

# Timeline Layout Algorithm: Complete Technical Specification

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**Core Concept:** “Tetris with Rubber Bands”

A constrained force-directed layout algorithm that arranges team nodes on horizontal “swim-lanes” while minimizing visual crossings and maintaining family proximity.

## Contents

# 1 Fundamental Definitions

## 1.1 What is a Node?

A **Node** represents a single cycling team with properties defining its lifecycle and identity:

```
1 {  
2   id: "LPR",                      // Unique identifier  
3   founding_year: 2004,            // Year the team was founded  
4   dissolution_year: 2009,          // Year the team dissolved (or null if still active)  
5   eras: [                          // Array of yearly "slices"  
6     { year: 2004, name: "LPR Brakes" },  
7     { year: 2005, name: "LPR Brakes" },  
8     // ... one entry per year  
9   ]  
10 }
```

**Visual Representation:** A node is drawn as a horizontal bar spanning from *founding\_year* to *dissolution\_year* + 1 (inclusive rendering).

**Example:** LPR (2004–2009) visually occupies the space from year 2004 through the end of year 2009.

## 1.2 What is Temporal Overlap?

Two nodes **temporally overlap** if they exist at the same time. This is determined using **inclusive** year boundaries:

$$Overlap(A, B) \iff (A_{start} \leq B_{end}) \wedge (B_{start} \leq A_{end}) \quad (1)$$

**Critical Edge Case - “Touching” Nodes:**

- LPR ends 2009, Utensilnord starts 2010  $\implies$  **NO OVERLAP** ( $2009 < 2010$ )
- Sanson ends 1980, Famcucine starts 1980  $\implies$  **OVERLAP** ( $1980 \leq 1980$ )

**Why this matters:** Nodes that overlap cannot share the same horizontal lane (swimlane) because they would visually collide.

## 1.3 What is a Chain?

A **Chain** is a linear sequence of nodes connected by 1-to-1 relationships with **no temporal overlap**.

```
1 {  
2   id: "chain-0",  
3   nodes: [LPR, Utensilnord, Katusha], // Array of node objects  
4   startTime: 2004,                  // founding_year of first node  
5   endTime: 2019,                   // dissolution_year of last node  
6   yIndex: 0                        // Current lane assignment  
7 }
```

**Chain Formation Rules:**

1. **Linear Topology:** Each node has exactly 1 predecessor and 1 successor (except endpoints).
2. **No Temporal Overlap:** Consecutive nodes must NOT overlap.
3. **Break on Split/Merge:** If a node has multiple children or multiple parents, the chain breaks.

**Example Chain:** LPR (2004–2009)  $\rightarrow$  Utensilnord (2010–2015)  $\rightarrow$  Katusha (2016–2019)

These three nodes form ONE chain because they satisfy all rules and do not overlap (2009 < 2010 and 2015 < 2016).

**Counter-Example (Chain Break):** Sanson (1963–1980)  $\times$  Famcucine (1980–1981)

These form TWO separate chains because they overlap ( $1980 \leq 1980$ ).

## 1.4 What is a Link?

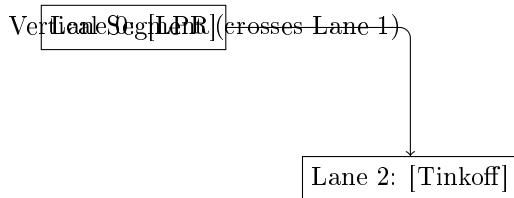
A **Link** represents a lineage connection between two teams:

```
1 {  
2   source: "LPR",           // Source node ID  
3   target: "Tinkoff",       // Target node ID  
4   type: "LEGAL_TRANSFER", // Type of connection  
5   year: 2007             // Year the connection occurred  
6 }
```

**Visual Representation:** Links are drawn as curved paths connecting the source node to the target node.

## 1.5 What is a Vertical Segment?

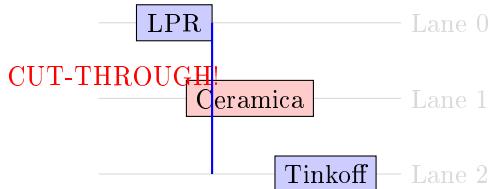
When a link connects nodes in different lanes, it creates a **Vertical Segment** - the portion of the link that crosses intermediate lanes.



**Key Property:** A vertical segment exists at a specific **year** (the link's year) and spans between two lanes.

## 1.6 What is a Cut-Through?

A **Cut-Through** occurs when a node sits in a lane that a vertical segment passes through.



**Detection Logic:**

```
1 // For a node in lane Y, check all vertical segments  
2 isCutThrough = (  
3   Y > segment.y1 &&           // Node is between the two lanes  
4   Y < segment.y2 &&  
5   segment.time >= node.start && // Link occurs during node's lifetime  
6   segment.time <= node.end + 1 // +1 accounts for inclusive rendering  
7 )
```

**Why +1?** Since nodes render inclusively to *dissolution\_year* + 1, a node ending in 2009 visually extends to the start of 2010. A link at year 2010 should detect a cut-through with this node.

## 1.7 What is a Blocker?

A **Blocker** occurs when a node sits on top of a vertical segment, blocking the visual “corridor” between parent and child.

**Key Difference from Cut-Through:**

- **Cut-Through:** The link slices through the node (node is the victim).
- **Blocker:** The node blocks someone else’s link (node is the perpetrator).

## 1.8 What is Lane Sharing?

**Lane Sharing** occurs when multiple chains occupy the same horizontal lane.

**Strict Stranger Rule:** Unrelated chains (“strangers”) are **strictly forbidden** from sharing a lane unless there is at least a 1-year gap between them. Since nodes render to *dissolution\_year* + 1:

- Node A ends in 2009 (renders to 2010)
- Node B starts in 2011
- Gap = 2011 - 2010 = 1 year ✓ (allowed)

**Family Exception:** Parent and child chains can share lanes with temporal overlap.

**Distance Decay** (Currently Disabled): The penalty formula remains but with weight = 0:

$$\text{Penalty} = \frac{W_{SHARE}}{\max(0.5, \Delta T)} \quad (2)$$

## 2 Math Symbols & Variables Reference

To clarify the formulas used in the optimization phases, here is a reference of the symbols and variables:

Symbol	Name	Description
$Y$	<b>Lane Index</b>	The vertical coordinate of a chain (0 = top).
$T$	<b>Time</b>	An integer year (e.g., 2007).
$\mu_{parents}$	<b>Mean Parent Lane</b>	Average $Y$ position of all parent chains connected to current chain.
$\mu_{children}$	<b>Mean Child Lane</b>	Average $Y$ position of all child chains connected to current chain.
$\Delta T$	<b>Temporal Gap</b>	Years between two nodes. Positive = gap, negative = overlap.
$J$	<b>Total Cost</b>	The “energy” of a specific lane assignment to be minimized.
$W_{XXX}$	<b>Weights</b>	Penalty multipliers defining constraint importance.
$P$	<b>Parent Lane</b>	The $Y$ coordinate of an individual parent chain.
$C$	<b>Child Lane</b>	The $Y$ coordinate of an individual child chain.

Table 1: Math Symbols and Variables

### 3 Algorithm Overview

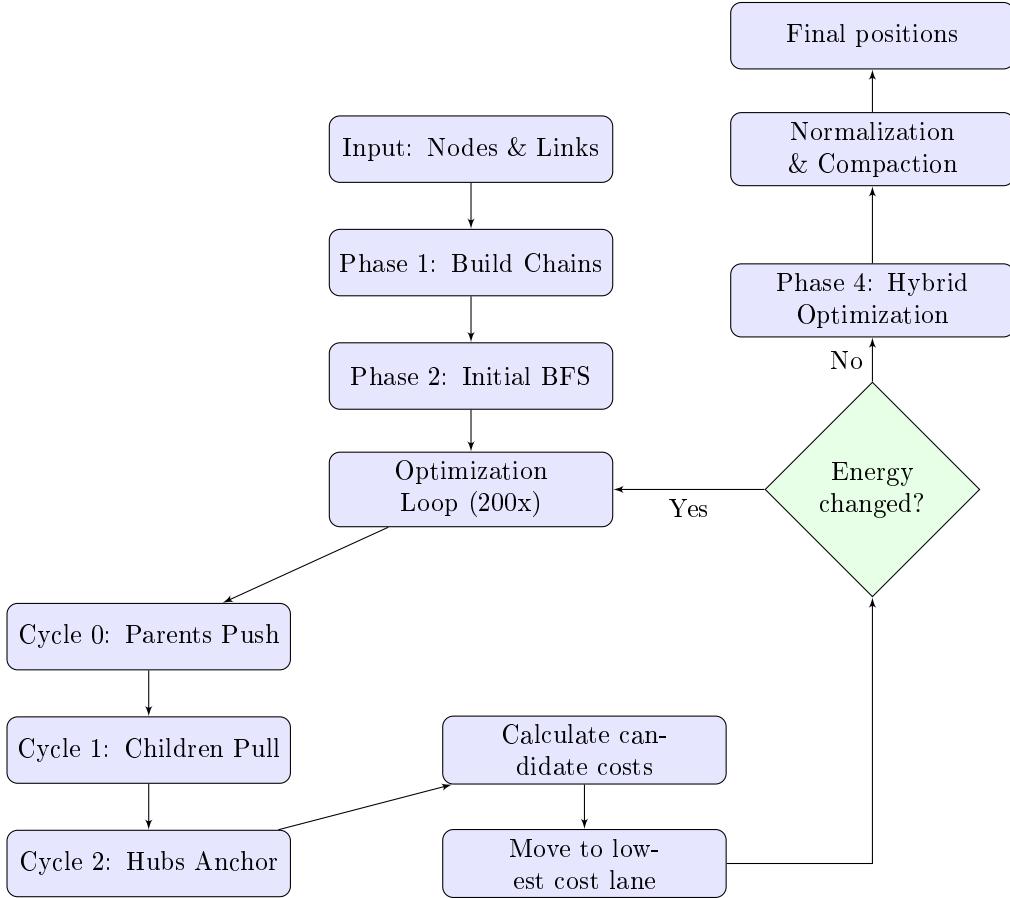


Figure 1: Layout Algorithm Pipeline

### 4 Phase 1: Chain Decomposition

**Goal:** Group nodes into rigid linear units that move together.

**Algorithm:**

1. Build predecessor/successor maps from links.
2. For each unvisited node:
  - (a) If it's a chain start (0 or  $> 1$  predecessors):
    - Walk forward following single successors.
    - Stop if: no successor,  $> 1$  successors, or temporal overlap.
    - Create chain from collected nodes.
  - (b) Mark all nodes in chain as visited.

### 5 Phase 2: Initial Placement

**Goal:** Create a starting layout using Breadth-First Search (BFS). Root chains are placed first (lane 0), then descendants are searched for the first available non-overlapping lane.

## 6 Phase 3: Optimization Loop

### 6.1 Iteration Strategy (Tri-State Cycle)

The loop alternates between three sorting strategies every iteration:

- **Cycle 0 - Parents Push:** Sort by *startTime* ASC.
- **Cycle 1 - Children Pull:** Sort by *startTime* DESC.
- **Cycle 2 - Hubs Anchor:** Sort by *degree* DESC.

### 6.2 Candidate Search Strategy

For each chain at current lane  $Y$ , the algorithm searches:

1. **Local Neighborhood:**  $Y \pm 50$  lanes.
2. **Parent Vicinity:**  $P \pm 10$  lanes.
3. **Child Vicinity:**  $C \pm 10$  lanes.

## 7 Phase 4: Hybrid Groupwise Optimization

**Goal:** Fine-tune the layout by optimizing entire family branches together.

After the main optimization loop (Phase 3) converges, an additional pass runs to fix local minima that individual chain moves couldn't resolve, such as "knots" or family blocks trapped in suboptimal global positions.

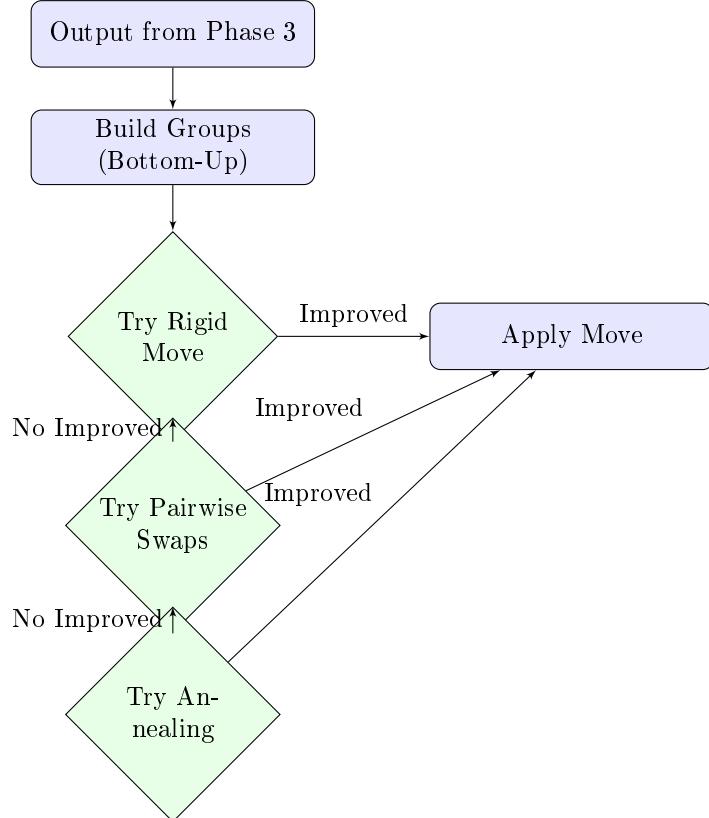


Figure 2: Hybrid Optimization Strategy

## 7.1 1. Build Groups (Bottom-Up)

Chains are grouped into tightly coupled “blocks” based on connectivity.

- **Start:** Leaf nodes or roots (low degree).
- **Grow:** Add connected parents/children using BFS.
- **Stop:** When the group reaches a natural boundary.

## 7.2 2. Strategy A: Rigid Group Move

**Concept:** Move the entire group ( $G$ ) up or down by  $\delta$  lanes without changing relative internal positions.

- **Search Space:**  $\pm 20$  lanes.
- **Constraint:** No chain in  $G$  can collide with a chain outside  $G$ .
- **Objective:** Find  $\delta$  that minimizes total global cost.
- **Why:** Fixes cases where a whole family branch is stuck “too high” or “too low” relative to its neighbors.

## 7.3 3. Strategy B: Pairwise Swaps

**Concept:** Swap the lanes of any two chains ( $A, B$ ) within the group.

- **Search Space:** All distinct pairs ( $A, B$ ) in  $G$ .
- **Constraint:** Swap is valid only if neither chain collides in its new position.
- **Objective:** Fix internal ordering issues (e.g., “crossing links”).

## 7.4 4. Strategy C: Simulated Annealing (Fallback)

**Concept:** If deterministic methods fail, use stochastic optimization to “shake” the group out of a local minimum.

- **Mechanism:** Propose random move, accept if better or probabilistically if worse ( $P = e^{-\Delta J/T}$ ).
- **Cooling:** Temperature decays geometrically ( $T_{k+1} = T_k \times 0.95$ ).
- **Why:** Resolves complex “tangles” needing multiple moves to escape.

# 8 Cost Function Details

The total cost  $J$  for a chain considering lane  $Y$  is:

$$J = C_{ATTR} + C_{CUT} + C_{BLOCK} + C_{SHARE} + C_{YSHAPE} \quad (3)$$

## 8.1 Attraction Cost ( $C_{ATTR}$ )

**Formula:**  $C_{ATTR} = W_{ATTR} \times (|Y - \mu_{parents}|^2 + |Y - \mu_{children}|^2)$

**Weight:** 100

**Example:** Chain at  $Y = 5$  with parents at average lane 3 and children at average lane 8.

$$C_{ATTR} = 100 \times ((5 - 3)^2 + (5 - 8)^2) = 100 \times (4 + 9) = 1,300.$$

## 8.2 Cut-Through Cost ( $C_{CUT}$ )

**Formula:**  $C_{CUT} = W_{CUT} \times (\text{Number of cuts})$

**Weight:** 10,000

**Example:** Chain Ceramica [2005–2010] at  $Y = 1$ . Segment LPR(0) → Tinkoff(2) at 2007.

$Y = 1$  is between 0 and 2; 2007 is within [2005, 2010]  $\implies$  1 cut.

$$C_{CUT} = 10,000 \times 1 = 10,000.$$

### 8.3 Blocker Cost ( $C_{BLOCK}$ )

**Formula:**  $C_{BLOCK} = W_{BLOCK} \times (\text{Number of segments blocked})$

**Weight:** 5,000

### 8.4 Lane Sharing Cost ( $C_{SHARE}$ )

**Formula:**  $C_{SHARE} = W_{SHARE} / \max(0.5, \Delta T)$

**Weight:** 0 (disabled)

**Strict Rule:** Strangers must have  $\geq 1$ -year gap or lane is forbidden. Family can overlap.

### 8.5 Y-Shape Symmetry Cost ( $C_{YSHAPE}$ )

**Formula:**  $C_{YSHAPE} = W_{YSHAPE} \times (\text{Number of violations})$

**Weight:** 150

## 9 Normalization & Compaction

1. **Normalization:**  $Y_{final} = Y - Y_{min}$ .
2. **Compaction:** Shift lanes to remove empty horizontal gaps.

## 10 Configuration Parameters

```
1 export const LAYOUT_CONFIG = {
2   HYBRID_MODE: true,
3   ITERATIONS: { MIN: 20, MAX: 100, MULTIPLIER: 5 },
4   SEARCH_RADIUS: 50,
5   TARGET_RADIUS: 10,
6   GROUPWISE: {
7     MAX_RIGID_DELTA: 20,
8     SA_MAX_ITER: 50,
9     SA_INITIAL_TEMP: 100
10   },
11   WEIGHTS: {
12     ATTRACTION: 100.0,
13     CUT_THROUGH: 10000.0,
14     BLOCKER: 5000.0,
15     LANE_SHARING: 0.0,           // Disabled
16     Y_SHAPE: 150.0
17   }
18 };
```

## 11 Known Limitations

- **Local Optimization:** Greedy nature can lead to jitter or local minima.
- **Asymmetric Penalties:** Mover pays the cost, potentially causing chains to "flee" each other.
- **Temporal Overlap Edge Cases:** Inclusive comparison ( $\geq$ ) prevents touch points.

## 12 Debugging Tips

- **Visualizing Costs:** Log output of `calculateCost` for specific node IDs.
- **Tracing Moves:** Log source and target lanes during optimization iterations.

## 13 Glossary

- **Node:** A single team with founding/dissolution years.
- **Chain:** Linear sequence of nodes with no temporal overlap.
- **Lane:** Horizontal swimlane (Y-coordinate).
- **Link:** Connection between two nodes (parent→child).
- **Vertical Segment:** Portion of a link crossing intermediate lanes.
- **Cut-Through:** Node sitting in a lane crossed by another family's link.
- **Blocker:** Node blocks another family's vertical link.