Algorithmic Sustainable Design: The Future of Architectural Theory.

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Supplement

- More on universal scaling and the scaling factor: the assembly problem
- New material that was not originally presented as part of the lecture series

1.4. Scaling from division

- A larger form can be virtually divided into smaller parts
- Division generates the smaller scales
- Grouping of smaller elements occurs within larger scale
- Similarity establishes scaling coherence between distinct scales

Analogy with embryonic development

- The embryo starts out as a single cell
- It subdivides into an increasing number of cells, clustering into groups
- All the subsequent cell divisions work together to form the growing embryo
- Insights of Christopher Alexander

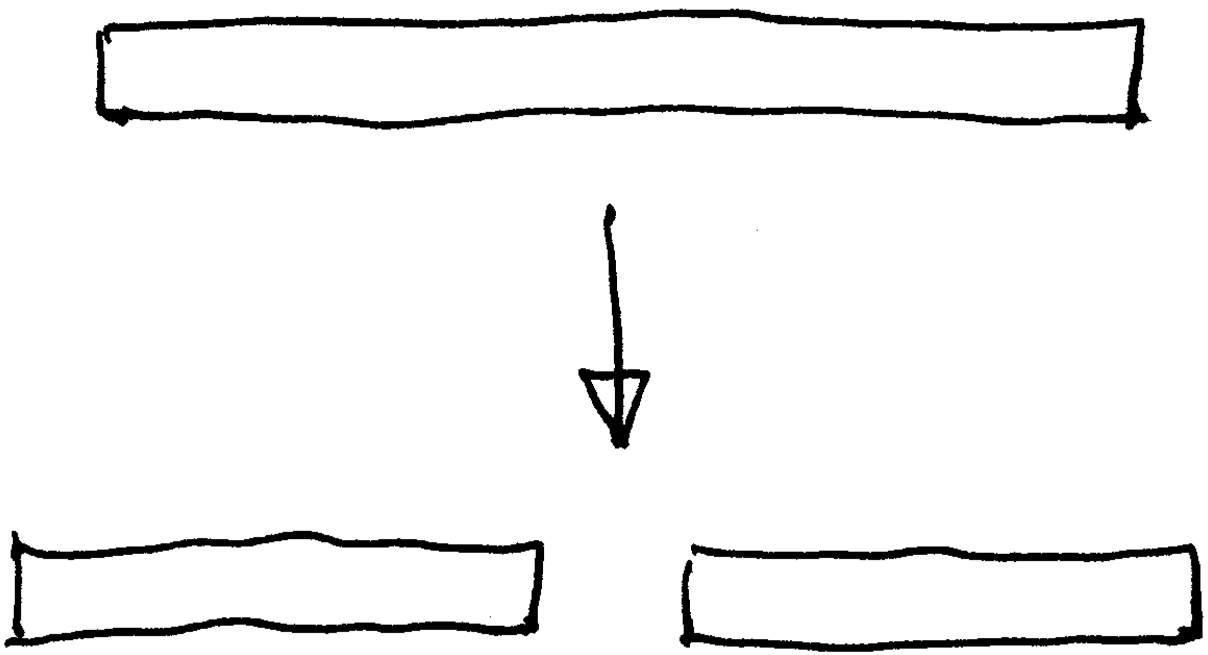
Division in one dimension

- To illustrate scale formation through division, consider only lengths
- One-dimensional architectural model makes computations easier
- Divide a length into 2, 3, or more parts of comparable size

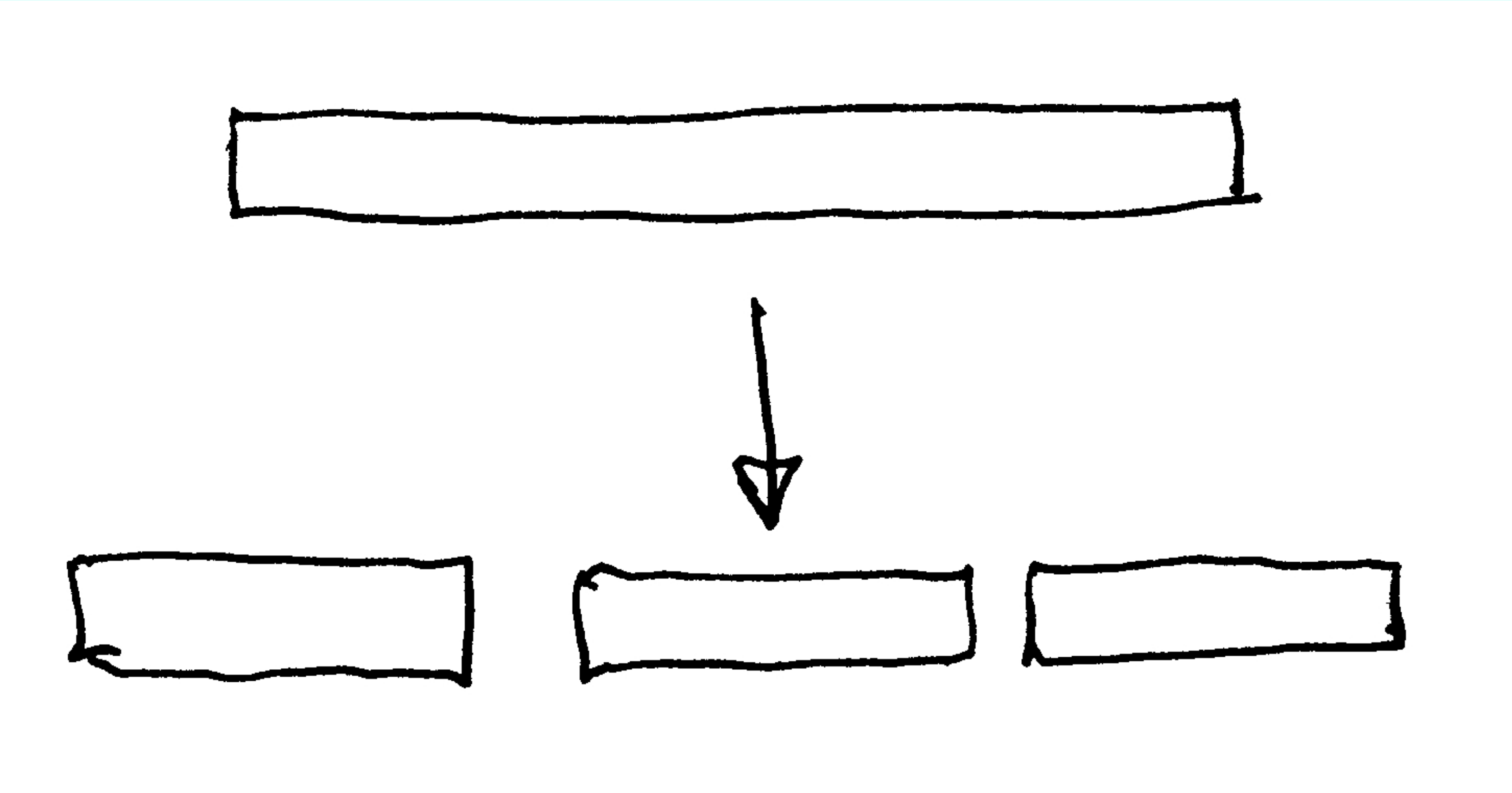
How many divisions?

- Smaller scales are created by subdividing the larger scale
- Simplest division is into two parts
- Too many identical parts, however, produce combinatorial complexity

Divide into two identical parts



Divide length into 3 parts



Recombination

- The parts created by division must be appropriate for reconstructing the original larger scale
- Division is a process that reinforces, and does not destroy, the whole
- Grouping and recombination relates daughter and parent scales

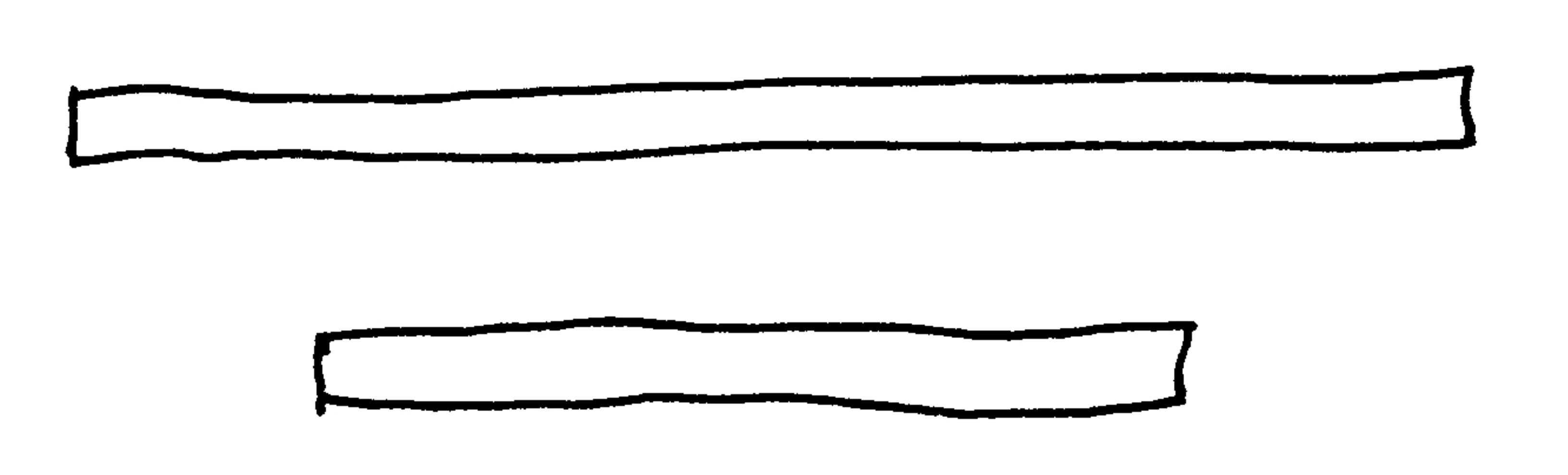
Linking scales

- Scaling hierarchy grows out of a relationship among three scales:
- A particular scale
- — generates an immediately smaller scale through division
- — and is related to its immediately larger scale through grouping

The Golden Mean doesn't apply

- It is impossible to divide a form into fewer than 2 comparable parts!
- Therefore, we cannot use a scaling factor of $\Phi = 1.618$ to divide a form
- This elementary error was made by Le Corbusier in proposing his Modulor scheme for design

Relationship of 1.62 : 1



Adding unrelated structure

- Suppose we try using 1.62 as a scaling factor generating smaller parts
- A group of objects on this new smaller scale cannot fit into the original scale
- The resulting smaller scale is NOT a division, but an entirely unrelated scale

Conclusion: the scaling factor

- Scaling from division defines the lowest value for the scaling factor
- The scaling factor must be larger than or equal to 2
- — but not so large that we face the problem of combinatorial complexity

1.5. Combinatorial complexity

- Suppose we have a large number of identical smaller parts
- Triggers comparison, a combinatorial process that generates fatigue
- Monotonous repetition is thus not only boring, it can actually be stressful

Unexpected complexity

- NOT Kolmogorov complexity, which considers monotonous repetition as simple instead of complex
- — measures complexity as the length of the algorithm required to produce it
- We are instead interested in a very different combinatorial complexity

Neural system

- Evolved to cope with the natural world
- Expends energy to arrange data from senses into coherent patterns
- Tries to group similar pieces into larger wholes (Gestalt)
- Keeps working to find some grouping

Conjecture on perception

- The brain works combinatorially
- Tries out all possible geometric combinations, deciding which is more effective for understanding
- In the absence of explicit groupings, this process leads to stress and fatigue

Cognitive stress

- We don’t really know the cognitive mechanism that evaluates a configuration
- A monotonous sequence with too many similar pieces is cognitively exhausting
- Our perception works continuously to evaluate all NONEXISTENT groupings in possible combinations

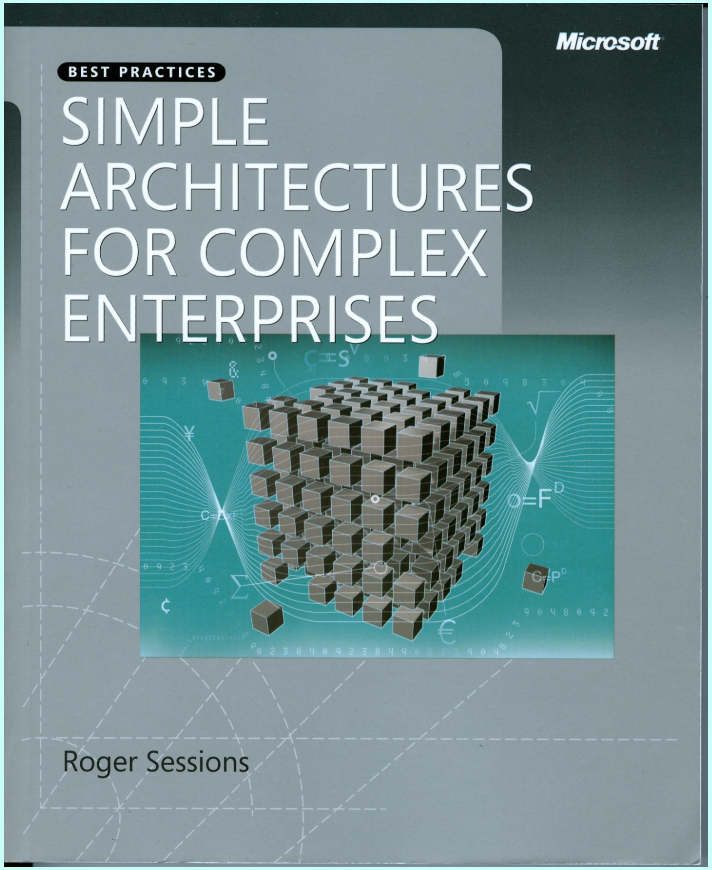
Support from “Enterprise Architecture”

- The structure and processes of a business, and how information systems and technology help those processes
- An economic pillar of 20C society
- “Architecture” is used here in the sense of designing software and business systems — analogy to buildings

Sessions' Law of Software Complexity

- "The complexity of a software system is a function of the number of states in which that system can find itself"
- Combinatorial complexity increases with the number of identical parts
- Solution is to iteratively partition sets of parts into coherent groups

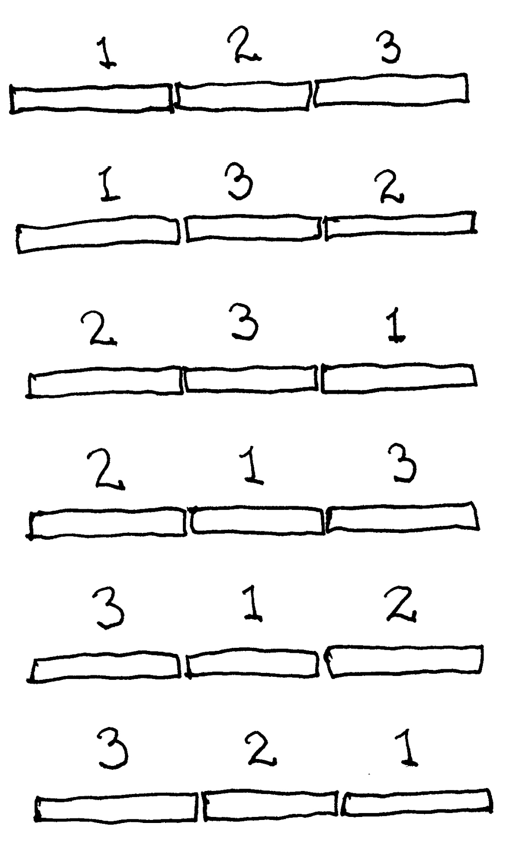
Roger Sessions: "Simple Architectures for Complex Enterprises", 2008



Possible permutations

- In what permutation can we assemble *n* parts to create a higher scale?
- The number of possible permutations of *n* distinct parts is equal to *n*!
- $2! = 1\times2 = 2$, $3! = 1\times2\times3 = 6$, $4! = 24$
- A well-known result from combinatorics

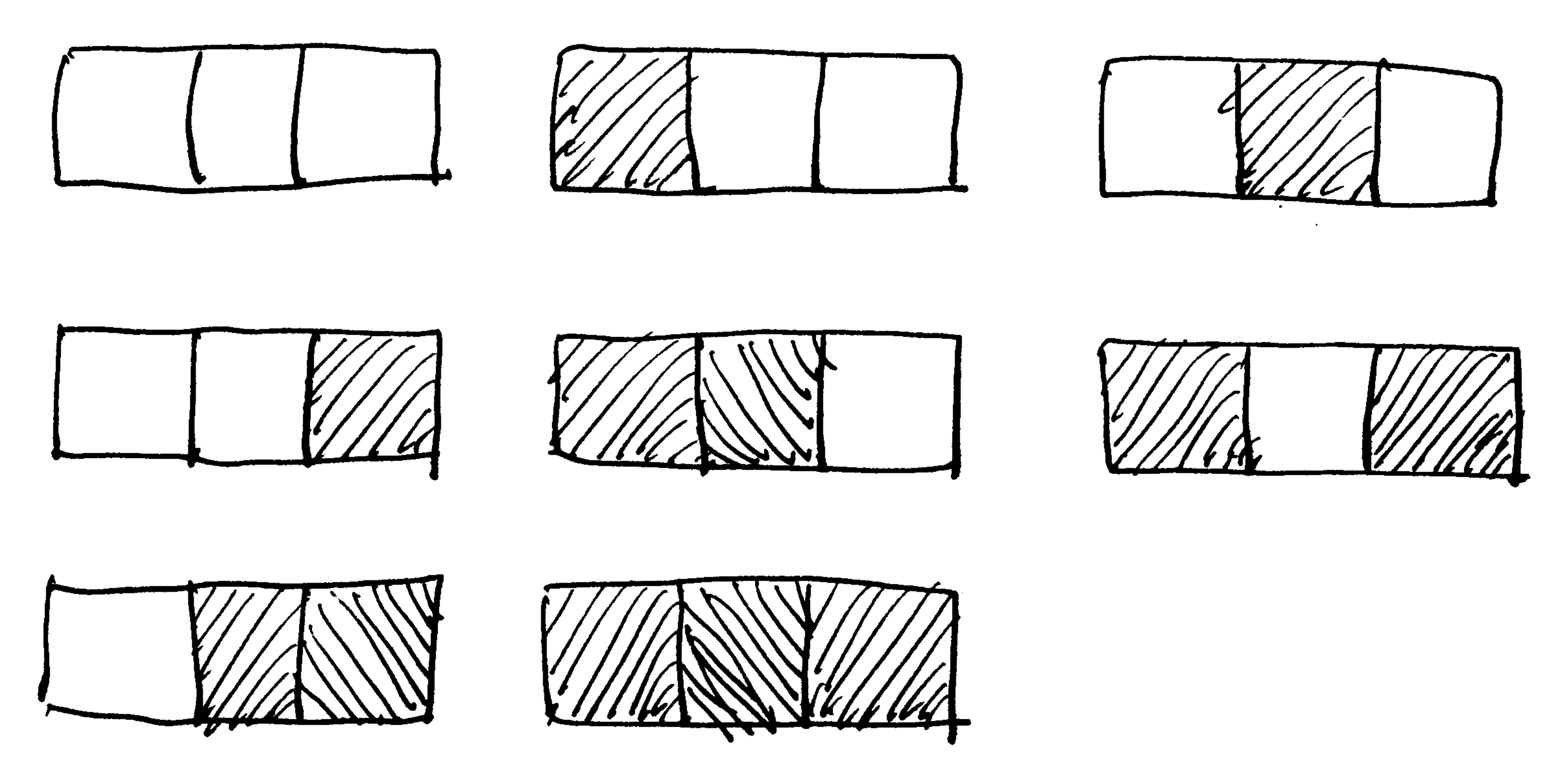
Six ways of assembling three similar parts



Total number of states

- A “binary” cellular automaton has cells that can be either black or white
- A row of n cells can assume 2^n states
- For n parts, the number of comparisons equals the possible states = 2^n
- The choices grow exponentially as n increases

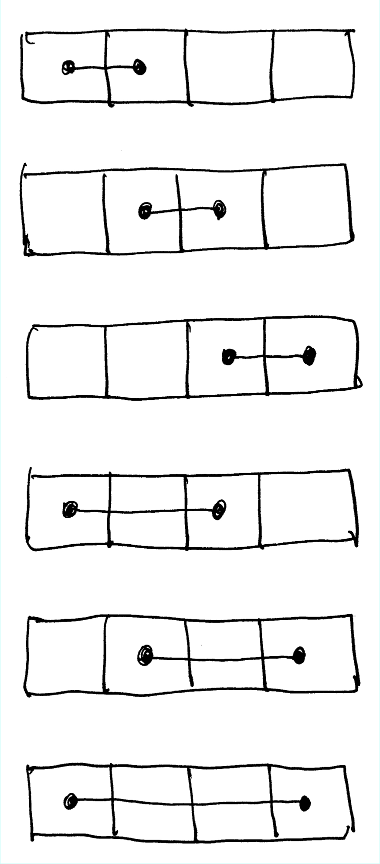
Cellular automaton with 3 cells



Comparisons of combinations

- Suppose that the mind compares pairs to find similarities, symmetries, groupings, and patterns
- For n parts, the number of pair-wise comparisons equals $n(n-1)/2$
- The choices grow as $n^2/2$ as n increases

Pair-wise matching of 4 cells



Comparisons of different counts

- Does cognition evaluate all possible permutations of the repeating parts?
- Or does it count repetitions as states of a one-dimensional cellular automaton?
- Or does it work according to pair-wise comparisons among identical parts?

Complexity we cannot handle

- Suppose we have 10 repeating parts:
- — there are10! = 3,628,800 possible permutations
- — there are 2^{10} = 1,024 states of a binary Cellular Automaton
- — there are 45 pair-wise comparisons

The magic number 7

- The human mind can simultaneously handle around 7 pieces of information, and preferably nearer 5
- We can grasp 5 to 7 combinations
- Applying this concept, we should prefer a set of repeating units that leads to no more than about 7 comparisons

Complexity that we CAN handle

- Compare three different mechanisms:
- Permutations: 3 parts = 6 states, 4 parts = 24 states (too many)
- Binary cellular automata: 3 parts = 8 states, 4 parts = 16 states (too many)
- Pair-wise comparisons: 4 parts = 6, 5 parts = 10, 6 parts = 15 (too many)

Sessions' Third Law of Partitions

- "The number of autonomous units that make up a given partition should be in the range of 3 through 8"
- Support from Enterprise Architecture for the number of elements in a group
- This is precisely the optimal size of a group so as to avoid cognitive fatigue

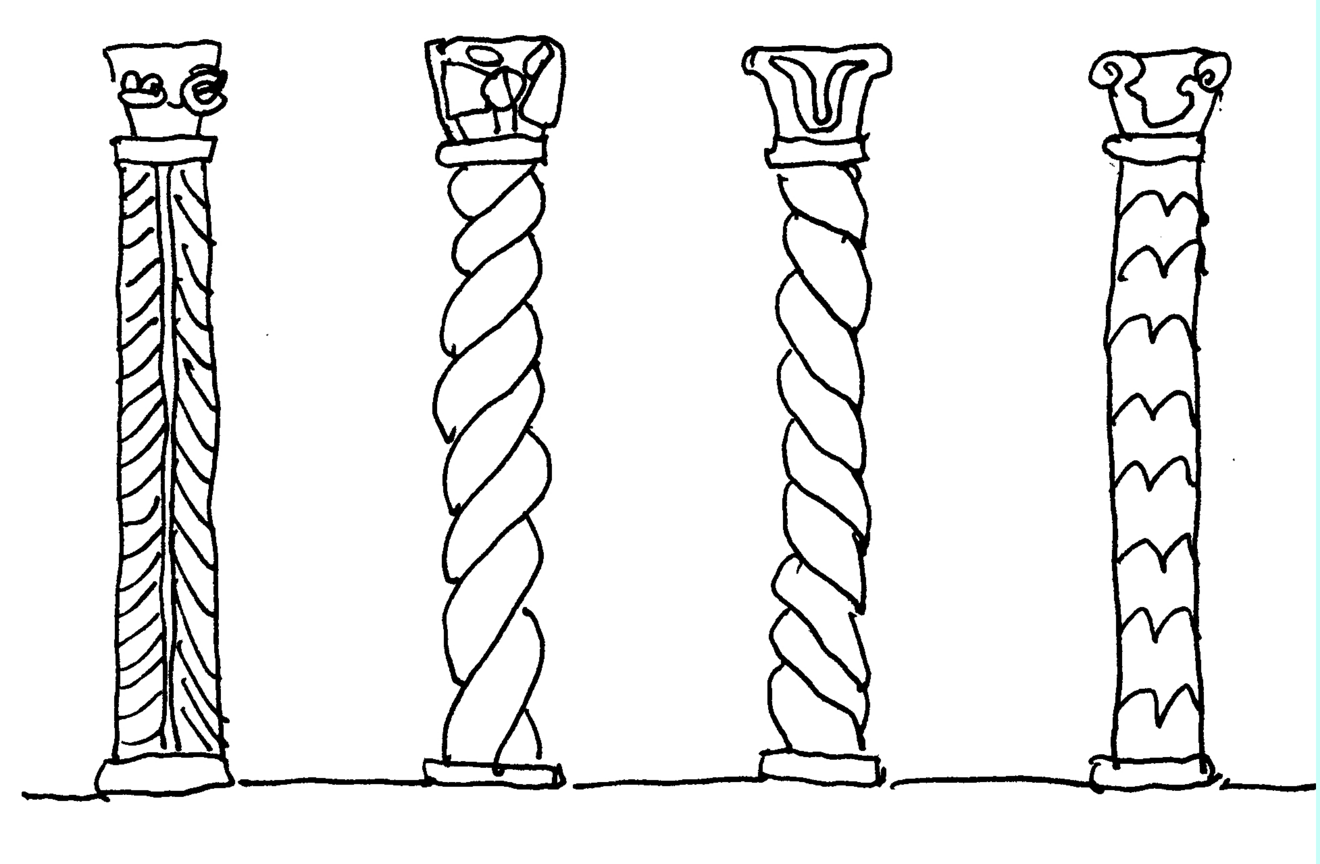
Monotonous repetition is tiring

- According to our conjecture, repetition of identical parts is cognitively tiring
- Need to break the monotony:
- (A) either make each similar part slightly different using variety
- (B) or group the parts into clusters

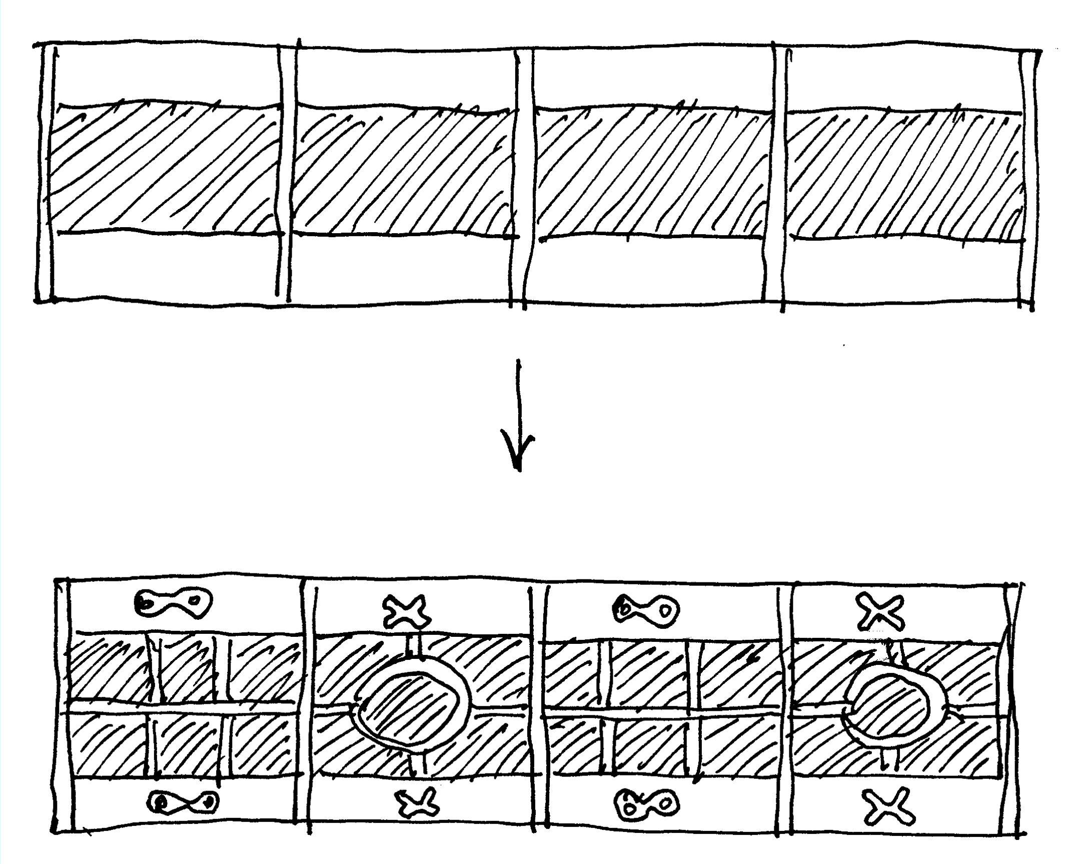
First solution: symmetry with variety

- Different capitals or surface design on Medieval columns
- Variations in a row of repeating windows, but still in strict alignment
- Repeating units are distinguished by variety on a lower scale

Columns with variety



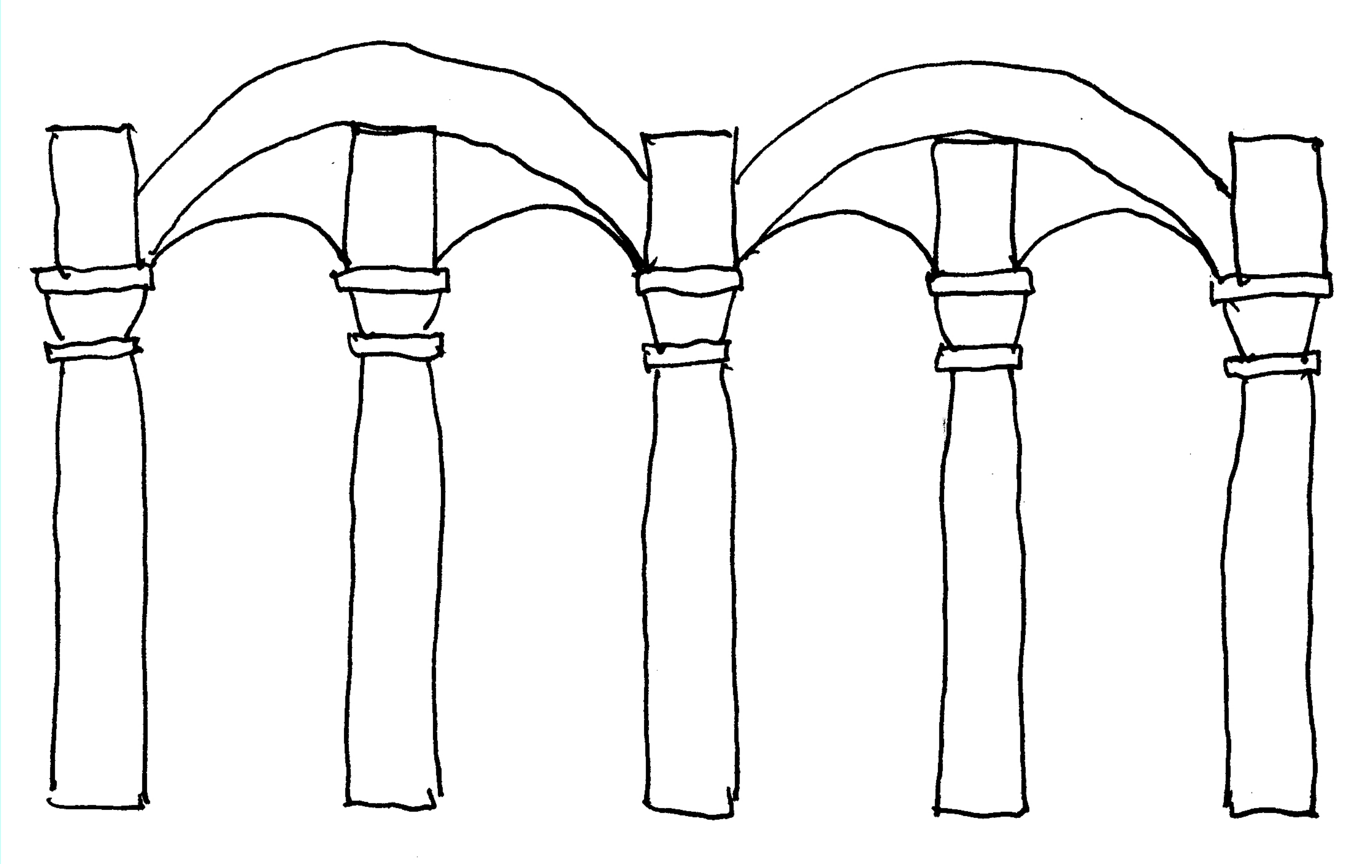
Windows gain variety



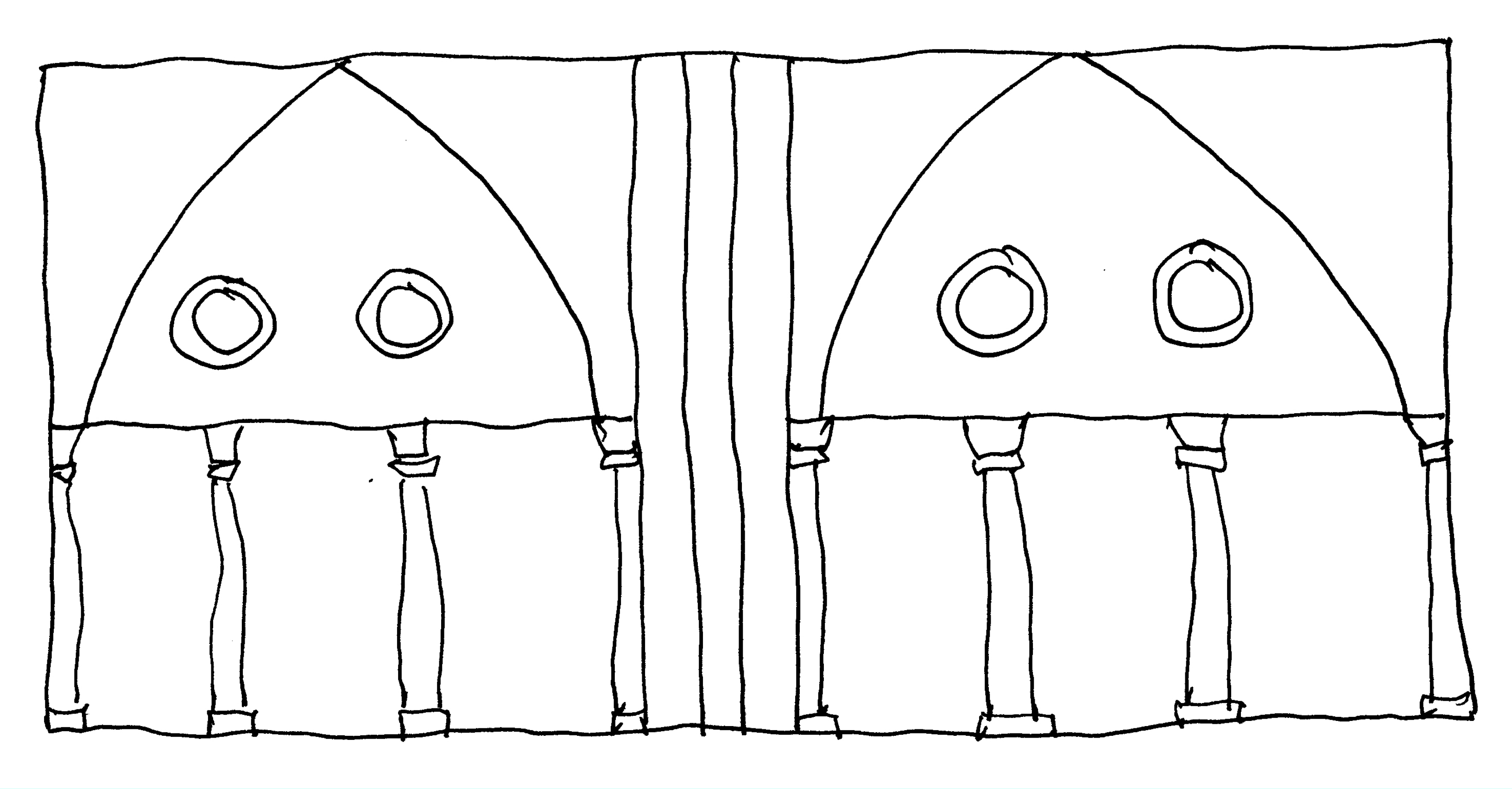
Second solution: grouping parts

- Create intermediate clusters into which several parts assemble into groups
- Grouping generates intermediate scales
- The process of grouping according to scales recursively generates the universal scaling hierarchy

Grouping into clusters of three



Grouping into clusters of four



Creation of scales

- Solving the combinatorial complexity problem generates the scaling hierarchy
- VARIETY acts on a smaller scale, thus differentiation creates several smaller scales
- GROUPING PARTS creates a larger scale
- But monotonous repetition prevents the formation of the scaling hierarchy

Conclusion: repetition

- Scaling hierarchy aids cognition
- Monotonous repetition is not only boring, it is stressful for our perception
- But it forms part of 20C design
- We strongly condemn the stressful effects of the modernist design canon
- Variation and groupings are necessary