 0 && $elementToInsert < $elements[$insertIndex - 1]) {
                $elements[$insertIndex] = $elements[$insertIndex - 1];
                $elements[$insertIndex - 1] = $elementToInsert;
                $insertIndex--;
            }
        }
        return $elements;
    }
}
```

INSERTION SORT *(CONT.)*

CODE: ITERATE THROUGH THE LIST

```
public function sort(array $elements) {
    // At least one iteration per element
    $iterations = count($elements);

    for ($index = 1; $index < $iterations; $index++) {
        // If no other variable operations happen here:
        // algorithm is O(n)
    }
}
```

INSERTION SORT *(CONT.)*

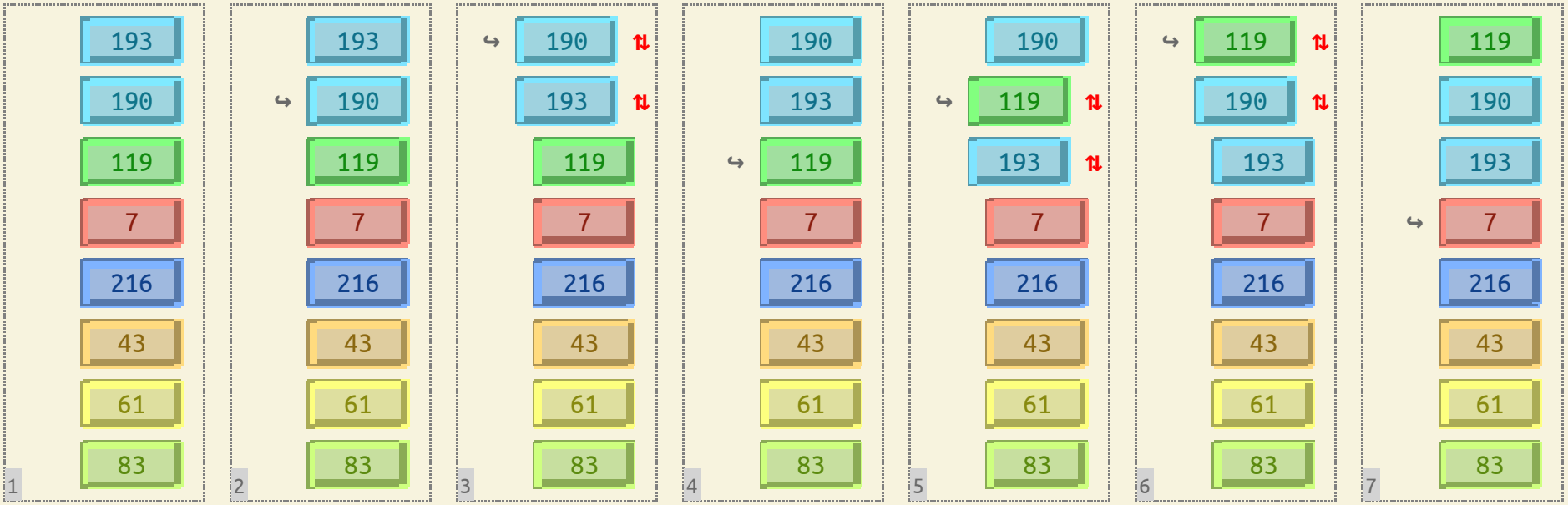
CODE: COMPARE ELEMENTS

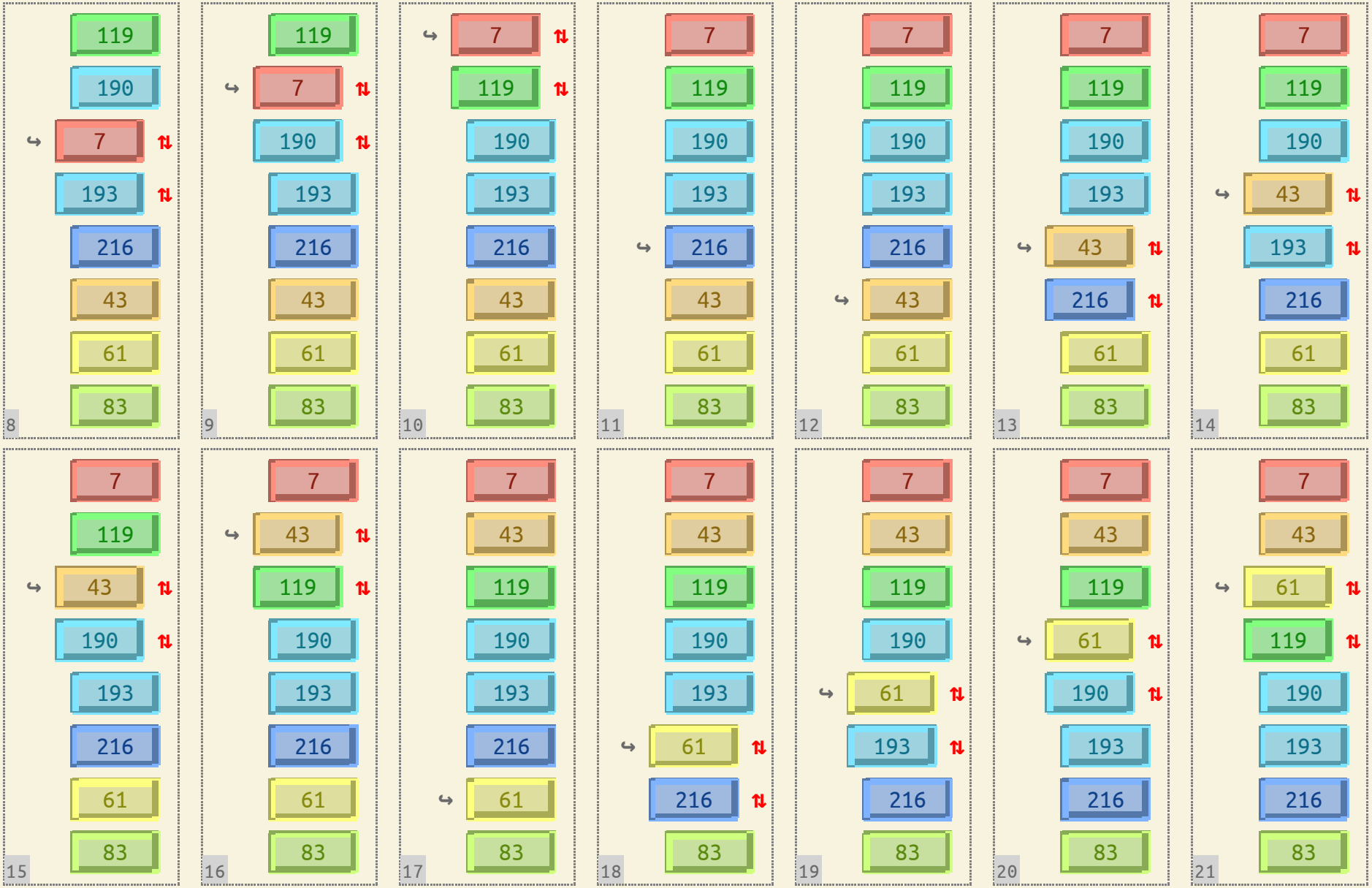
```
for ($index = 1; $index < $iterations; $index++) {
    // "Pick up" the current element and its position
    $elementToInsert = $elements[$index];
    $insertIndex = $index;

    // Iterate back through the elements
    // until the correct position it reached
    while ($insertIndex > 0 && $elementToInsert < $elements[$insertIndex - 1]) {
        // Swap out of order elements
        $elements[$insertIndex] = $elements[$insertIndex - 1];
        $elements[$insertIndex - 1] = $elementToInsert;
        $insertIndex--;
    }
}
```

If the list is in order, the `while` loop is not entered.

INSERTION SORT *(CONT.)*

ITERATIONS

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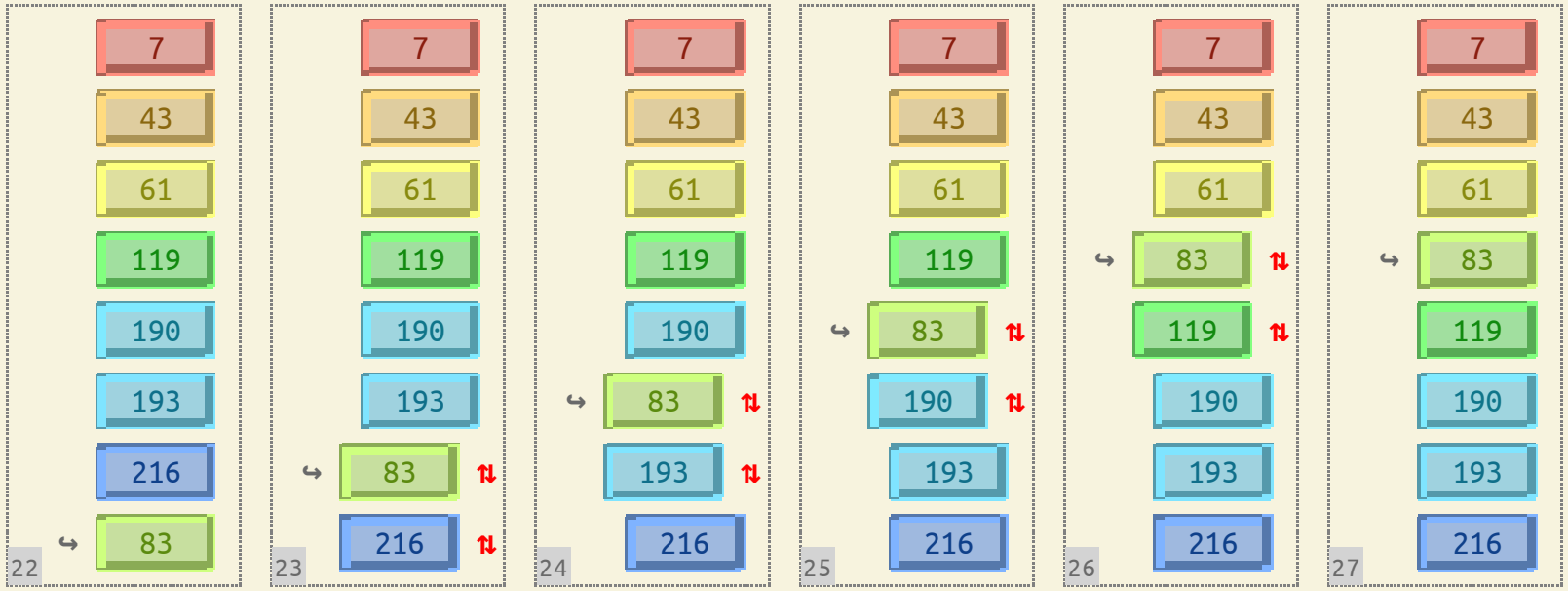
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Sorted!

INSERTION SORT *(CONT.)*

SUMMARY

- Best case: $O(n)$
- Average / worst case: $O(n^2)$
- Memory usage: $O(n)$
- Adaptive, stable, in place, and on line(n)

BUBBLE SORT

CODE

```
class BubbleSort {
    public function sort(array $elements) {
        for ($index = count($elements); $index > 0; $index--) {
            $swapped = false;
            for ($swapIndex = 0; $swapIndex < $index - 1; $swapIndex++) {
                if ($elements[$swapIndex] > $elements[$swapIndex + 1]) {
                    $tmp = $elements[$swapIndex];
                    $elements[$swapIndex] = $elements[$swapIndex + 1];
                    $elements[$swapIndex + 1] = $tmp;
                    $swapped = true;
                }
            }
            if (!$swapped) { return $elements; }
        }
    }
}
```

BUBBLE SORT *(CONT.)*

CODE: ITERATE THROUGH THE LIST

```
// Iterate through the elements
for ($index = count($elements); $index > 0; $index--) {
    $swapped = false;
    // Swap out of order elements
    // until there's nothing left to swap
    if (!$swapped) { return $elements; }
}
```

BUBBLE SORT *(CONT.)*

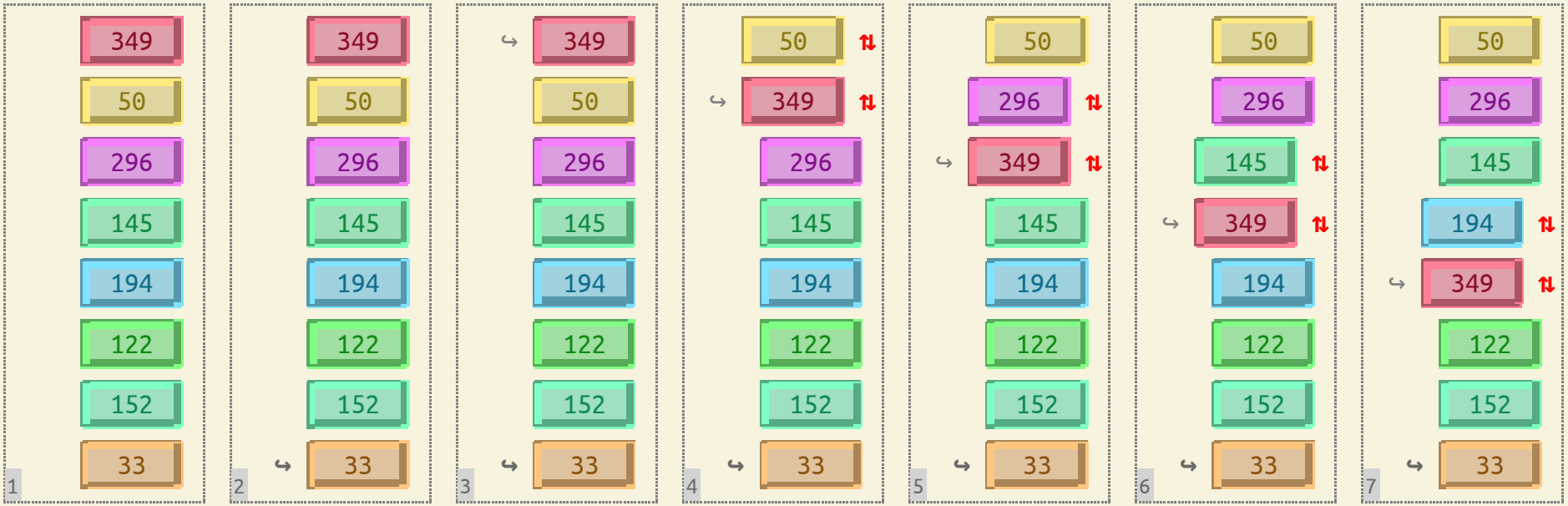
CODE

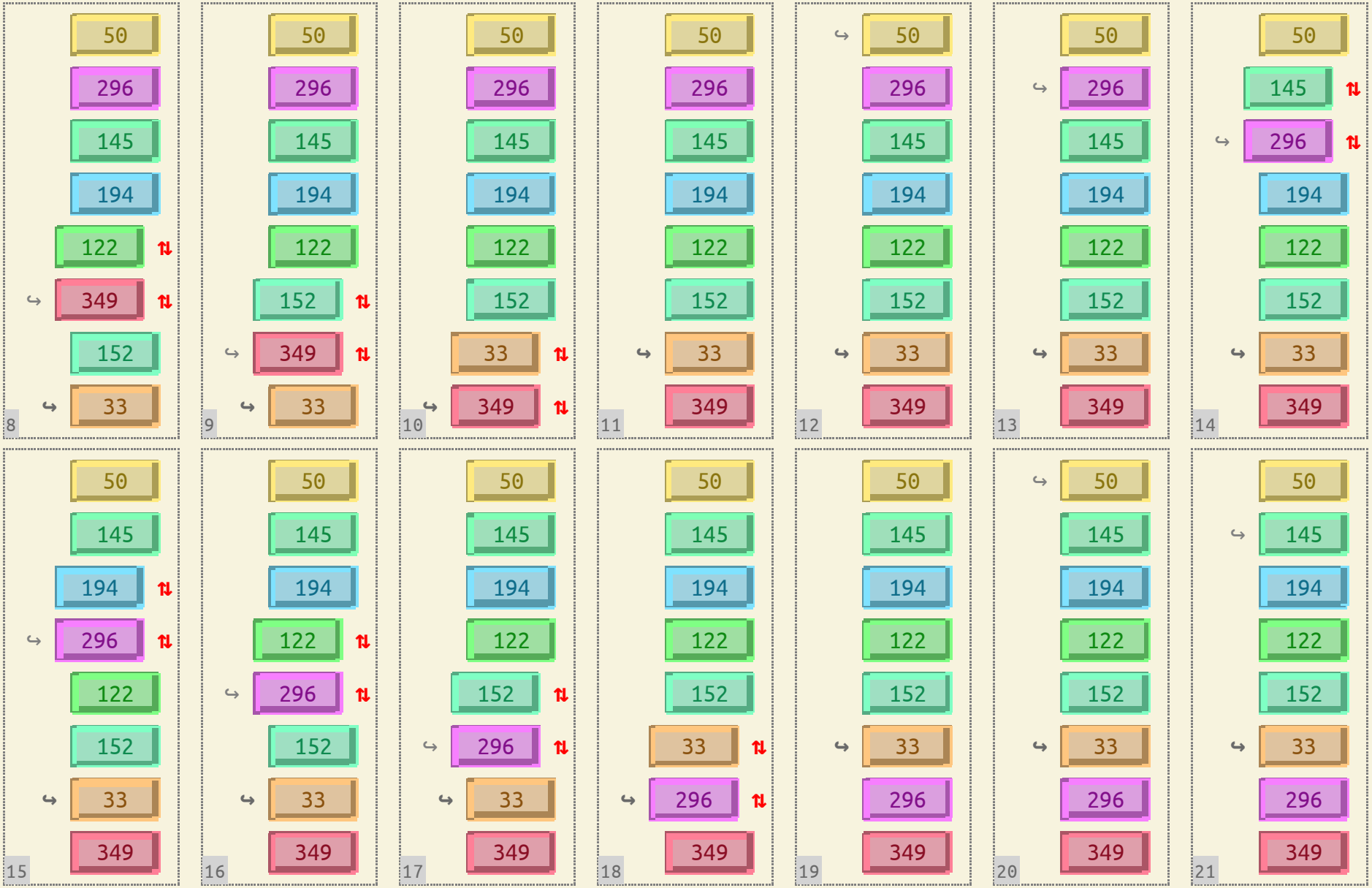
```
for ($index = count($elements); $index > 0; $index--) {
    $swapped = false;
    // Iterate through the unsorted portion of the list
    for ($swapIndex = 0; $swapIndex < $index - 1; $swapIndex++) {
        // Compare and swap elements
        if ($elements[$swapIndex] > $elements[$swapIndex + 1]) {
            $tmp = $elements[$swapIndex];
            $elements[$swapIndex] = $elements[$swapIndex + 1];
            $elements[$swapIndex + 1] = $tmp;
            $swapped = true;
        }
    }
    if (!$swapped) { return $elements; }
}
```

If the list is in order, then `$swapped` stays `false`.

BUBBLE SORT *(CONT.)*

ITERATIONS

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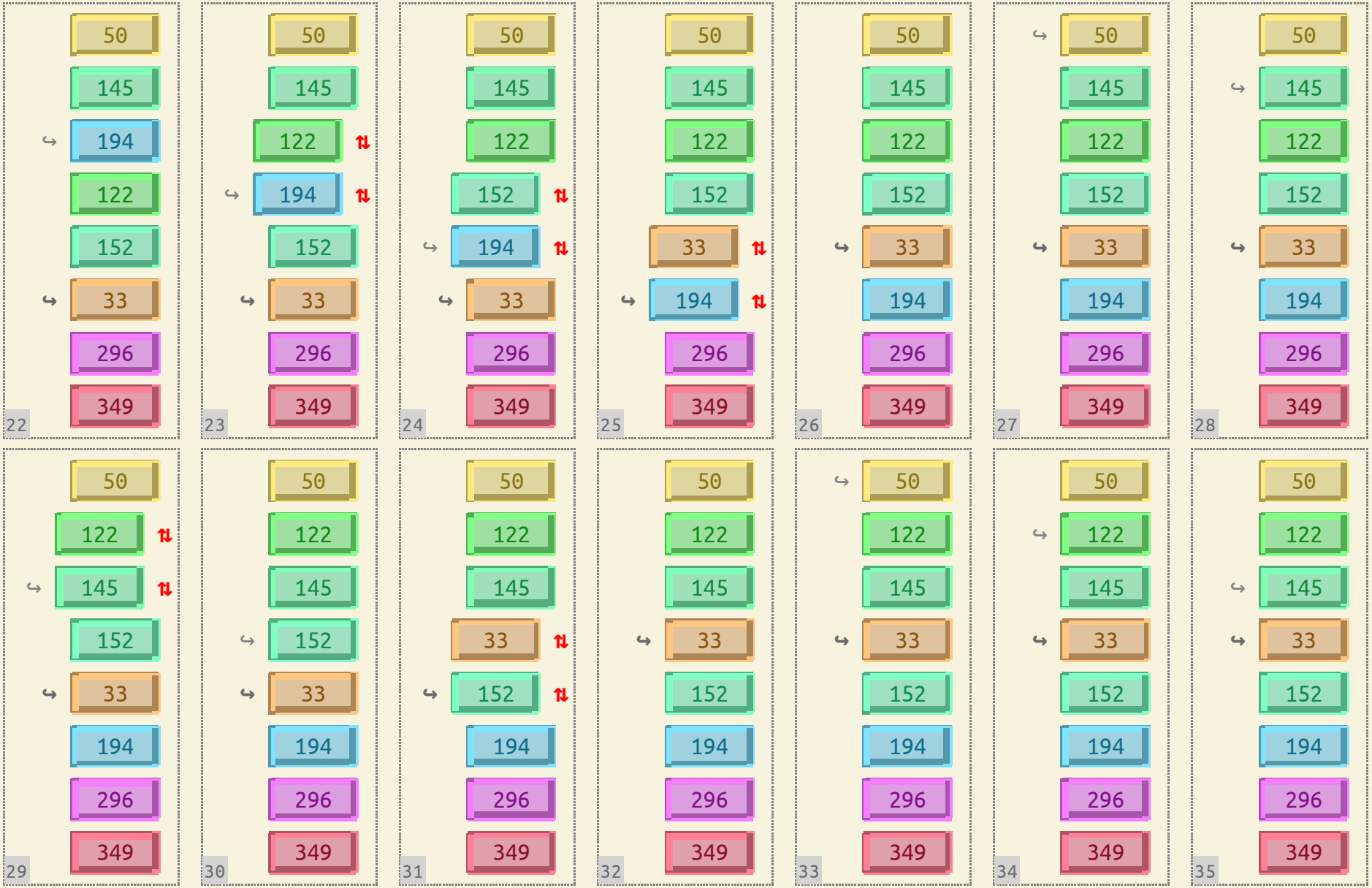
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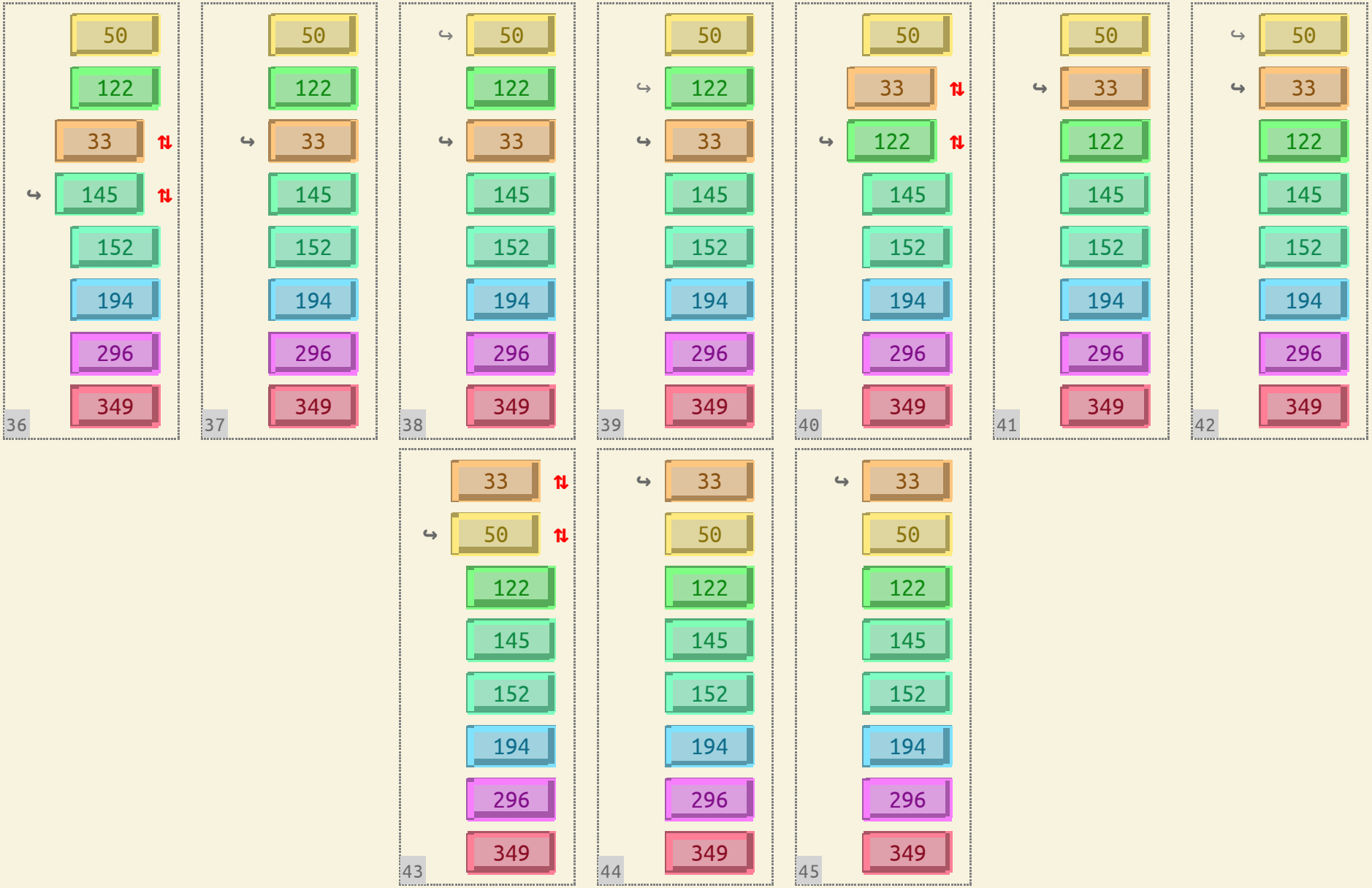


Sorted!

BUBBLE SORT *(CONT.)*

SUMMARY

- Best case: $O(n)$
- Average / worst case: $O(n^2)$
- Memory usage: $O(n)$

BUBBLE SORT *(CONT.)*

THE UGLY KNUTH

> *"The bubble sort seems to have nothing to recommend it, except a catchy name and the fact that it leads to some interesting theoretical problems"*

QUICK SORT

CODE

```
class QuickSort {
    public function sort(array $elements) {
        $this->doQuickSort($elements, 0, count($elements) - 1);
        return $elements;
    }

    function doQuickSort($elements, $leftIndex, $rightIndex) {
        // Divide the array in two, creating a “pivot” value
        // Move any value lower than the pivot to the left array
        // Move any value higher than the pivot to the right array
        // Recursively repeat the same operation on both arrays
    }
}
```

QUICK SORT *(CONT.)*

CODE: CREATE A PIVOT

```
function doQuickSort($elements, $leftIndex, $rightIndex) {
    // Divide the array in two, creating a “pivot” value
    $pivotIndex = ceil($leftIndex + (($rightIndex - $leftIndex) / 2));
    $pivotElement = $elements[$pivotIndex];
    $leftSwapIndex = $leftIndex;
    $rightSwapIndex = $rightIndex;
    while ($leftSwapIndex <= $rightSwapIndex) {
        // Move the left index until we find an out of order element
        // Move the right index until we find an out of order element
        // Swap them
    }
}
```

QUICK SORT *(CONT.)*

CODE: SWAP VALUES

```
while ($leftSwapIndex <= $rightSwapIndex) {
    // Move the left index until we find an out of order element
    while ($elements[$leftSwapIndex] < $pivotElement) { $leftSwapIndex++; }
    // Move the right index until we find an out of order element
    while ($elements[$rightSwapIndex] > $pivotElement) { $rightSwapIndex--; }
    // Swap them
    if ($leftSwapIndex <= $rightSwapIndex) {
        $tmp = $elements[$leftSwapIndex];
        $elements[$leftSwapIndex] = $elements[$rightSwapIndex];
        $elements[$rightSwapIndex] = $tmp;
        $leftSwapIndex++;
        $rightSwapIndex--;
    }
}
```

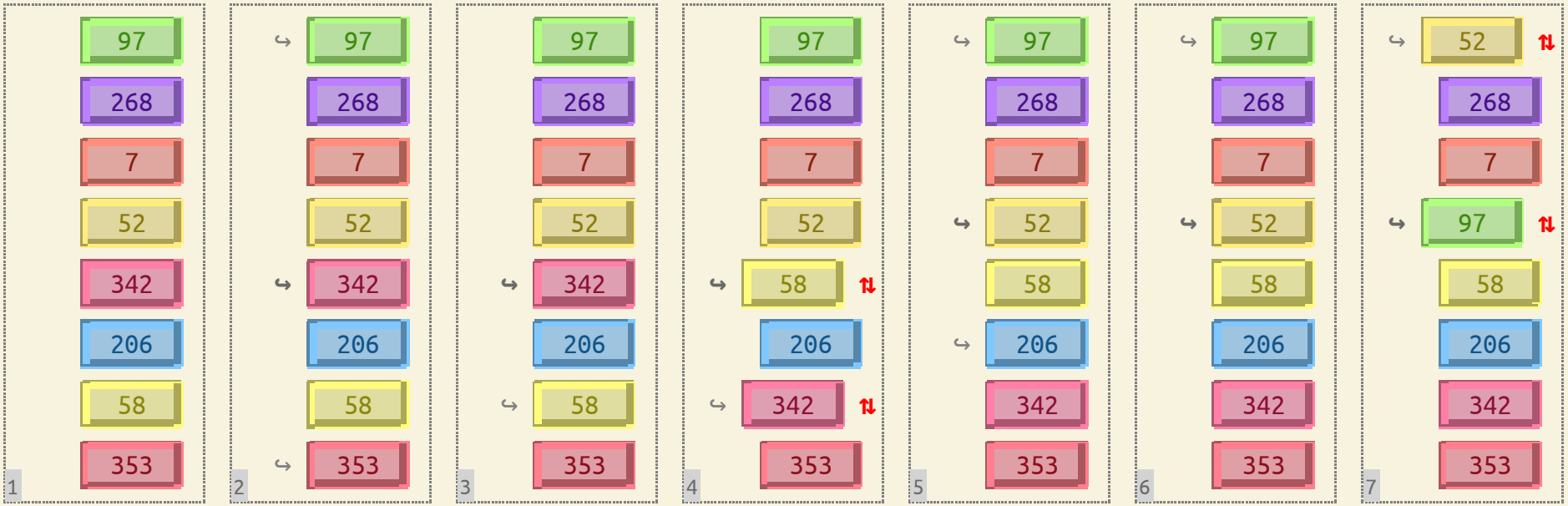
QUICK SORT *(CONT.)*

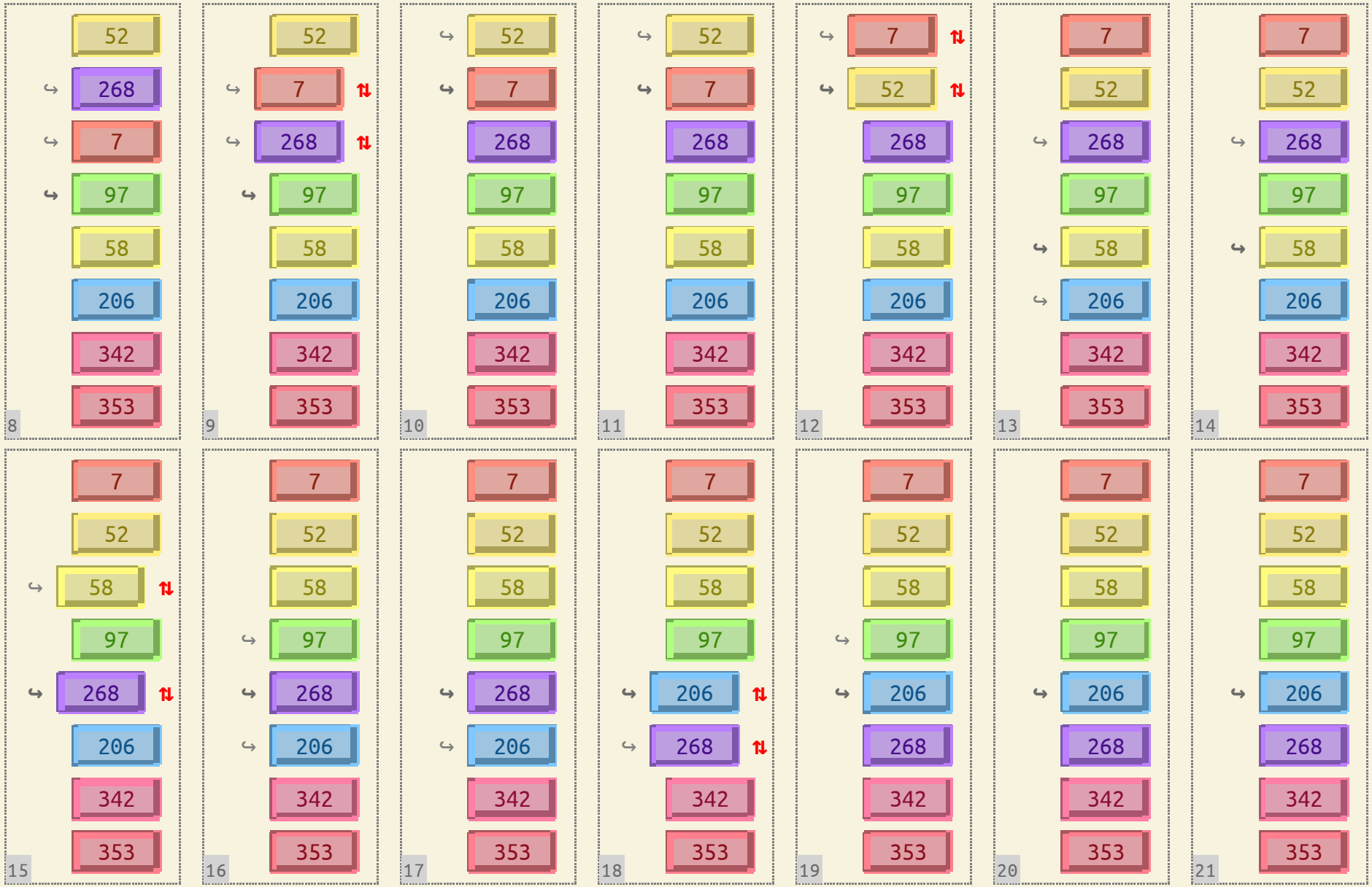
CODE: RECURSE

```
function doQuickSort($elements, $leftIndex, $rightIndex) {
    // Divide the array in two, creating a “pivot” value
    // Move any value lower than the pivot to the left array
    // Move any value higher than the pivot to the right array
    // Recursively repeat the same operation on both arrays
    if ($leftIndex < $rightSwapIndex) {
        $this->doQuickSort($elements, $leftIndex, $rightSwapIndex);
    }
    if ($leftSwapIndex < $rightIndex) {
        $this->doQuickSort($elements, $leftSwapIndex, $rightIndex);
    }
}
```

QUICK SORT *(CONT.)*

ITERATIONS

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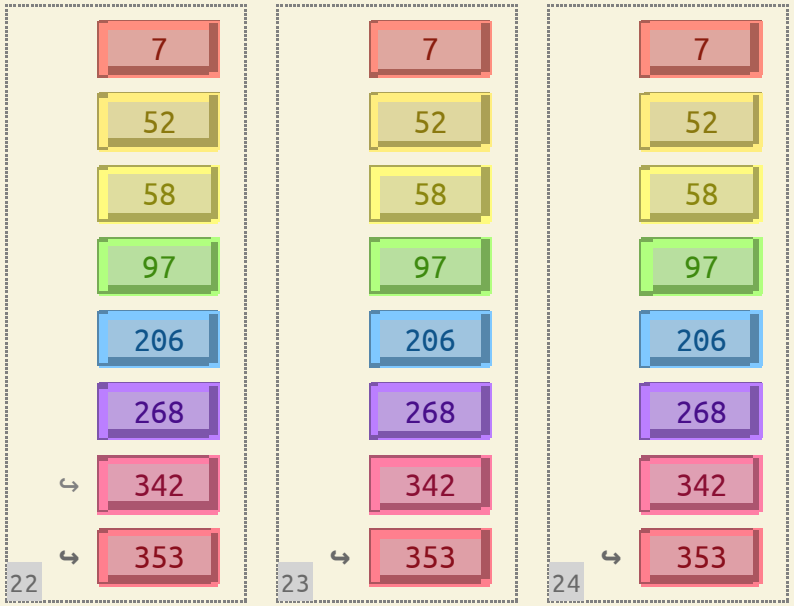
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Sorted!

QUICK SORT *(CONT.)*

SUMMARY

- Best / average case: $\mathrm{O}(n \log n)$
- Worst case: $\mathrm{O}(n^2)$
- Implemented by `sort()`
- Easily parallelized

HEAP SORT

CODE

```
class HeapSort {
    public function sort(array $elements) {
        $size = count($elements);
        for ($index = floor(($size / 2)) - 1; $index >= 0; $index--) {
            $elements = $this->siftDown($elements, $index, $size);
        }
        for ($index = $size - 1; $index >= 1; $index--) {
            $tmp = $elements[0];
            $elements[0] = $elements[$index];
            $elements[$index] = $tmp;
            $elements = $this->siftDown($elements, 0, $index - 1);
        }
        return $elements;
    }
}
```

HEAP SORT *(CONT.)*

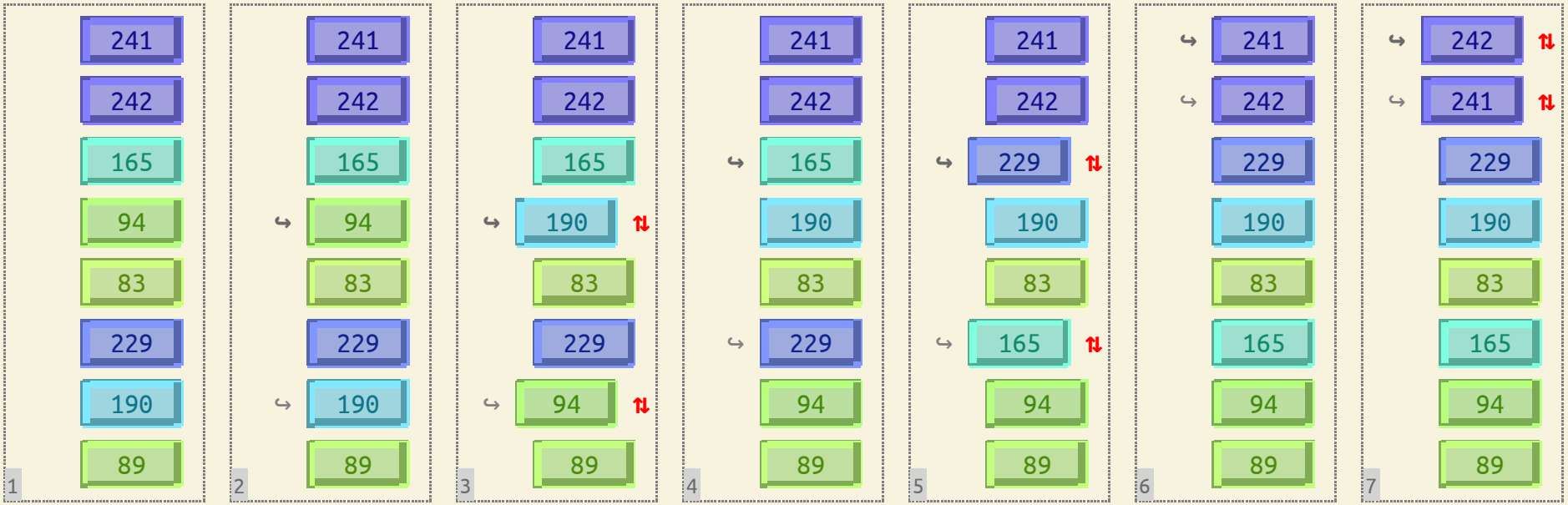
CODE: SIFT THE HEAP

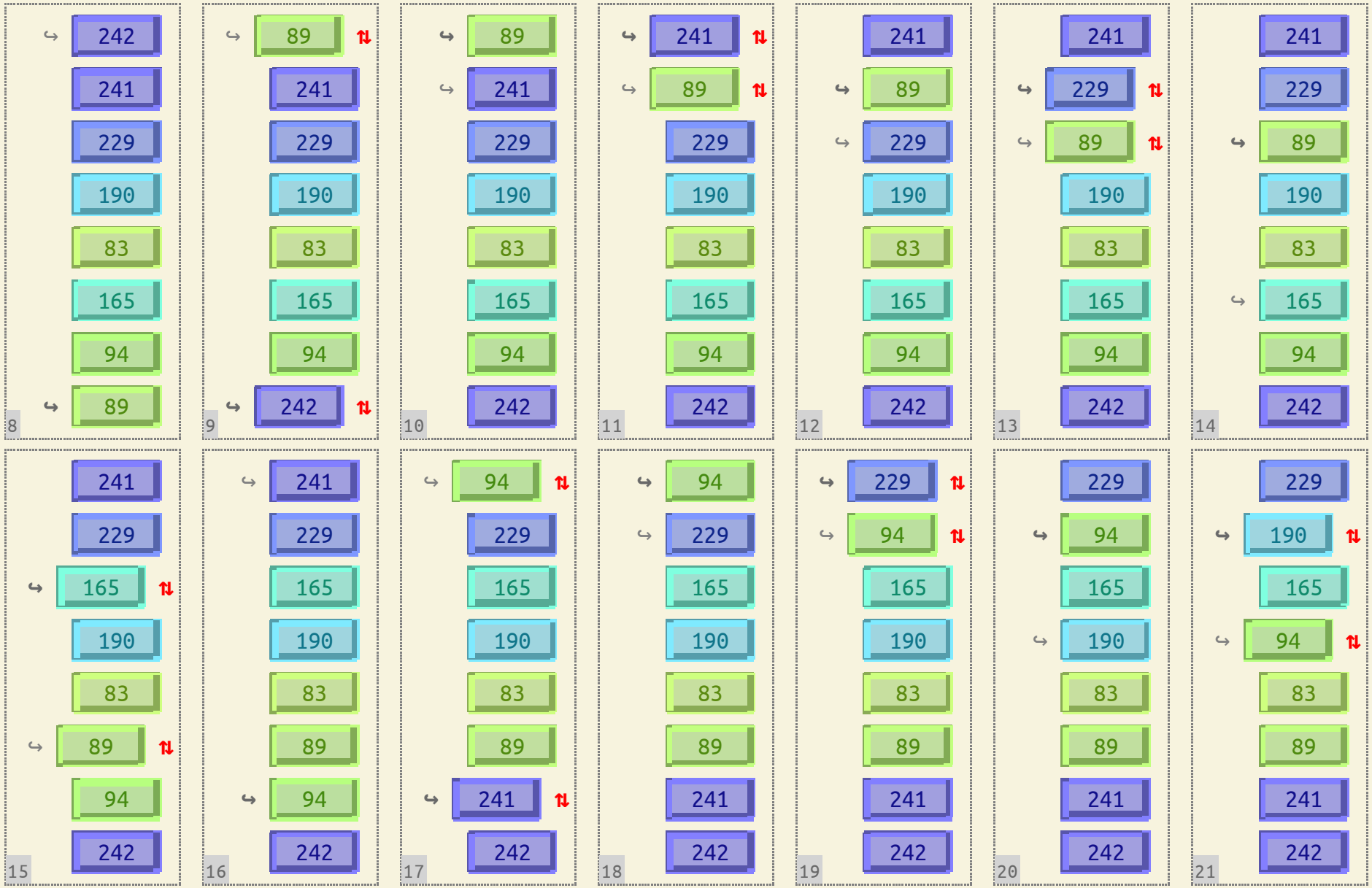
```
public function siftDown(array $elements, $root, $bottom) {
    $done = false;
    while (($root * 2 <= $bottom) && (!$done)) {
        if ($root * 2 == $bottom) $maxChild = $root * 2;
        elseif ($elements[$root * 2] > $elements[$root * 2 + 1]) $maxChild = $root * 2;
        else $maxChild = $root * 2 + 1;

        if ($elements[$root] < $elements[$maxChild]) {
            $tmp = $elements[$root];
            $elements[$root] = $elements[$maxChild];
            $elements[$maxChild] = $tmp;
            $root = $maxChild;
        } else
            $done = true;
    }
    return $elements;
}
```

HEAP SORT *(CONT.)*

ITERATIONS

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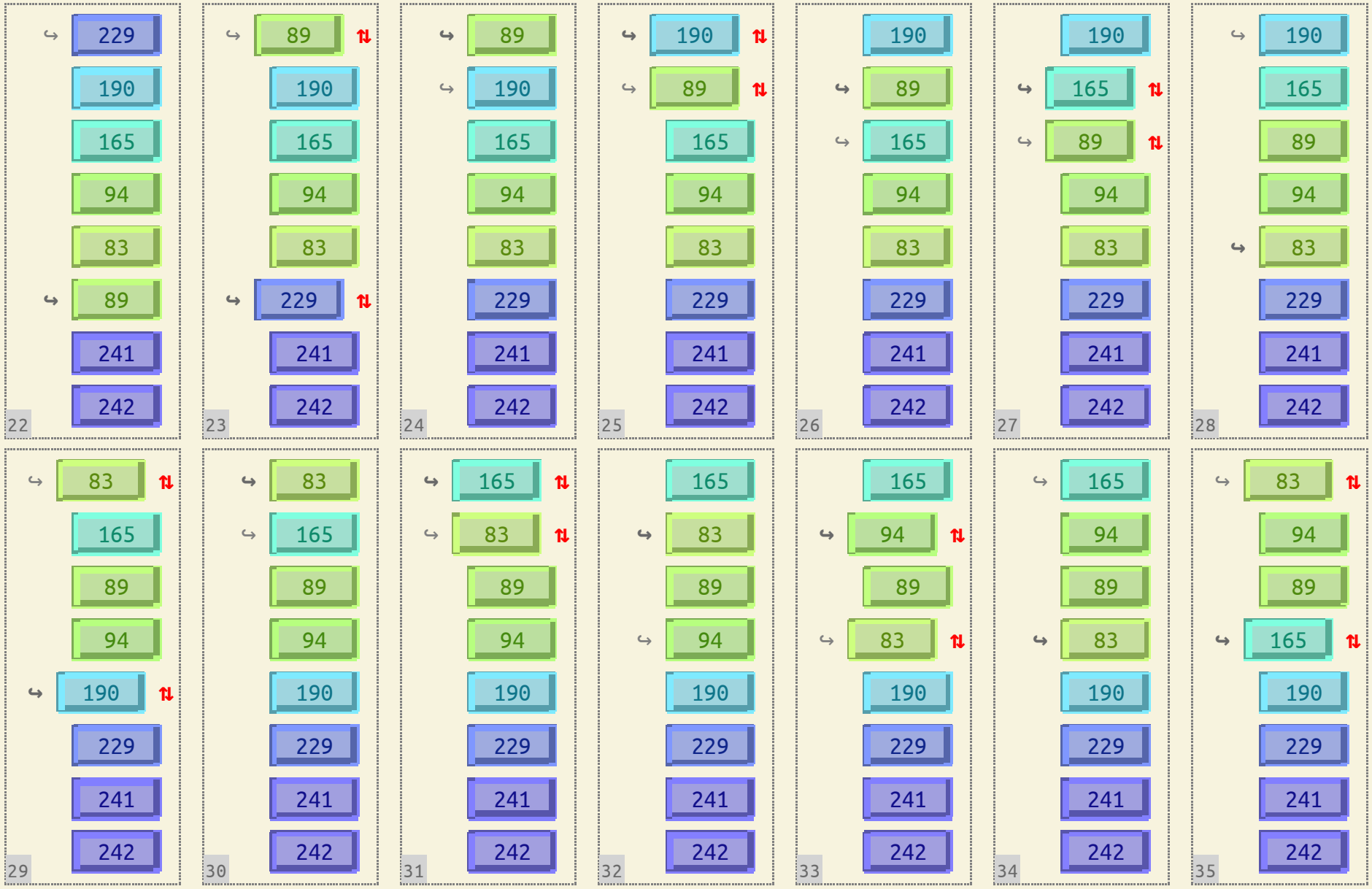
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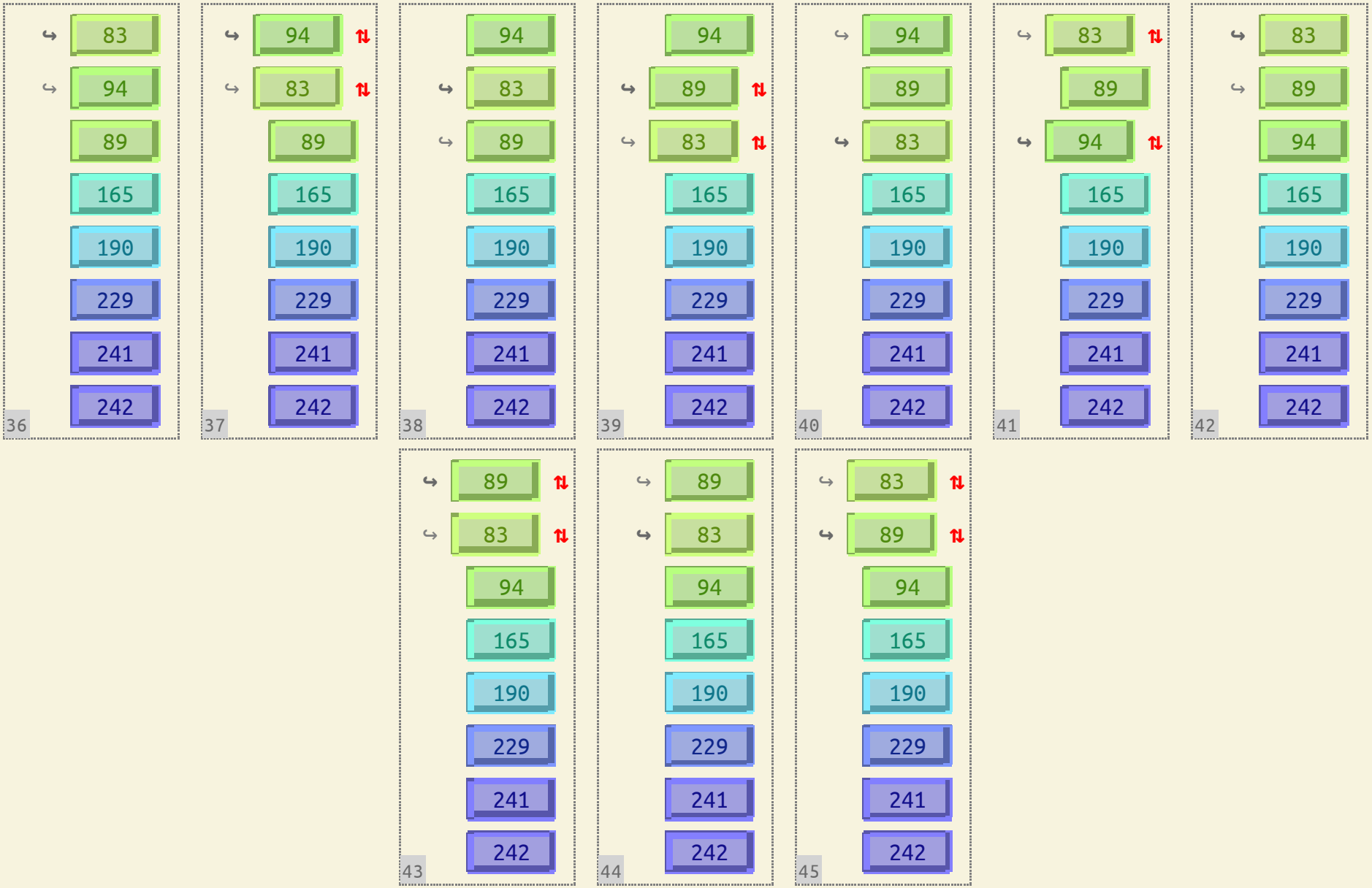
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Sorted!

HEAP SORT *(CONT.)*

SUMMARY

- Best / average / worst case: $O(n \log n)$
- Implemented by `SplMinHeap()`

```php
$h = new SplMinHeap();
foreach ($unsorted as $val) $h->insert($val);
$h->top();
while($h->valid()) {
    echo $h->current()."\n";
    $h->next();
}
```

SEARCHING ALGORITHMS

SEQUENTIAL SEARCH

CODE

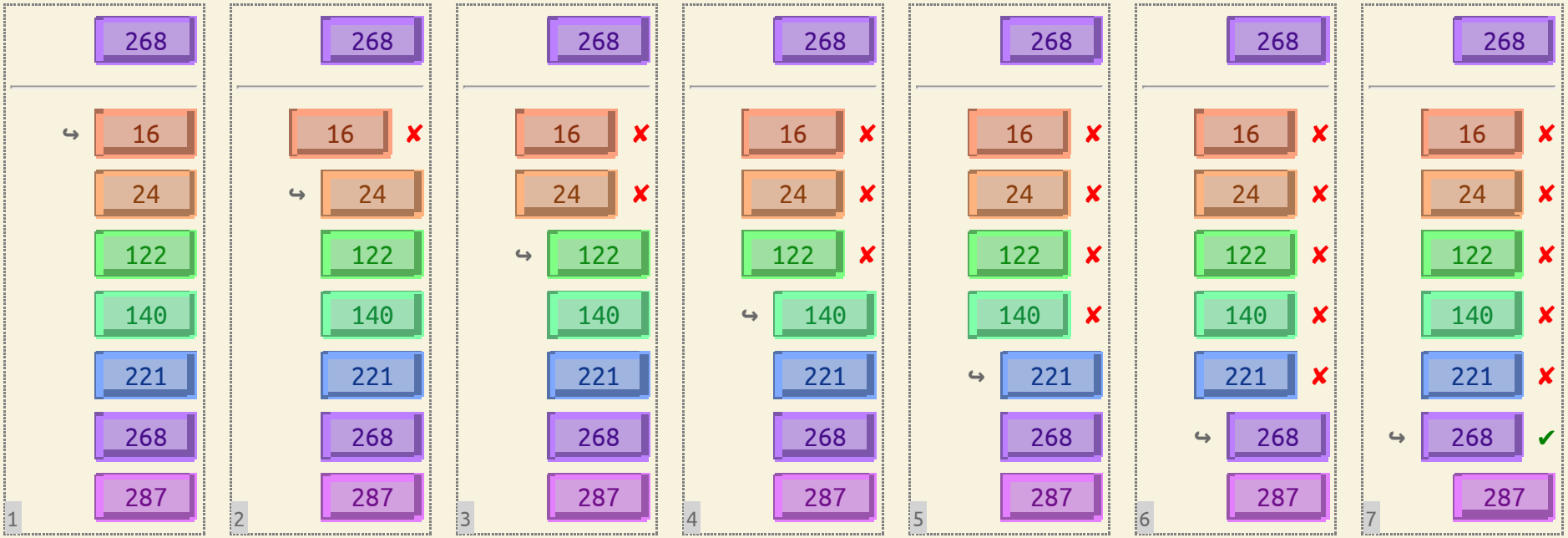
```
class SequentialSearch {
    public function search($target, array $elements) {
        $iterations = count($elements);

        for($index = 0; $index <= $iterations; $index++) {
            if ($target == $elements[$index]) {
                $this->notifyObservers(array($index));
                return true;
            }
        }

        return false;
    }
}
```

SEQUENTIAL SEARCH *(CONT.)*

ITERATIONS



Found you!

SEQUENTIAL SEARCH *(CONT.)*

SUMMARY

- Best case: $O(1)$
- Average / Worst case: $O(n)$
- Not as pointless as it looks...

BINARY SEARCH

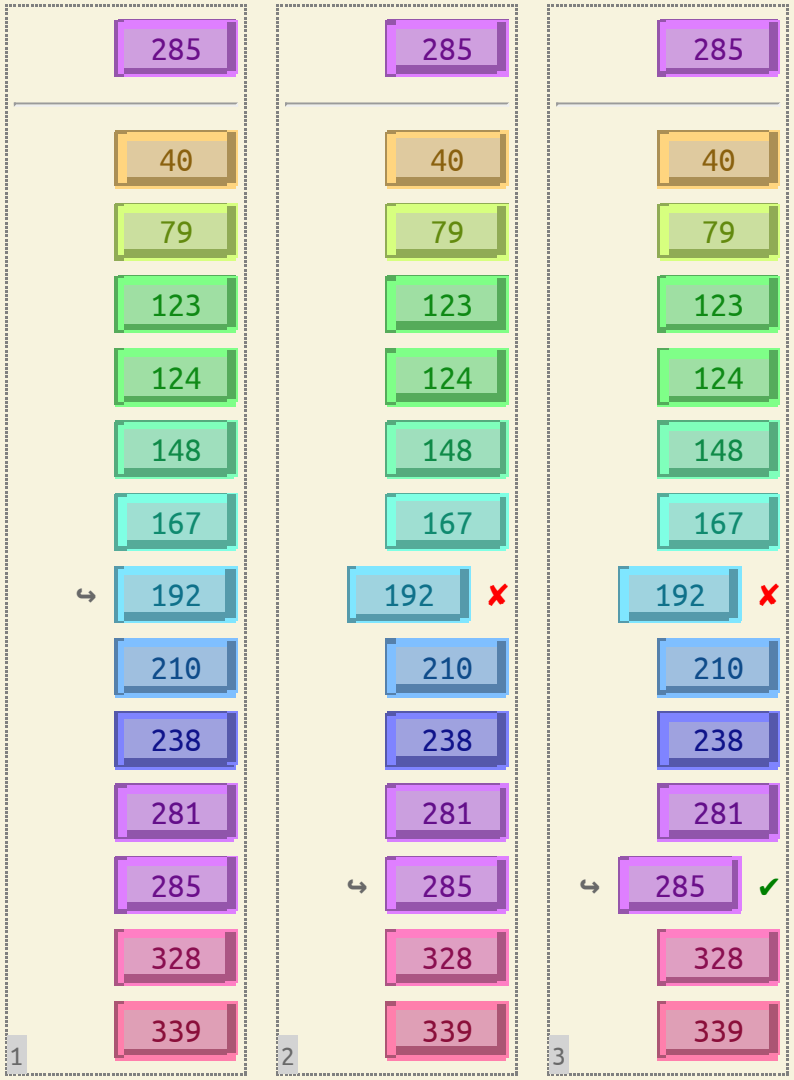
CODE

```
class BinarySearch {
    public function search($target, array $elements) {
        return $this->doBinarySearch($target, $elements, 0, count($elements));
    }

    public function doBinarySearch($target, array $elements, $minIndex, $maxIndex) {
        if ($maxIndex < $minIndex) { return false; }
        $midIndex = floor(($minIndex + $maxIndex) / 2);
        if ($elements[$midIndex] > $target) {
            return $this->doBinarySearch($target, $elements, $minIndex, $midIndex - 1);
        }
        if ($elements[$midIndex] < $target) {
            return $this->doBinarySearch($target, $elements, $midIndex + 1, $maxIndex);
        }
        return true;
    }
}
```

BINARY SEARCH *(CONT.)*

ITERATIONS


285
40
79
123
124
148
167
192
210
238
281
285
328
339
1
285
40
79
123
124
148
167
192
210
238
281
285
328
339
2
285
40
79
123
124
148
167
192
210
238
281
285
328
339
3

Found you!

BINARY SEARCH *(CONT.)*

SUMMARY

- Best case: $O(1)$
- Average / Worst case: $O(\log n)$
- Switch to linear search for smaller partitions

SUMMING UP

HISTORY

- Insertion Sort: optimised in 1959 (Shell Sort)
- Bubble Sort: improved in 1980 (Comb Sort)
- Quick Sort: developed in 1960 (C. A. R. Hoare)
- Heap Sort: improved in the '60s (Robert Floyd)

Oh, and there's Radix Sort used by Herman Hollerith in 1887

THANK YOU!

JOIND.IN/8454