Spatial Programming for Musical Representation and Analysis

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mgs.spatial-computing.org

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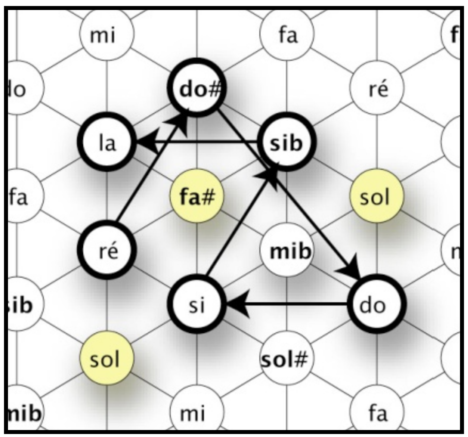
Context

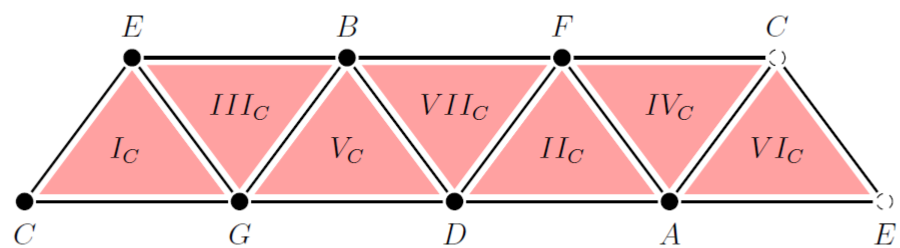
- Spatial computing
  - Compute in space
  - Compute space
- MGS: a programming language for spatial computing
  - Introduction of topological concepts in a programming language
  - Two main principles
    - Data structure: topological collection
    - Control structure: transformation
- Musical analysis

Outline

- Background on MGS spatial-computing
- Music and spatial computing



Space for musical representation



Space as musical representation

- Conclusion

Outline

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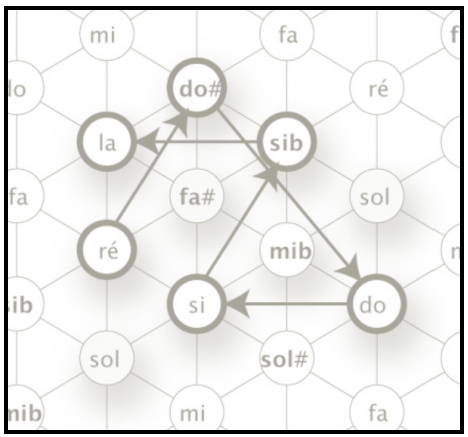

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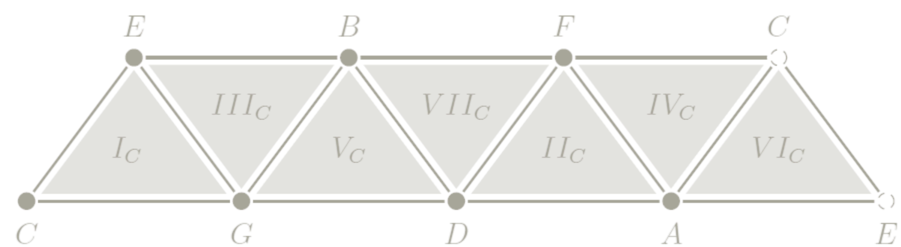
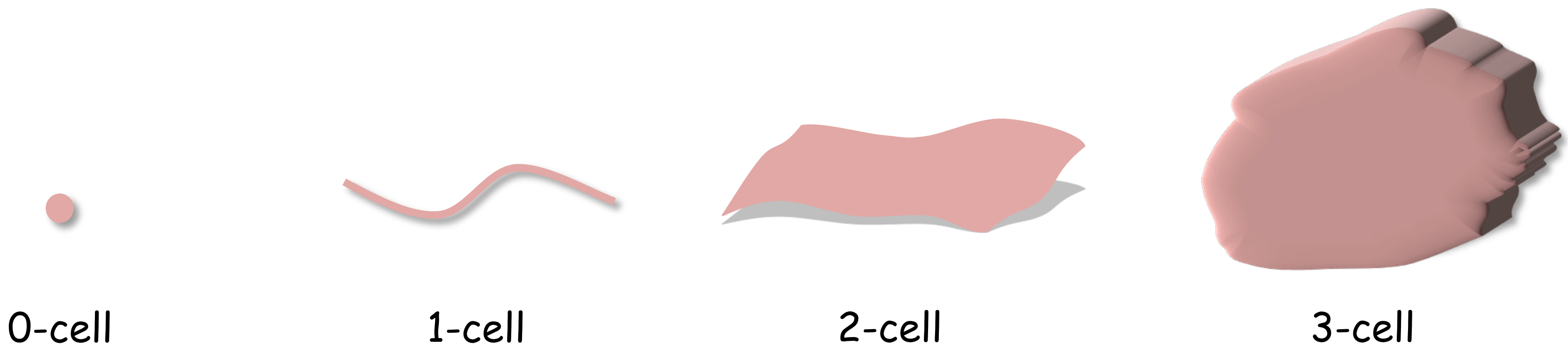


Space as musical representation

- Conclusion

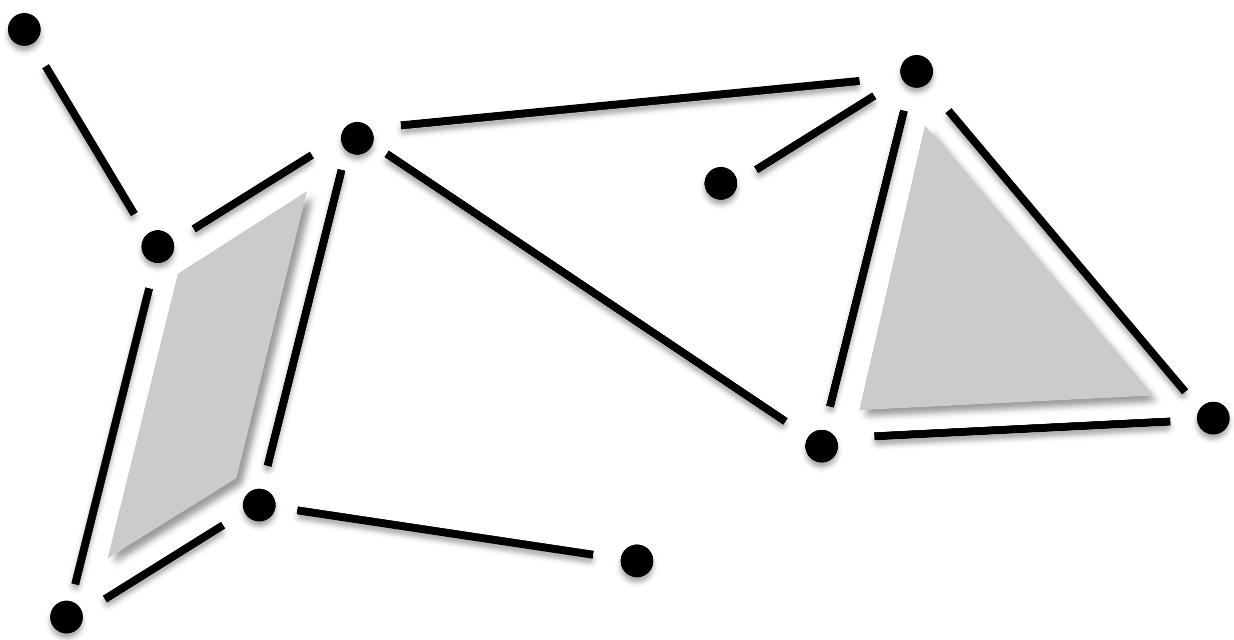
MGS Main Concepts

- Topological collections
  - Structure
    - A collection of ***topological cells***



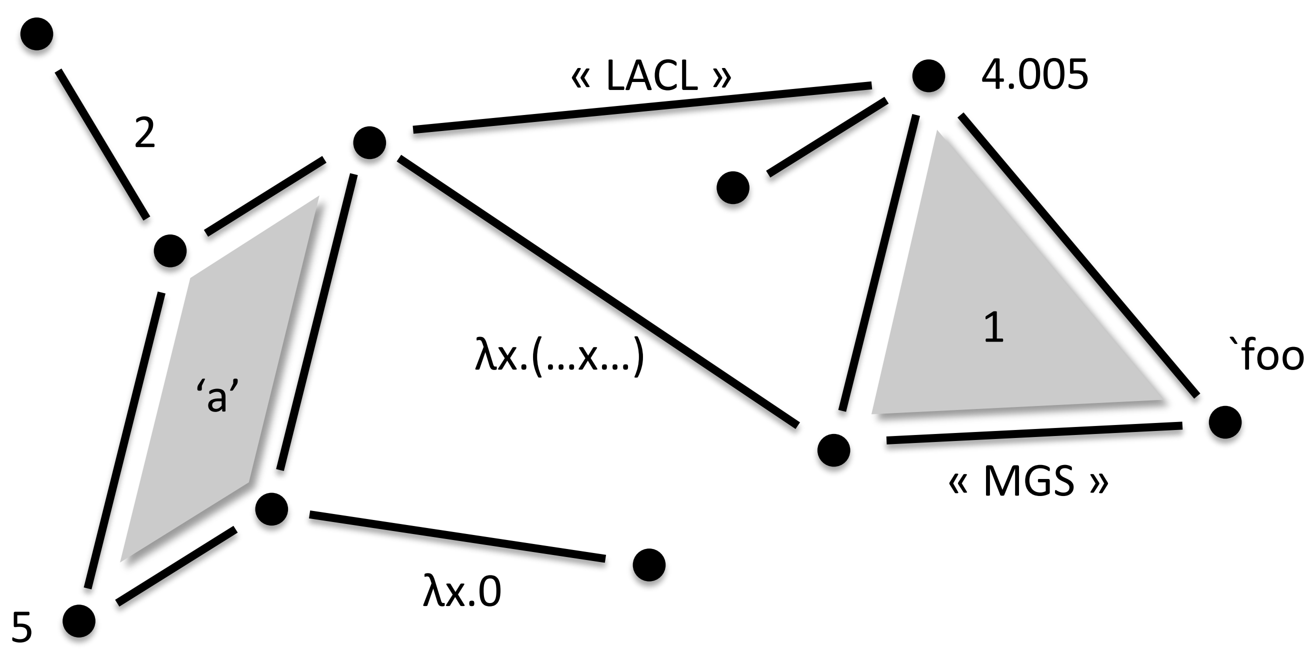
MGS Main Concepts

- Topological collections
  - Structure
    - A collection of topological cells
    - An ***incidence relationship***



MGS Main Concepts

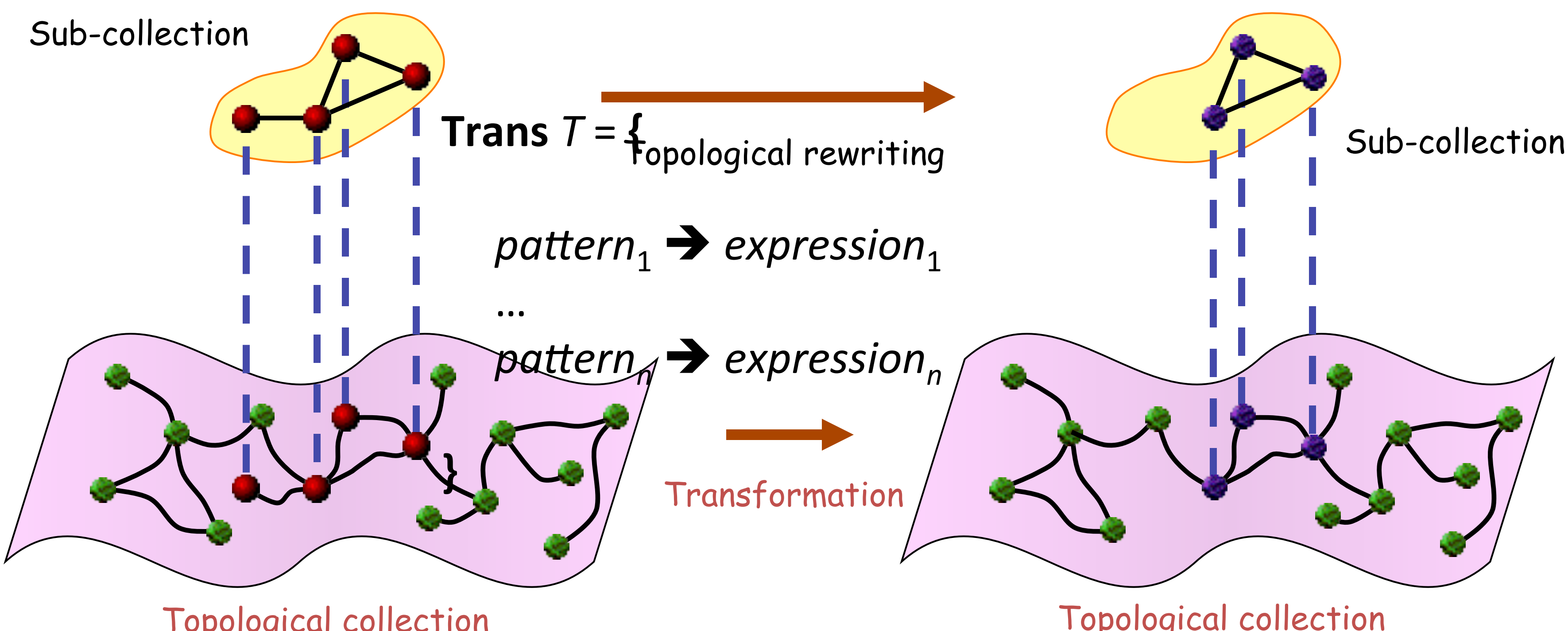
- Topological collections
  - Structure
    - A collection of topological cells
    - An incidence relationship
  - Data: **association of a value with each cell**



MGS Main Concepts

- Transformations
  - Functions defined by case on collections

    Each case (pattern) matches a sub-collection
  - Defining a rewriting relationship: ***topological rewriting***



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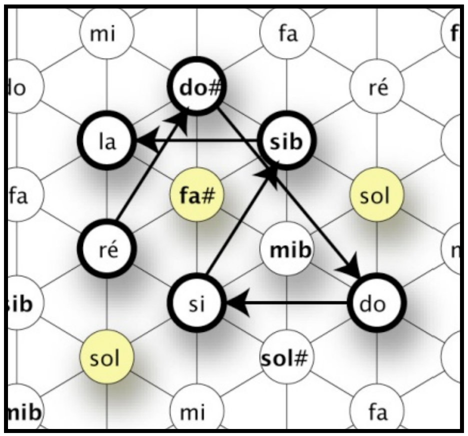
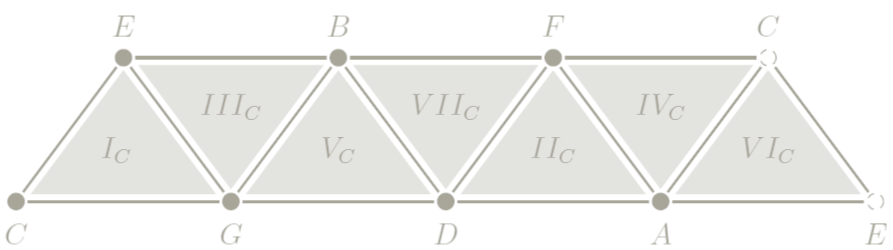
- Music and spatial computing



Space for musical representation



Space as musical representation

- Conclusion

Neo-Riemannian Problematic

- Traditional western music representation
  - Based on the use of a *staff*
  - Main drawbacks for visualization of harmony
    - *Contrapuntal* proximity

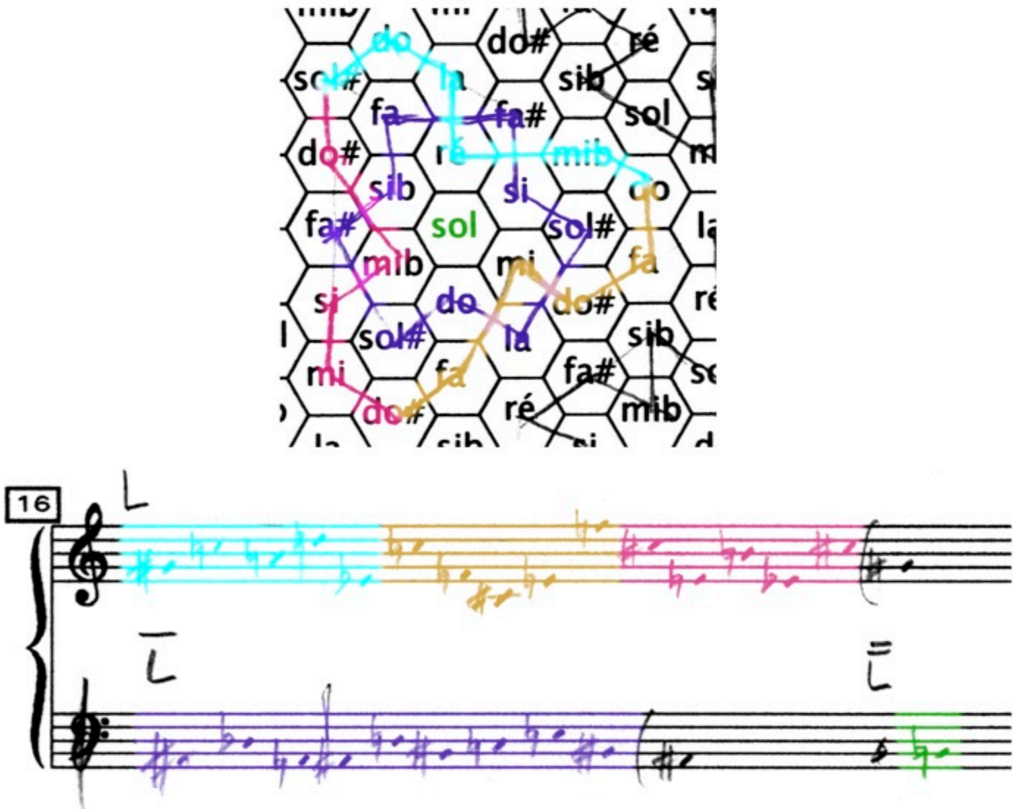
      The spatial distance between notes is not relevant for harmonic purpose
    - Spatially close patterns can sound very different

- Neo-Riemannian representation of music
  - Graphical representation of harmony rules
  - Consonance used as a graphical criterion

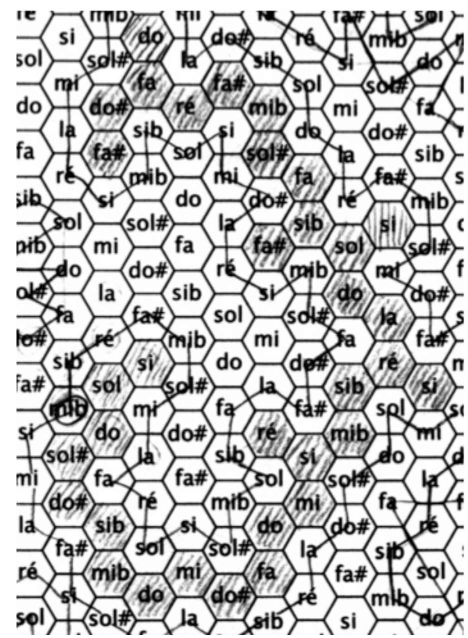
    Two notes that sound well must be spatially close

Neo-Riemannian Problematic

- Musical composition (J.-M. Chouvel)



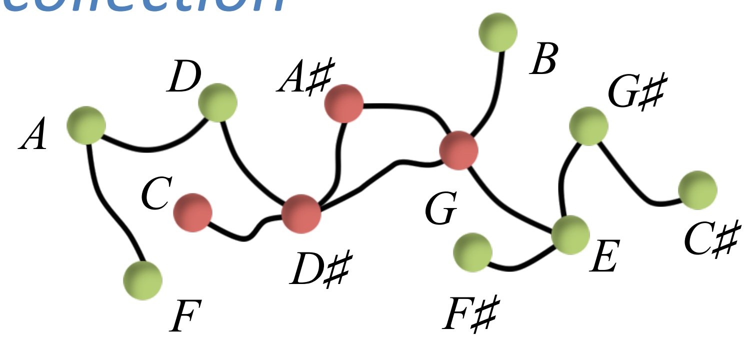
Musical segments as successive transformations of a shape in the lattice



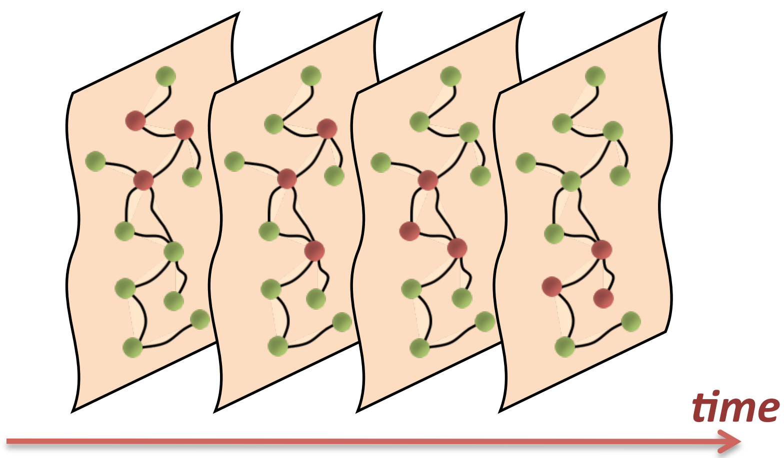
Musical melody as a path in the lattice

Spatial Representation of Musical Sequences

- Temporal succession of musical events
- Musical event as a *topological collection*
  - Positions are notes
  - Labels represent played notes



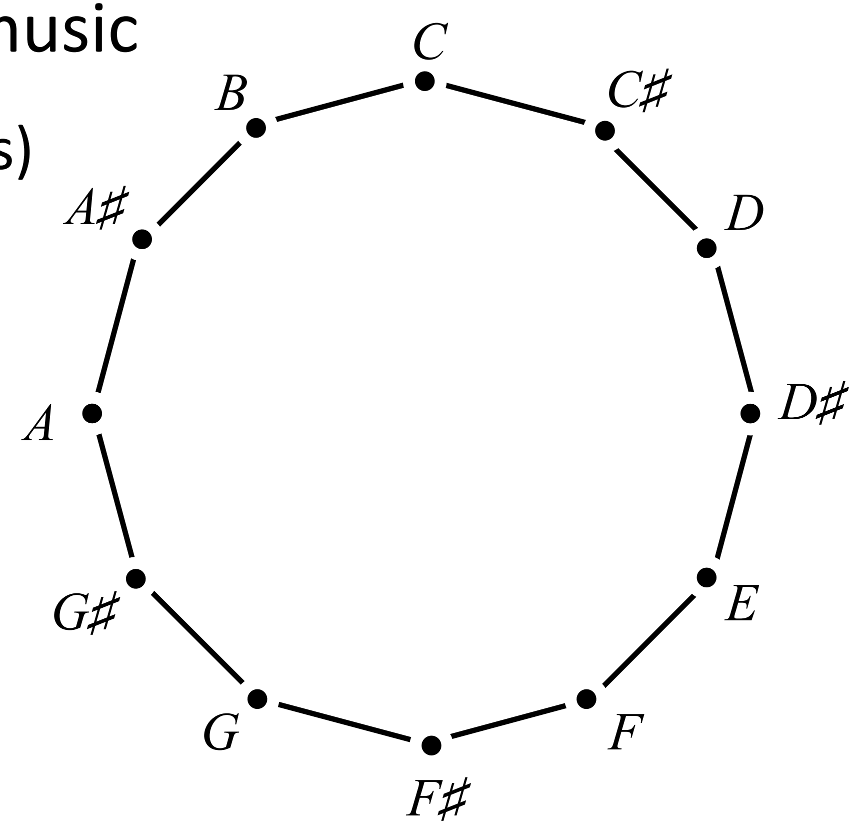
- Succession of events as a *stream of collections*



Extract of the 2nd movement of the Symphony No. 9 (L. van Beethoven)

Formalization of Notes Neighborhoods

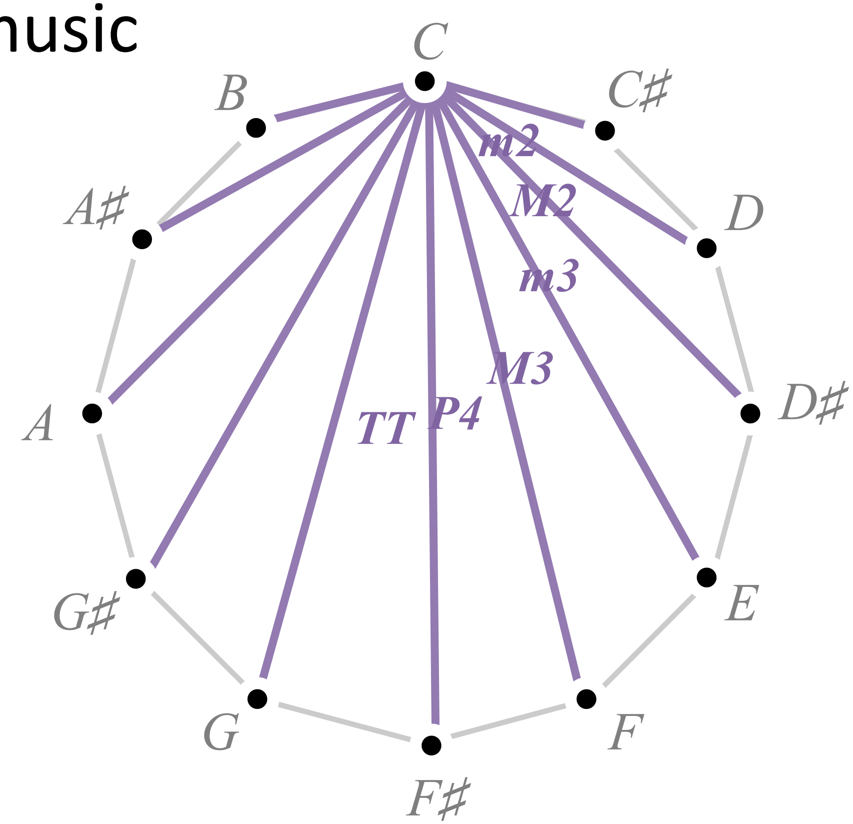
- Which neighborhoods for significant visualization?
- Strong algebraic structure of music
  - Set $\mathcal{N}$ of notes (i.e. pitch classes)
    We do not consider octaves



$$\mathcal{N} = \{\ C,\ C\#,\ D,\ D\#,\ E,\ F,\ F\#,\ G,\ G\#,\ A,\ A\#,\ B\ \}$$

Formalization of Notes Neighborhoods

- Which neighborhoods for significant visualization?
- Strong algebraic structure of music
  - Set $\mathcal{N} = \{ C, C\sharp, \ldots, A\sharp, B \}$
  - Group $(\mathcal{I},+)$ of intervals
    - Relative difference between notes

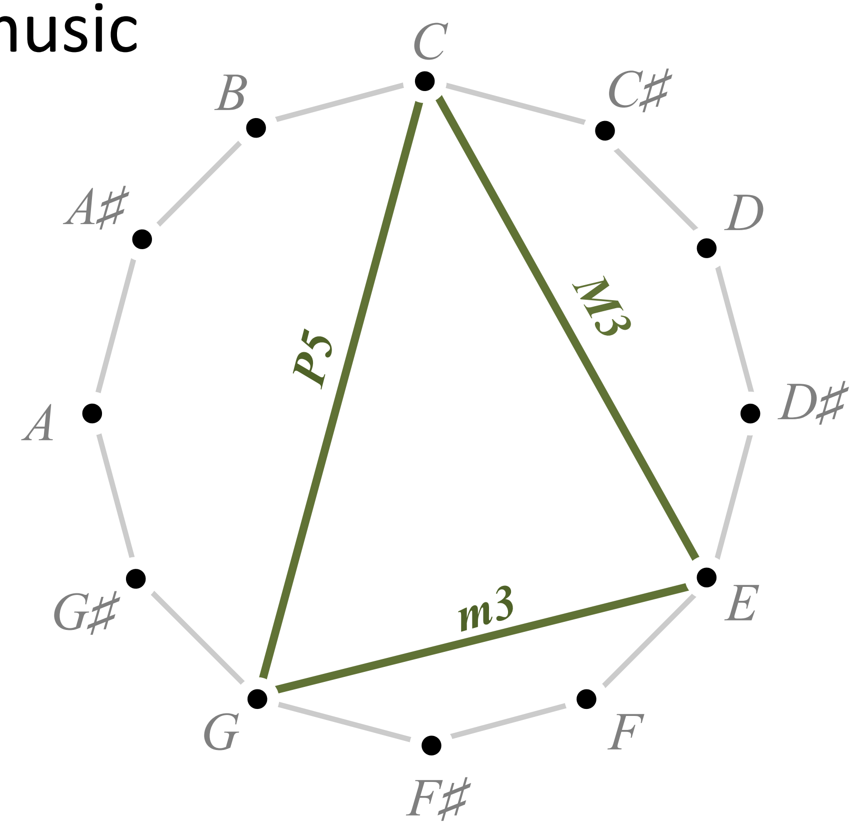


$$\mathcal{I} = \{ P1, m2, M2, m3, M3, P4, TT, P5, m6, M6, m7, M7 \}$$

Formalization of Notes Neighborhoods

- Which neighborhoods for significant visualization?
- Strong algebraic structure of music
  - Set $\mathcal{N} = \{ C, C\sharp, \ldots, A\sharp, B \}$
  - Group $(\mathcal{I},+)$ of intervals
    - Relative difference between notes
    - $(\mathcal{I},+) \cong (\mathcal{Z}_{12},+)$ (isomorphism)
    - Example

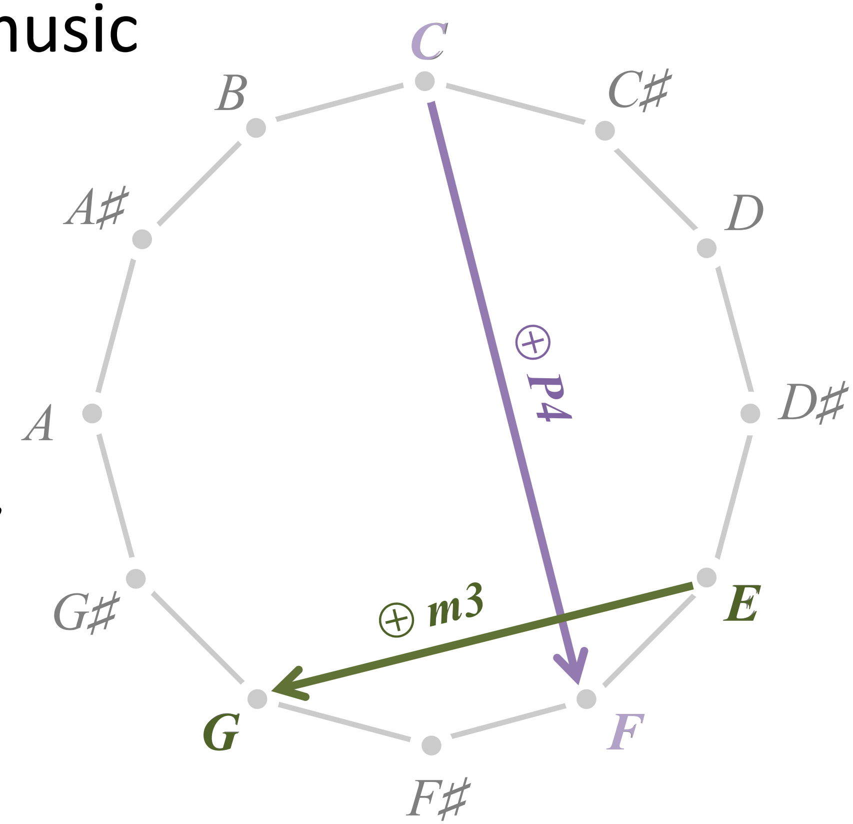
      $M3 + m3 = P5$



$$\mathcal{I} = \{ P1, m2, M2, m3, M3, P4, TT, P5, m6, M6, m7, M7 \}$$

Formalization of Notes Neighborhoods

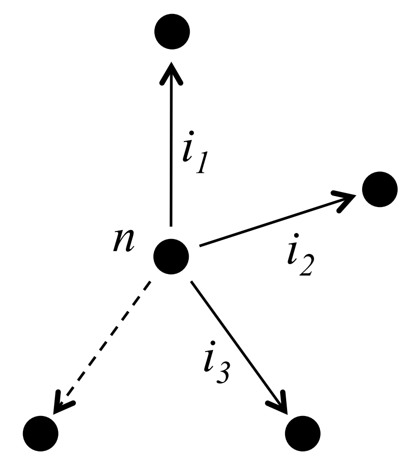
- Which neighborhoods for significant visualization?
- Strong algebraic structure of music
  - Set $\mathcal{N} = \{ C, C\sharp, \ldots, A\sharp, B \}$
  - Group $(\mathcal{I},+) = \{ P1, \ldots, M7 \}$
  - Transposition $\oplus$ of notes
    - $n \oplus i = n'$
      if i is the interval between n and n'
    - Example
      - $C \oplus P4 = F$
      - $E \oplus m3 = G$



$\oplus$ action of $\mathcal{I}$ over $\mathcal{N}$

Formalization of Notes Neighborhoods

- Consonance as a neighborhood relationship
  - $S \subset \mathcal{N} \times \mathcal{N}$
  - $(n_1, n_2) \in S$ if n_1 “sounds well” with n_2
- Assumptions on S
  - S is symmetric
    - $(n_1, n_2) \in S \Rightarrow (n_2, n_1) \in S$
  - S is defined up to a transposition
    - $\forall i \in \mathcal{I}, \quad (n_1, n_2) \in S \Rightarrow (n_1 \oplus i, n_2 \oplus i) \in \mathrm{S}$
    - (C, G) sounds well $\Rightarrow$ $(E = C \oplus M3, B = G \oplus M3)$ sounds well
- S characterized by a subset I of $\mathcal{I}$
    - $I = \{ i_1, i_2, \ldots, i_n \}$
    - $\forall n \in \mathrm{N}, \forall \mathrm{i} \in I, \quad (n, n \oplus i) \in S$



Formalization of Notes Neighborhoods

- Spatial representation of S
  - I as a set of group generators
    - $< I >$ subgroup of $\mathcal{I}$ generated by the elements of I
    - Example $I = \{ M2 \}$

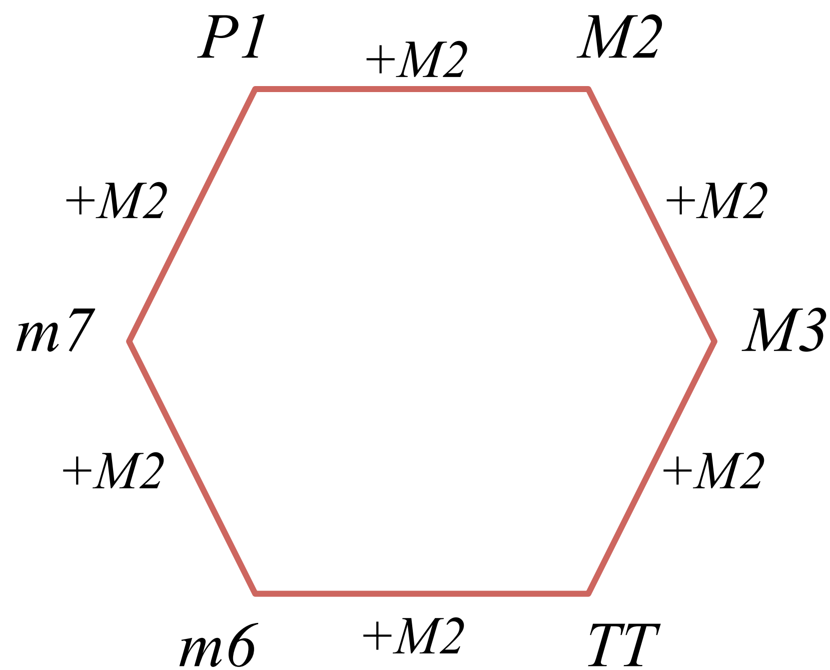
$$S = \{ (C,D), (C\#,D\#), \ldots \}$$

$$I = \{ M2 \}$$

$$\begin{aligned} < I > &= \{ P1, P1 + M2, P1 + 2.M2, \ldots \} \\ &= \{ P1, M2, M3, TT, m6, m7 \} \end{aligned}$$

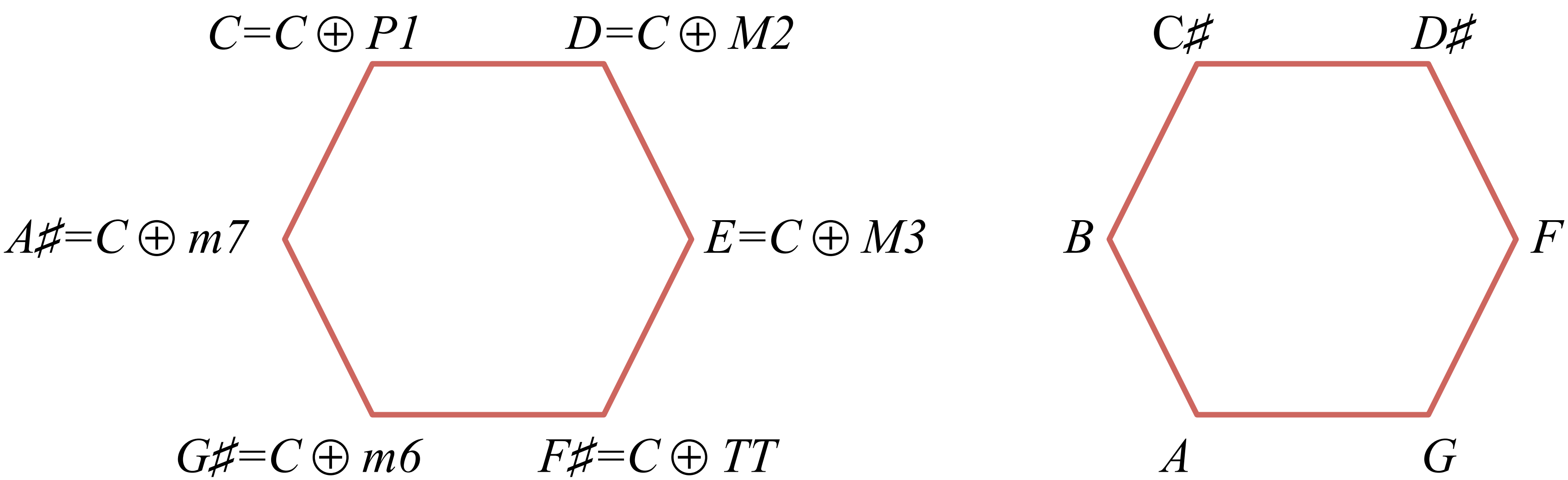
Formalization of Notes Neighborhoods

- Spatial representation of S
  - I as a set of group generators
  - Graph representation of $< I >$
    - Cayley's graph
      - Vertices: intervals of $< I >$
      - Edges: generators of I
    - Example with $I = \{ M2 \}$



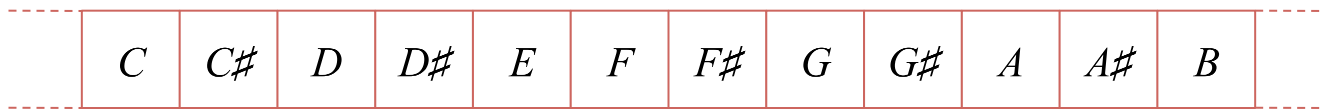
Formalization of Notes Neighborhoods

- Spatial representation of S
  - I as a set of group generators
  - Graph representation of $< I >$
  - Representation of S based on Cayley graph
    - Action of $< I >$ on N
    - Example with $I = \{\ M2\ \}$

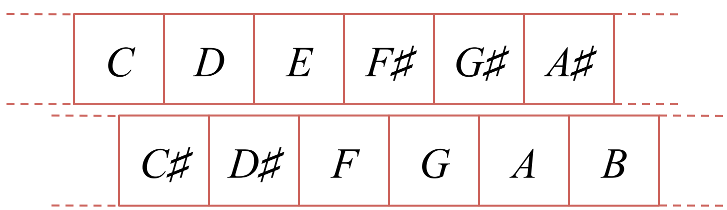


Applications

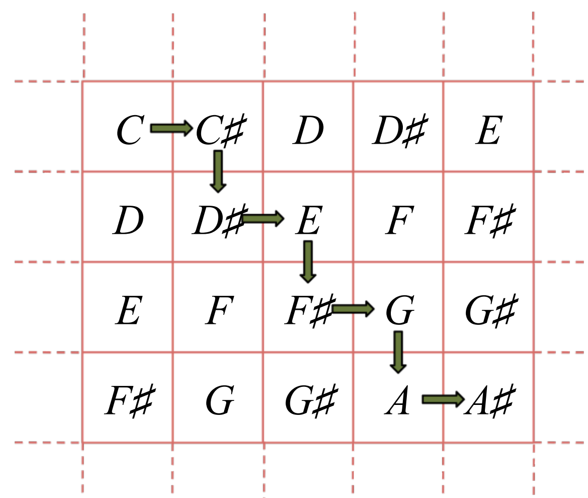
- Scale representations
  - Chromatic scale $I = \{ m2 \}$



  - Whole-tone scale $I = \{ M2 \}$

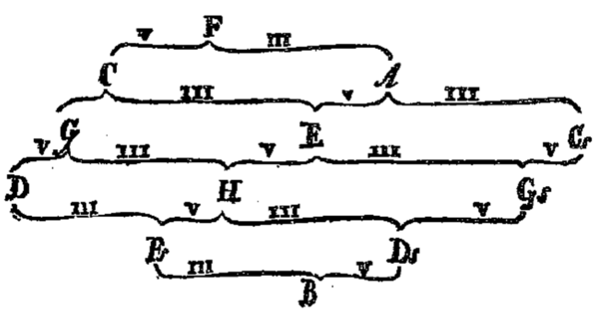


  - Diminished scale $I = \{ m2, M2 \}$

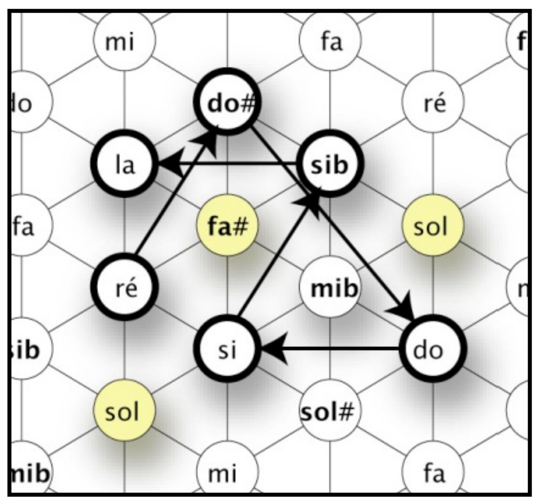


Applications

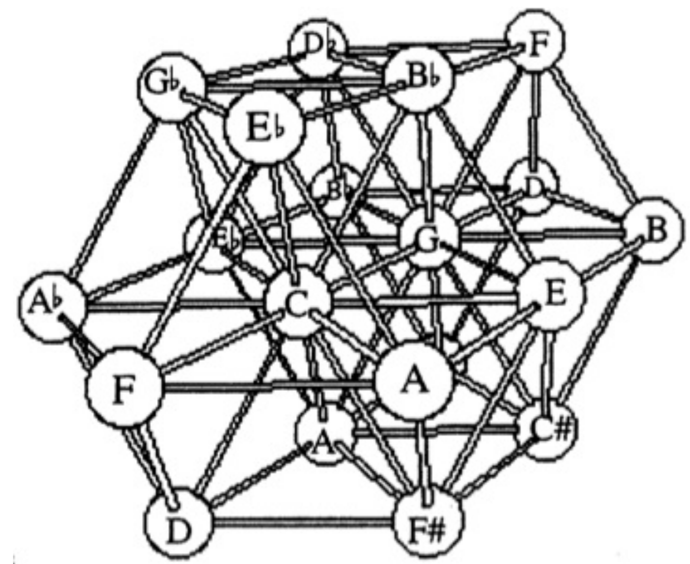
- Traditional harmony representation
  - $I = \{\ M3,\ P5\ \}$ (Euler's Tonnetz)
  - $I = \{\ m3,\ M3,\ P5\ \}$ (Harmonic table)
  - $I = \{\ m3,\ M3,\ P5,\ m7\ \}$ (3D-Tonnetz)



(Euler)



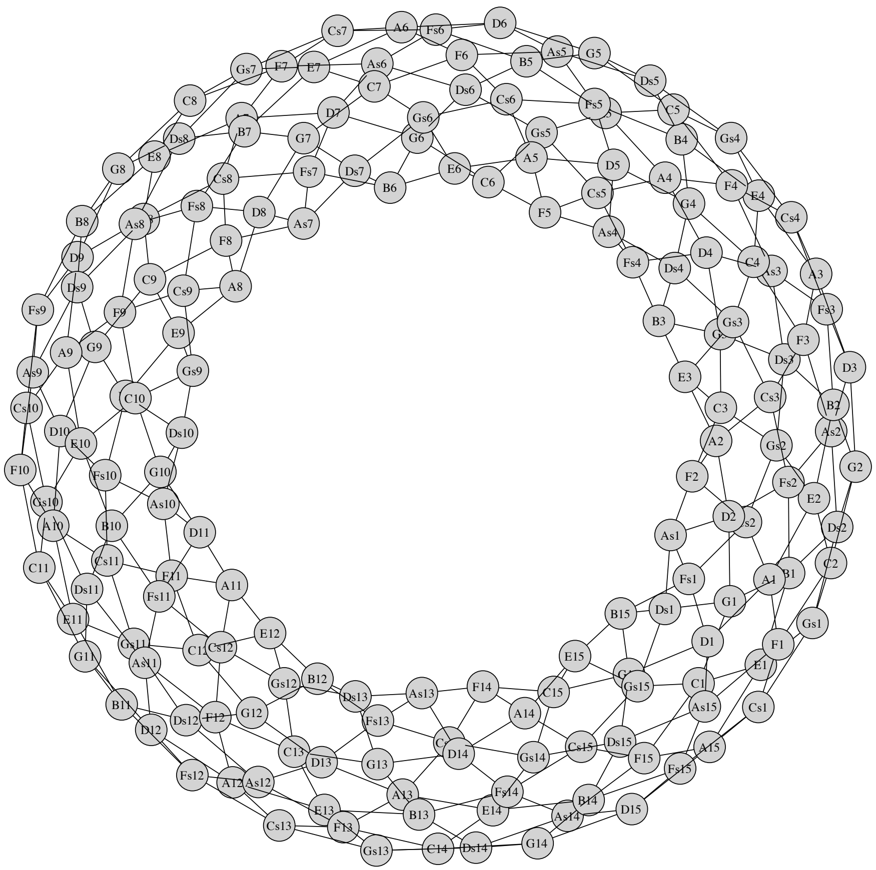
(J.-M. Chouvel)



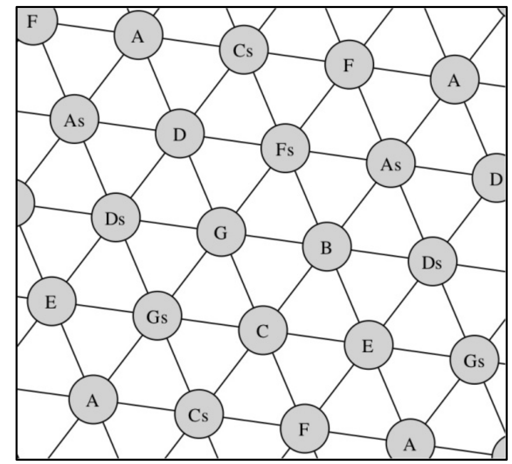
(E. Gollin)

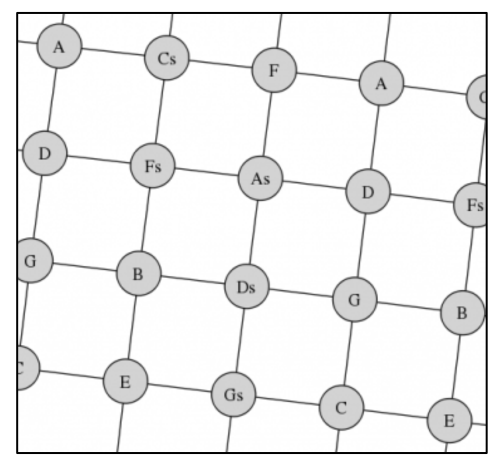
Applications

- Automatic graph generation



unfolding





Applications

- Instruments conception

$I = \{ m2, P4 \}$ (Guitar)

$I = \{ m2, P5 \}$ (Violin)

$I = \{ m2, M2, m3 \}$ (Accordion)

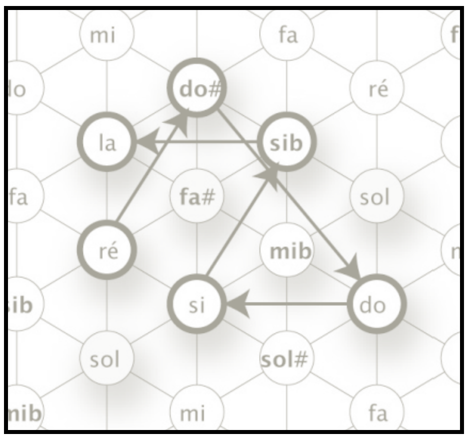
Applications

- Analysis example
  - Signature of a piece
  - Example : F. Chopin Prelude

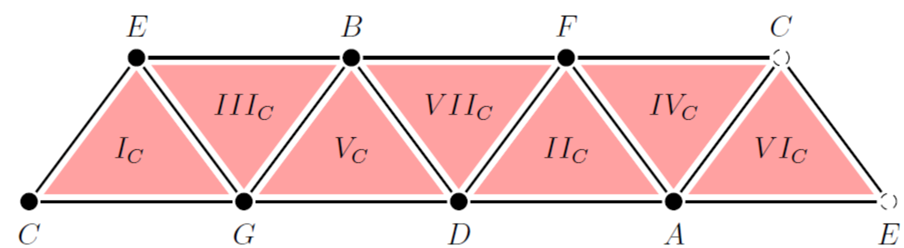
Extract of the Prelude N.4
Op28 of F. Chopin

Outline

- Background on MGS spatial-computing
- Music and spatial computing



Space for musical representation

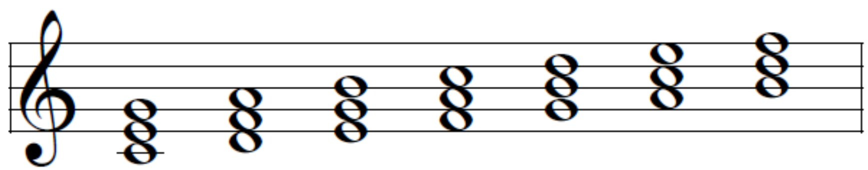


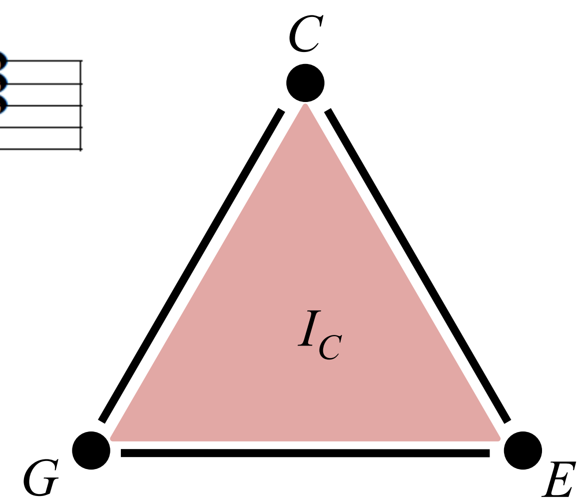
Space as musical representation

- Conclusion

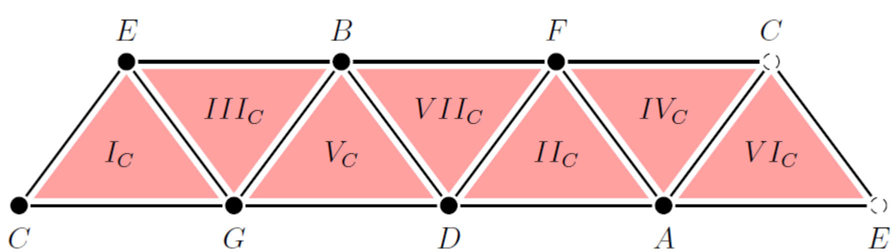
Tonality and Möbius Strip

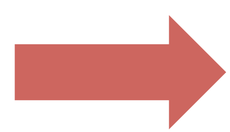
- Motivation: spatial visualization of tonality
- Association of a chord set with the tonality: the *degrees*
  - Example: C-major tonality

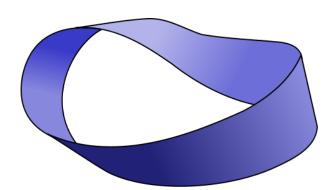




- Spatial representations
  - Note = vertex
  - Chord = surface
- Fusion of the common notes for the 7 degrees



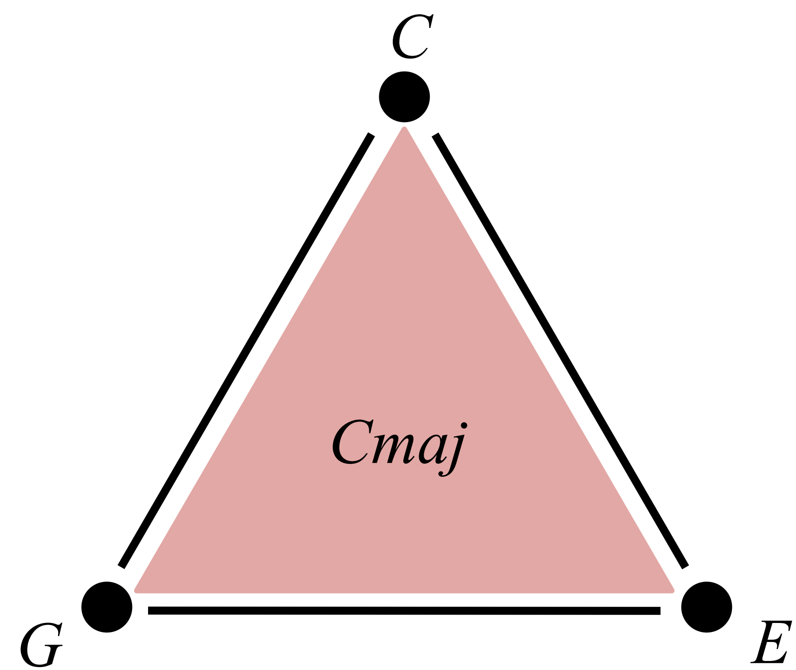




[Mazzola02]

Self-Assembly of Chords

- Automation of the process for the analysis of other chords sequences
- *Reaction* of the chords between themselves
- Simplicial representation of musical objects
  - Note: 0-simplex
  - 2-note chord: 1-simplex
  - 3-note chord: 2-simplex



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  - Note: 0-simplex
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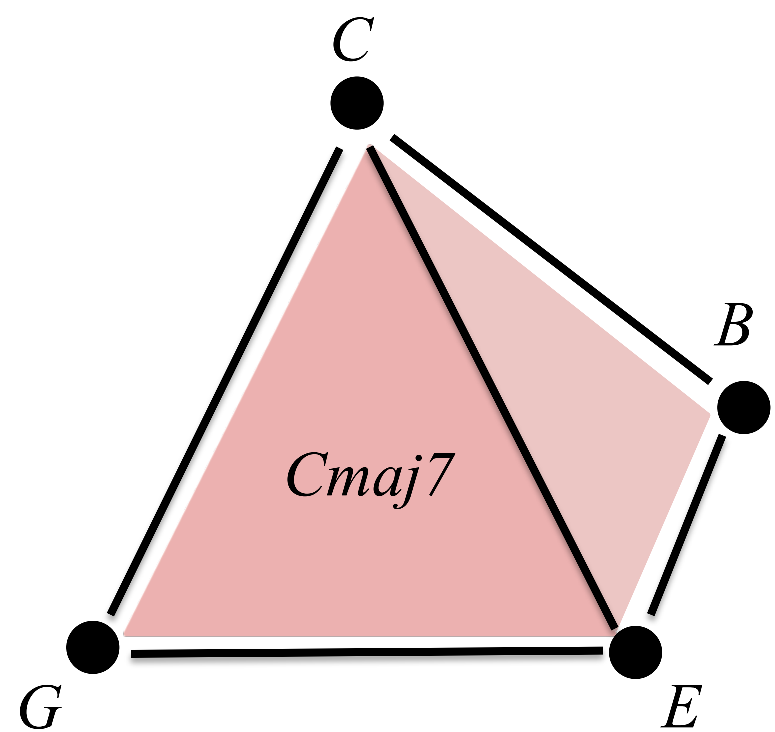
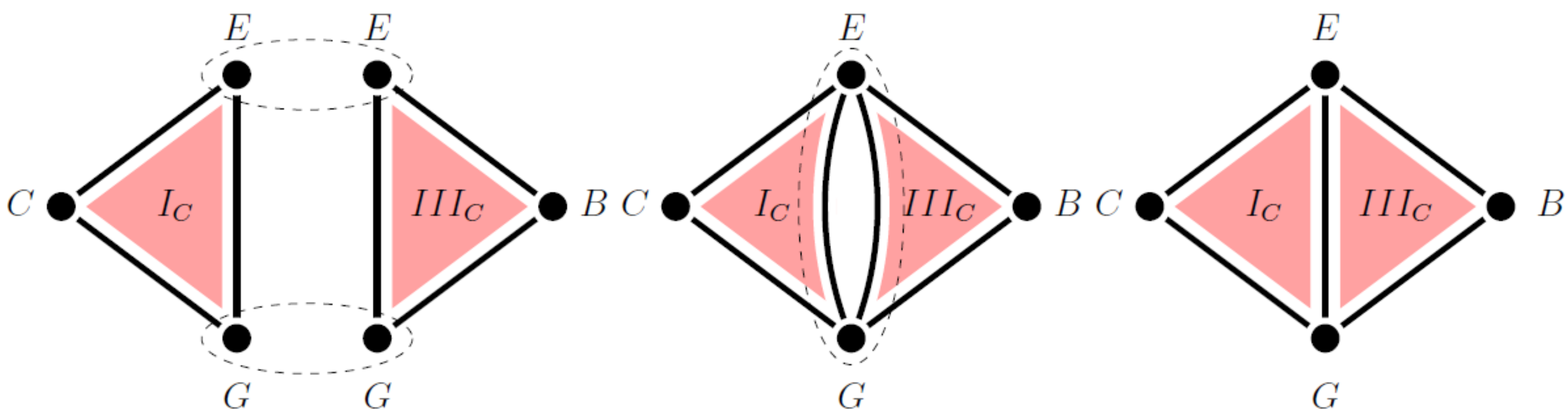
  - 3-note chord: 2-simplex
  - 4-note chord: 3-simplex



Self-Assembly of Chords

- MGS transformation for self-assembly process

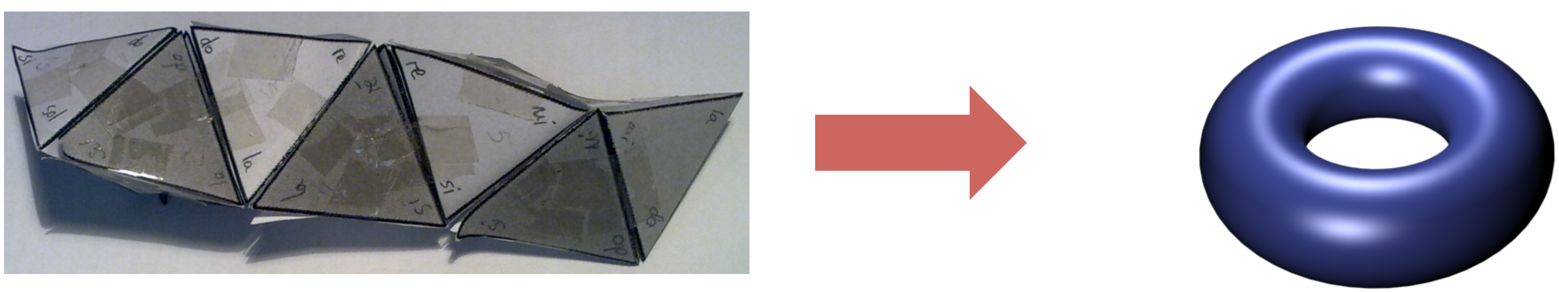



```
Trans identification = {
  s1 s2 / (s1 == s2 & (faces s1) == (faces s2))
    =>
      let c = new_cell (dim s1)
                       (faces s1)
                       (union (cofaces s1)
                              (cofaces s2))
      in s1 * c
}
```

Applications

- Four-note degrees of C-major tonality

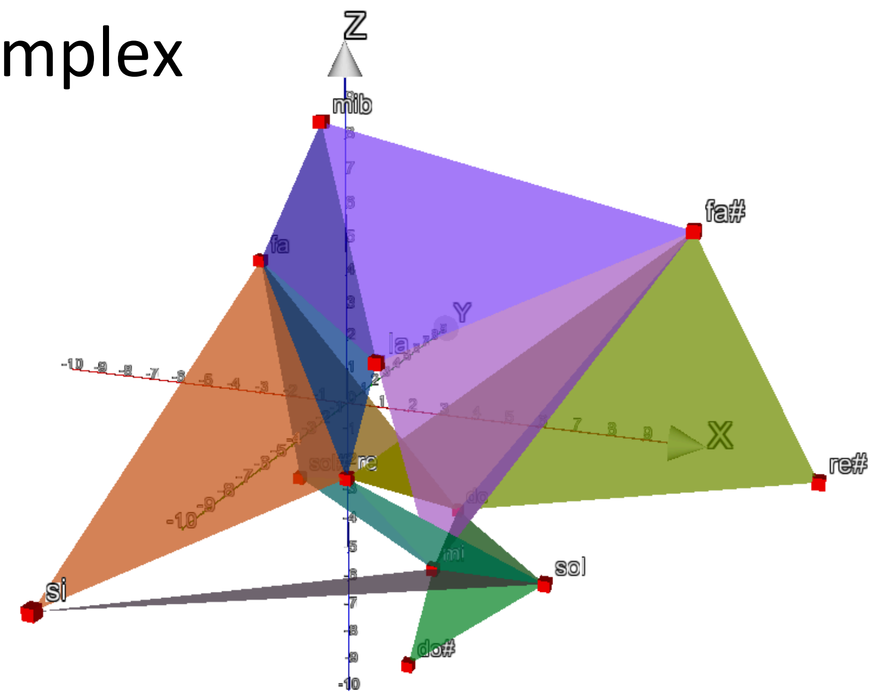
- Chord = 3-simplex (tetrahedrons)
- Self-assembly



Applications

- Extract of the Prelude No. 4 Op. 28 of F. Chopin

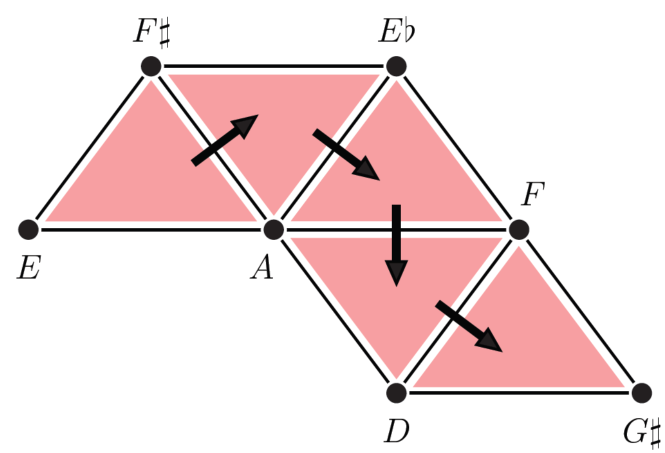
- Simplicial complex



Applications

- Extract of the Prelude No. 4 Op. 28 of F. Chopin

- Analysis of the path under the chords



- The path chosen by F. Chopin is associated with the smallest movements on the chords

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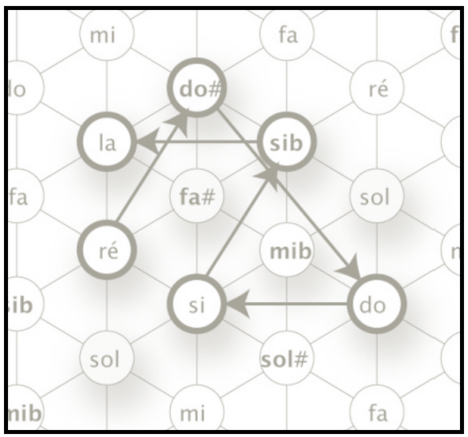
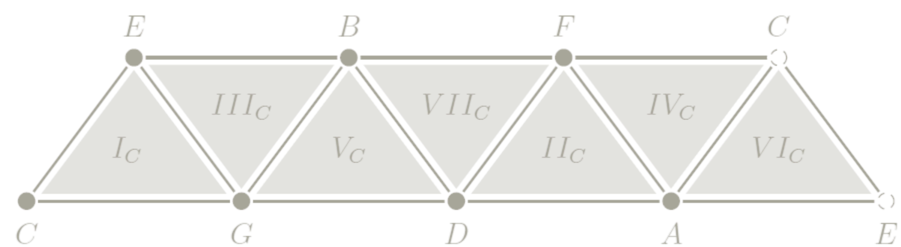


Space for musical representation



Space as musical representation

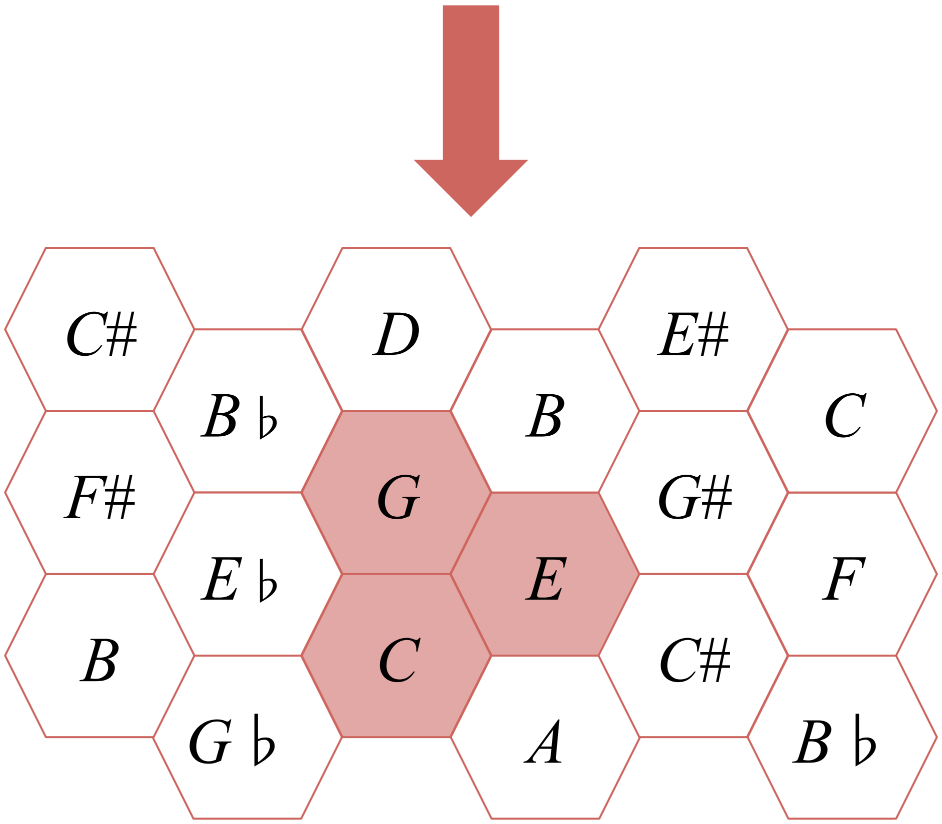
- Conclusion

Conclusion & Perspectives

- Preliminary work
- Strong collaborations with composers / musicologists
- Extend the validation on more musical problems
  - Spatial representations of other musical properties (timbre, rythm, fingering etc.)
- Extension to study musical styles
- Spatial properties ⇔ musical properties
- Acknowledgements

Jean-Louis Giavitto, Moreno Andreatta, Carlos Agon,
Jean-Marc Chouvel

Extract of the 2nd movement of the Symphony No. 9 (L. van Beethoven)



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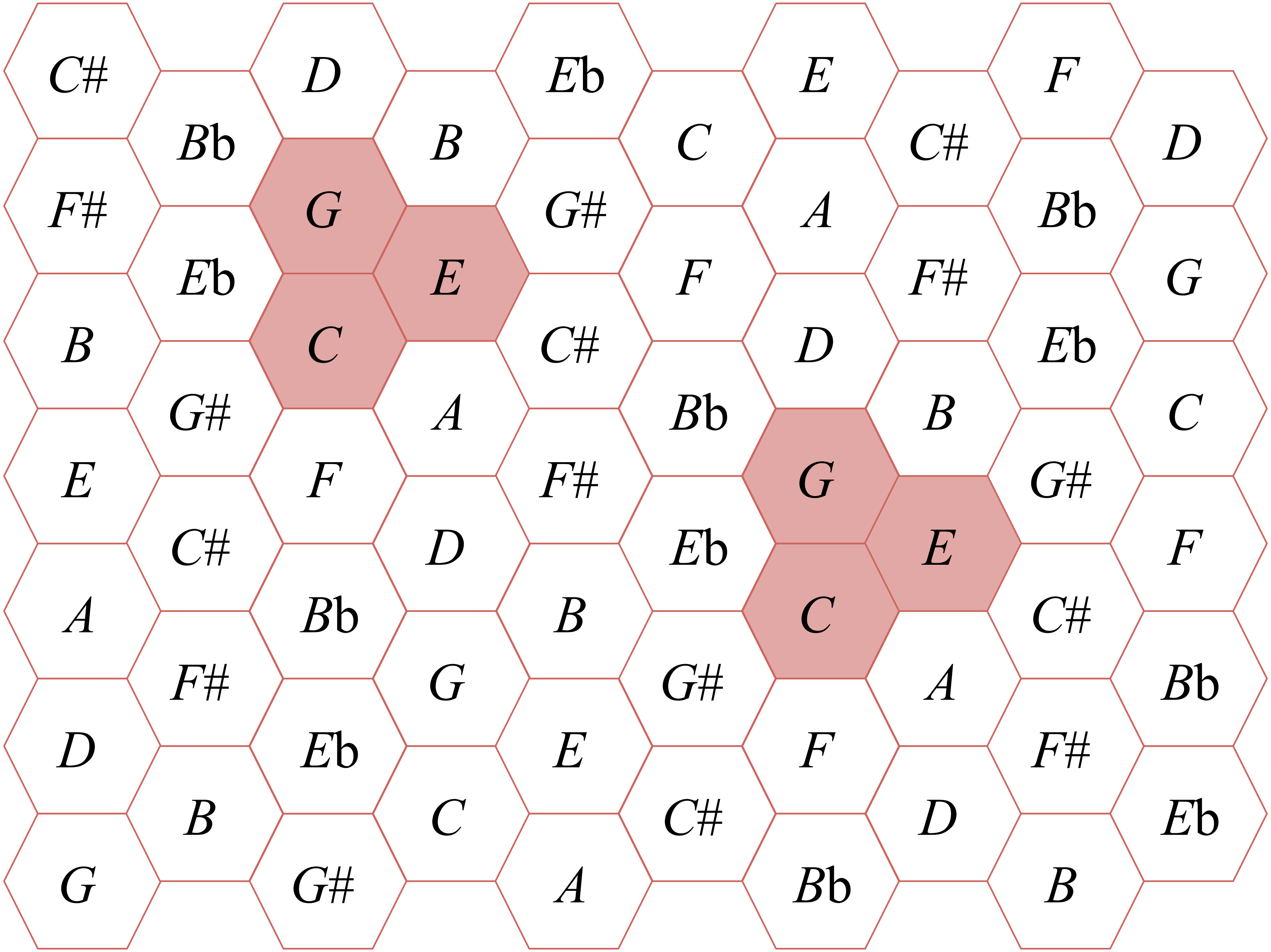

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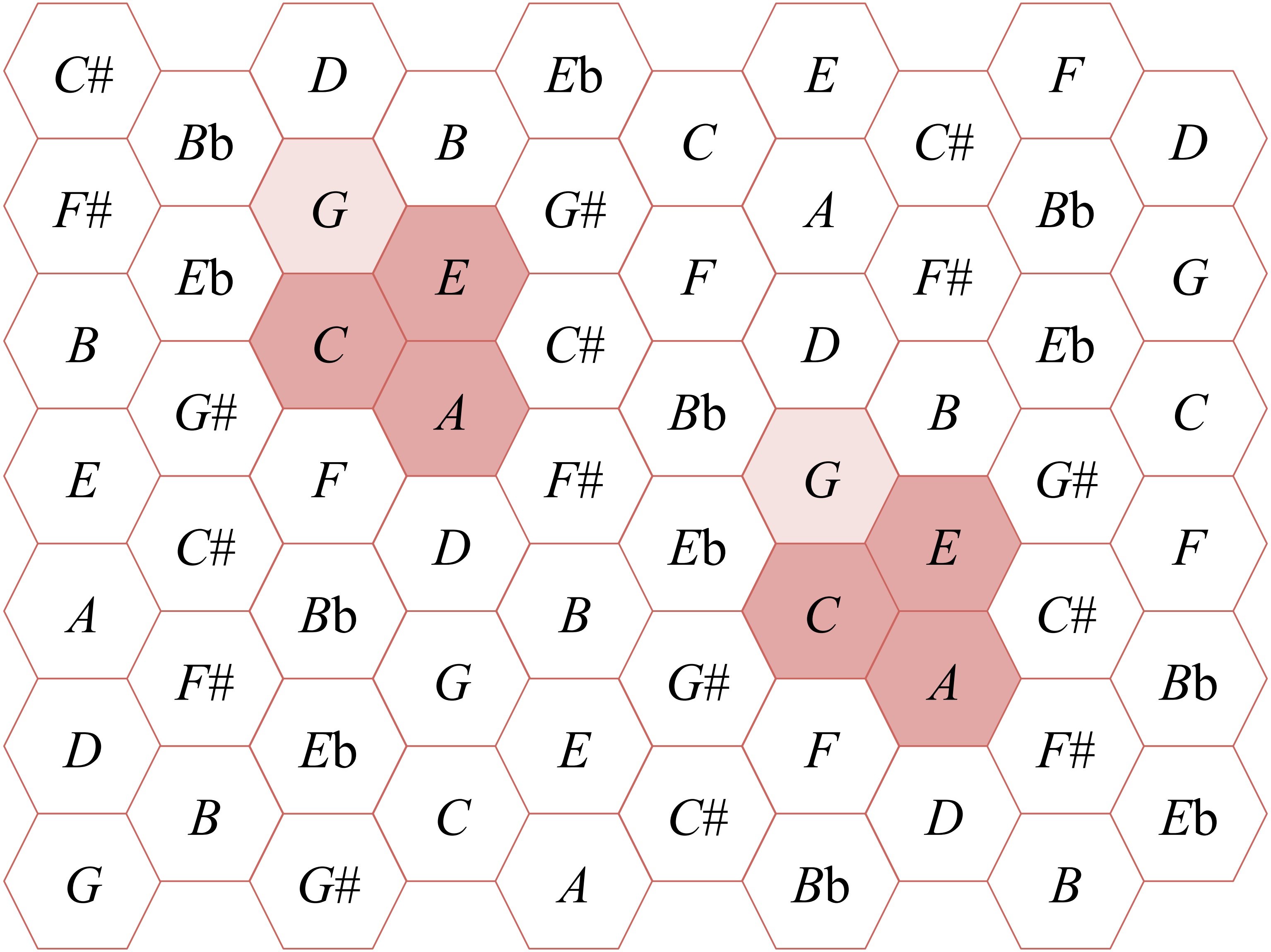

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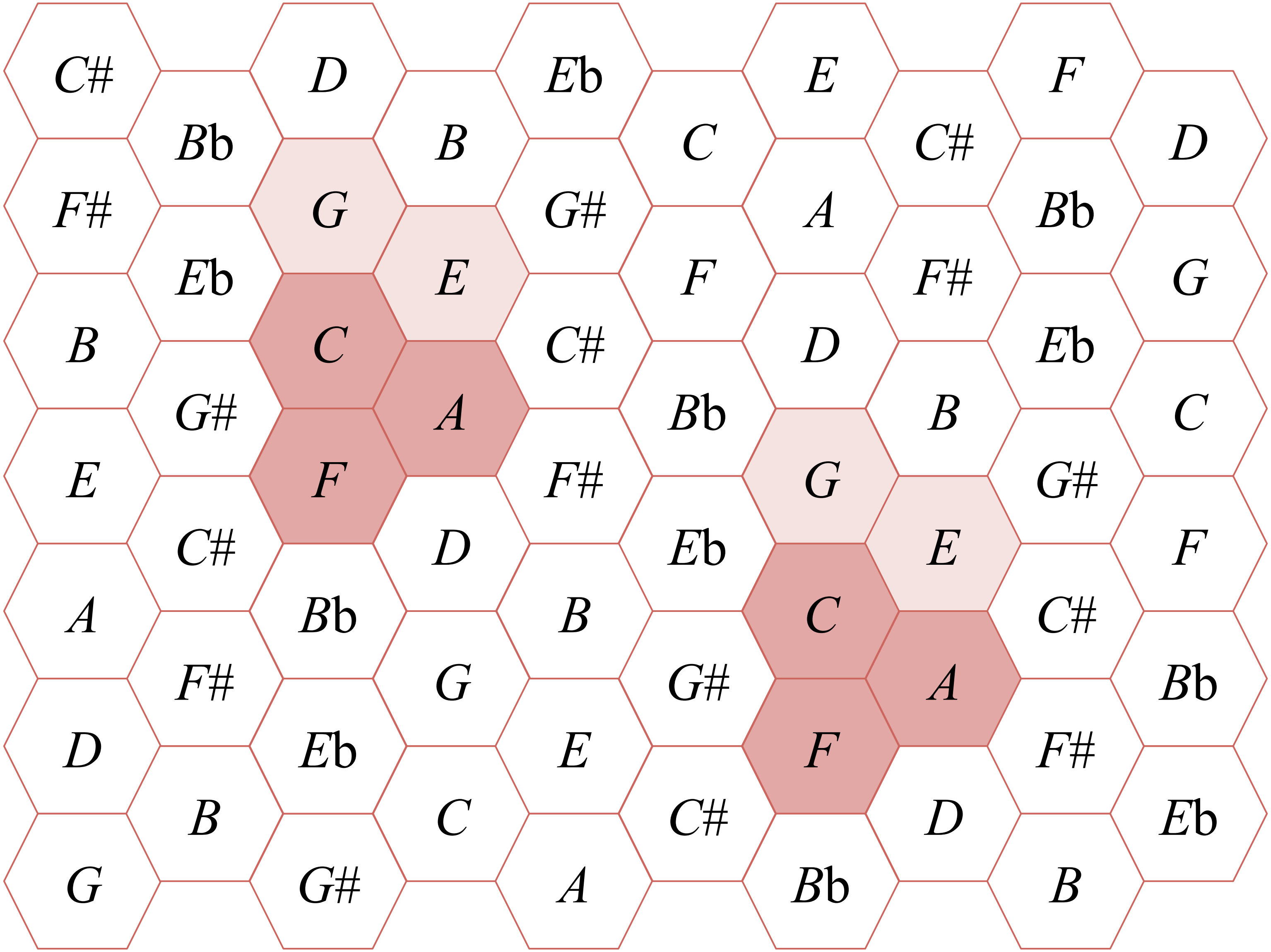

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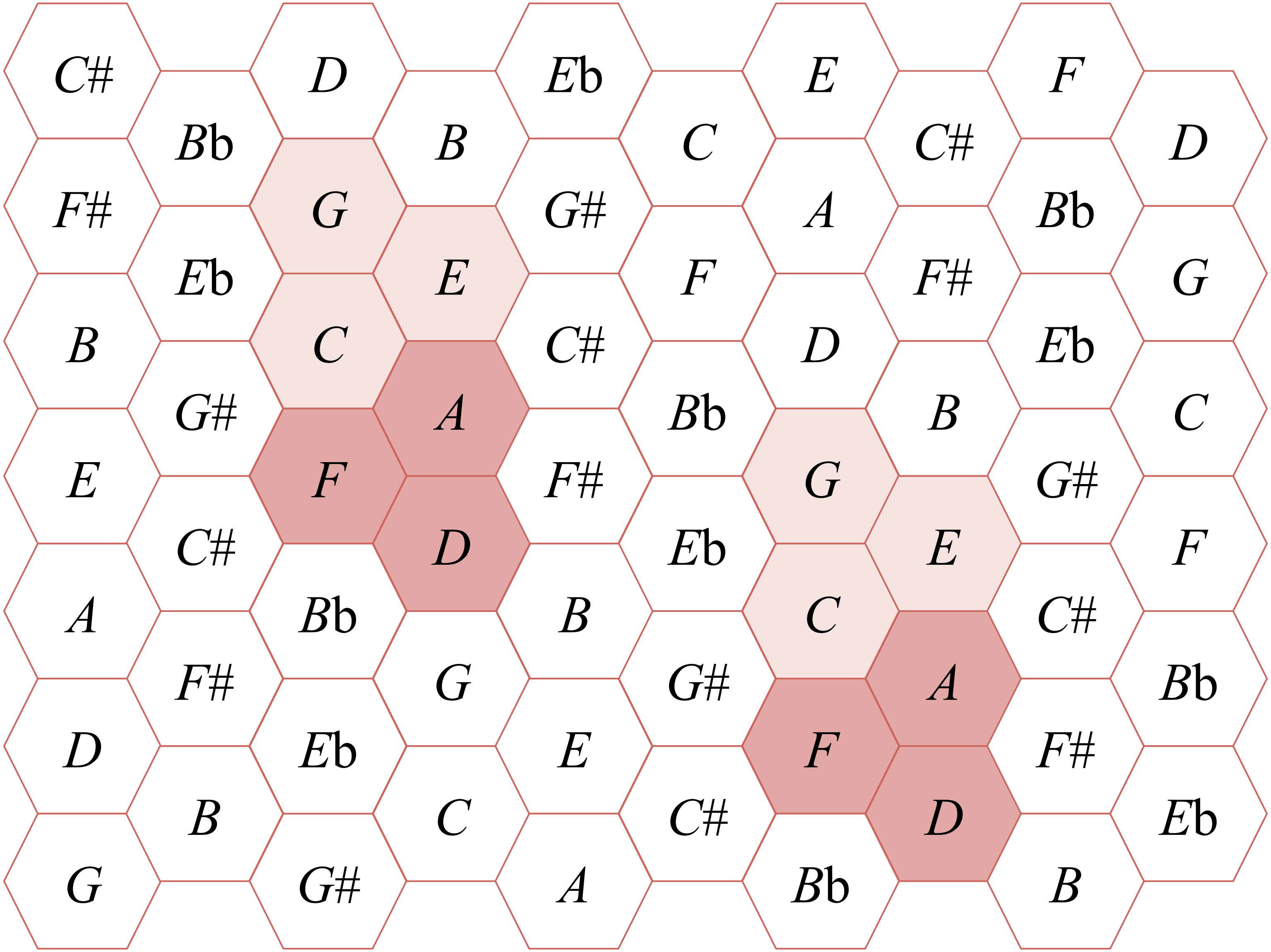
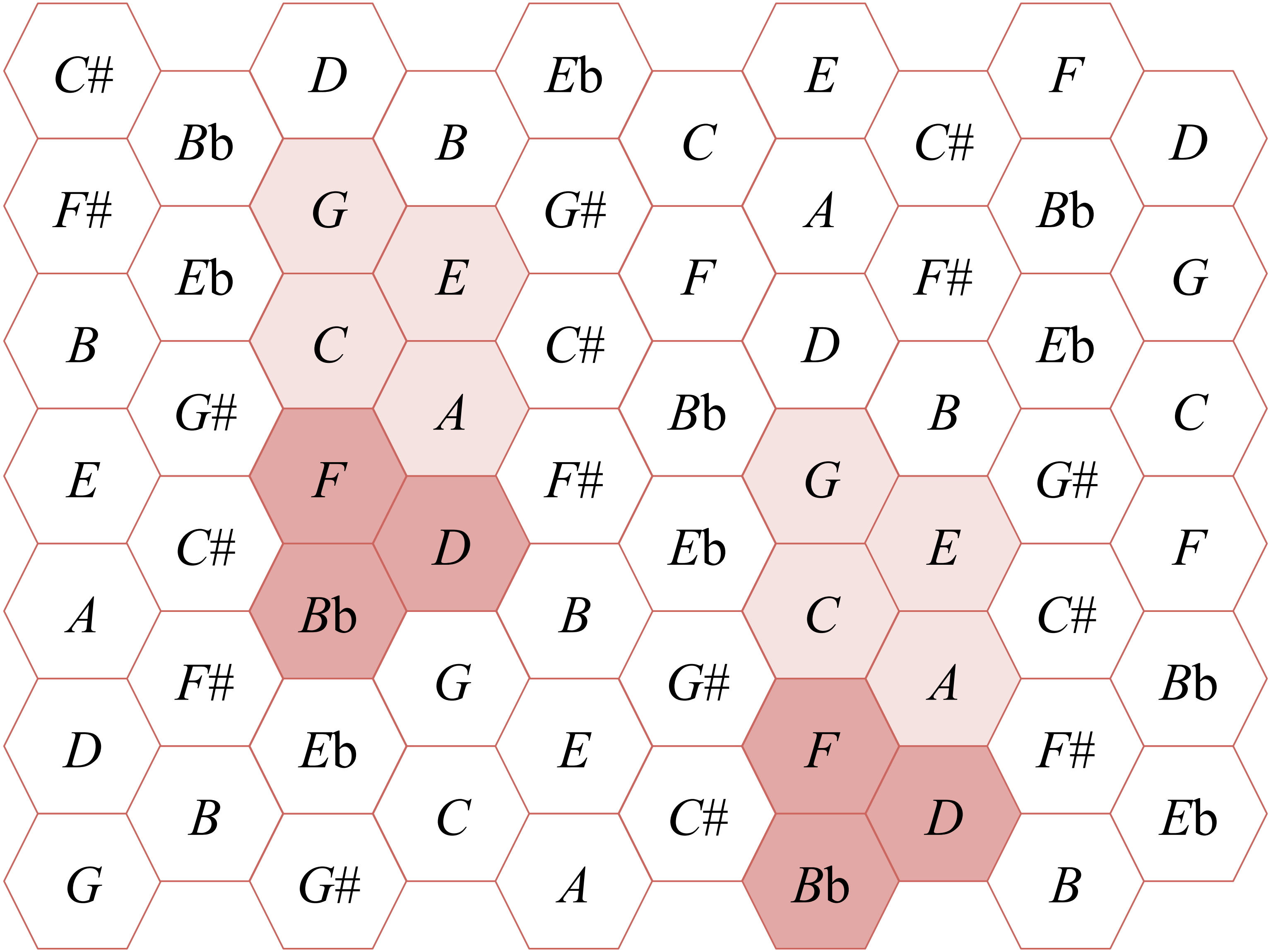
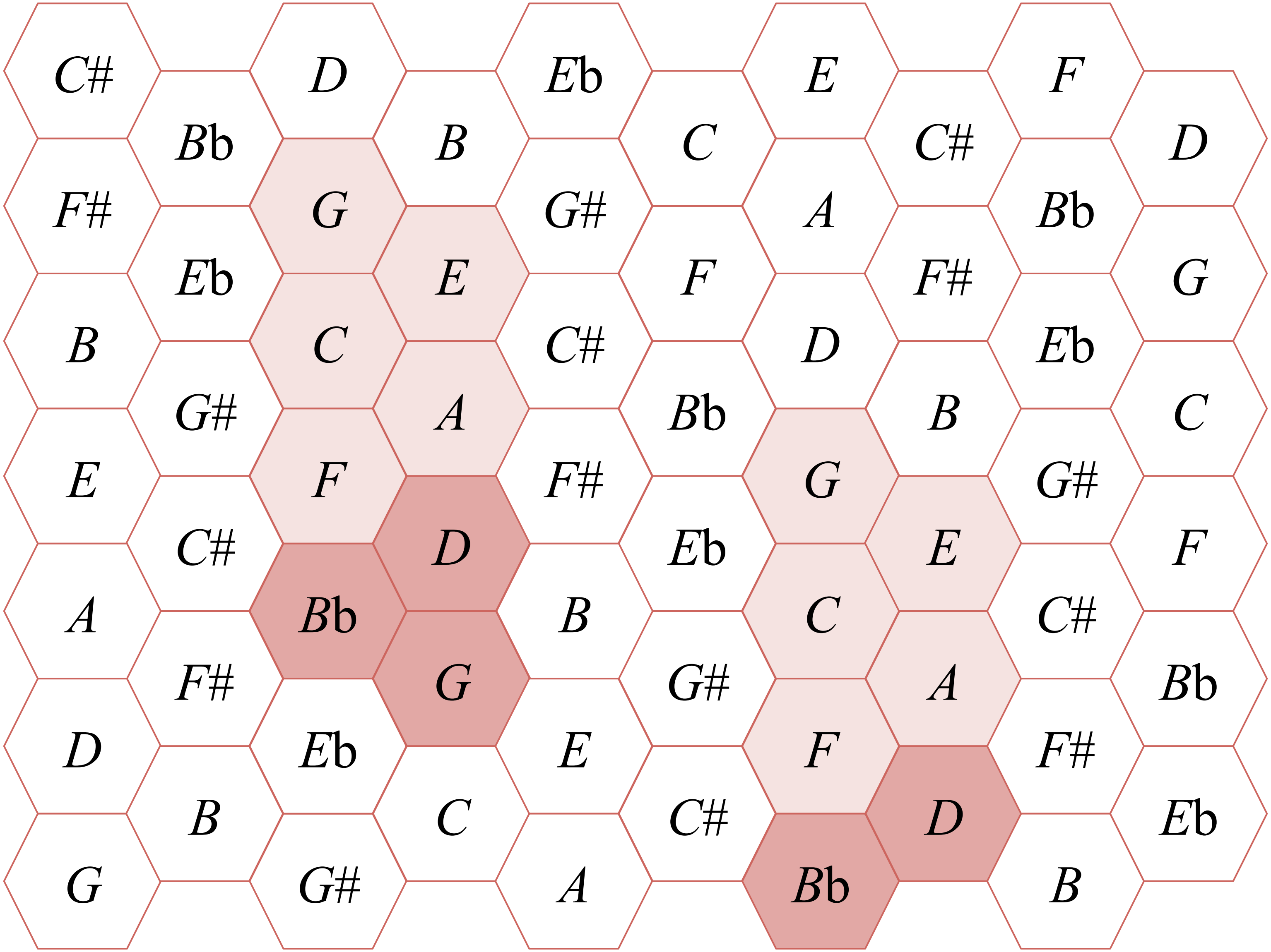


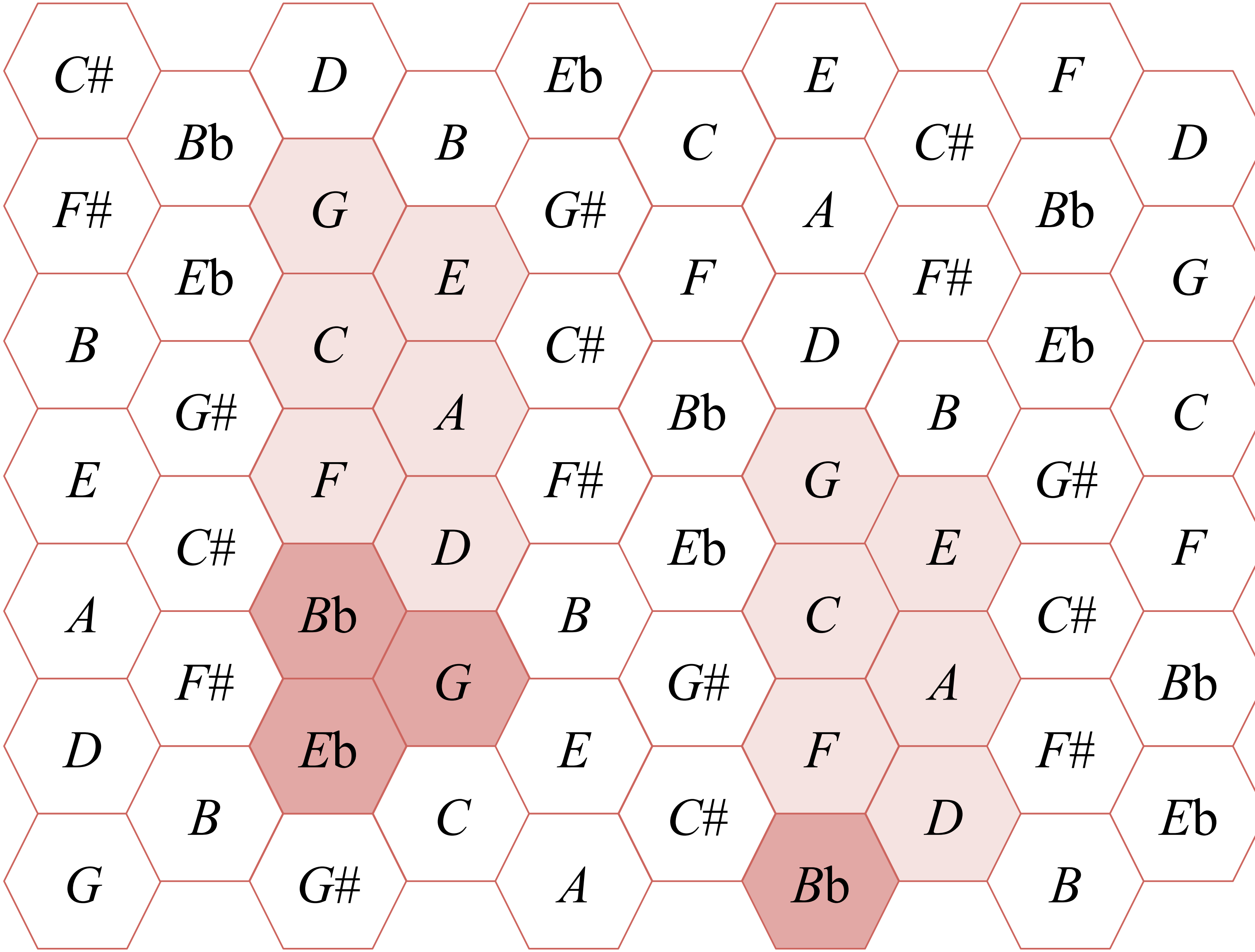
Extract of the 2nd movement of the Symphony No. 9 (L. van Beethoven)



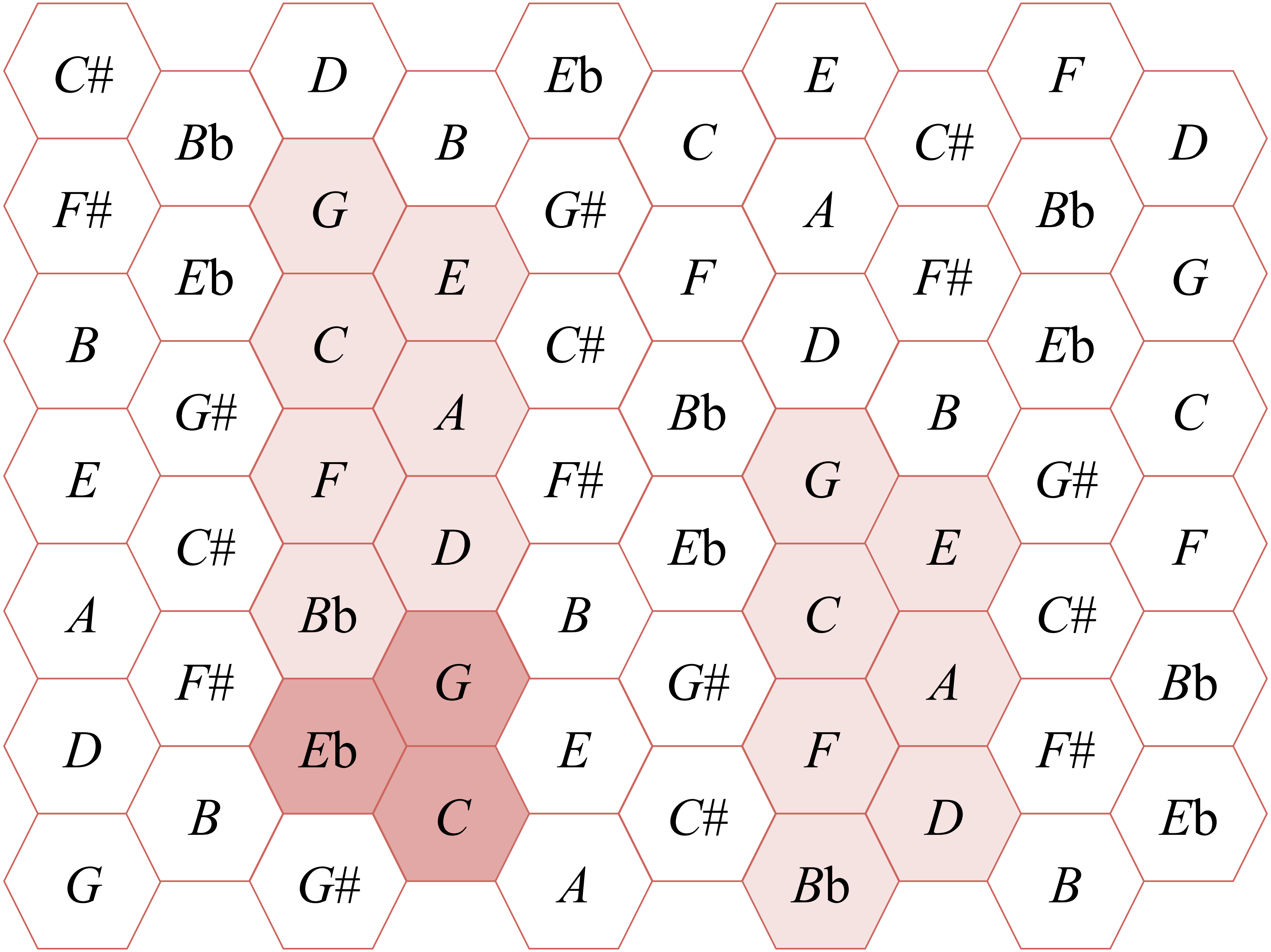
Extract of the 2nd movement of the Symphony No. 9 (L. van Beethoven)



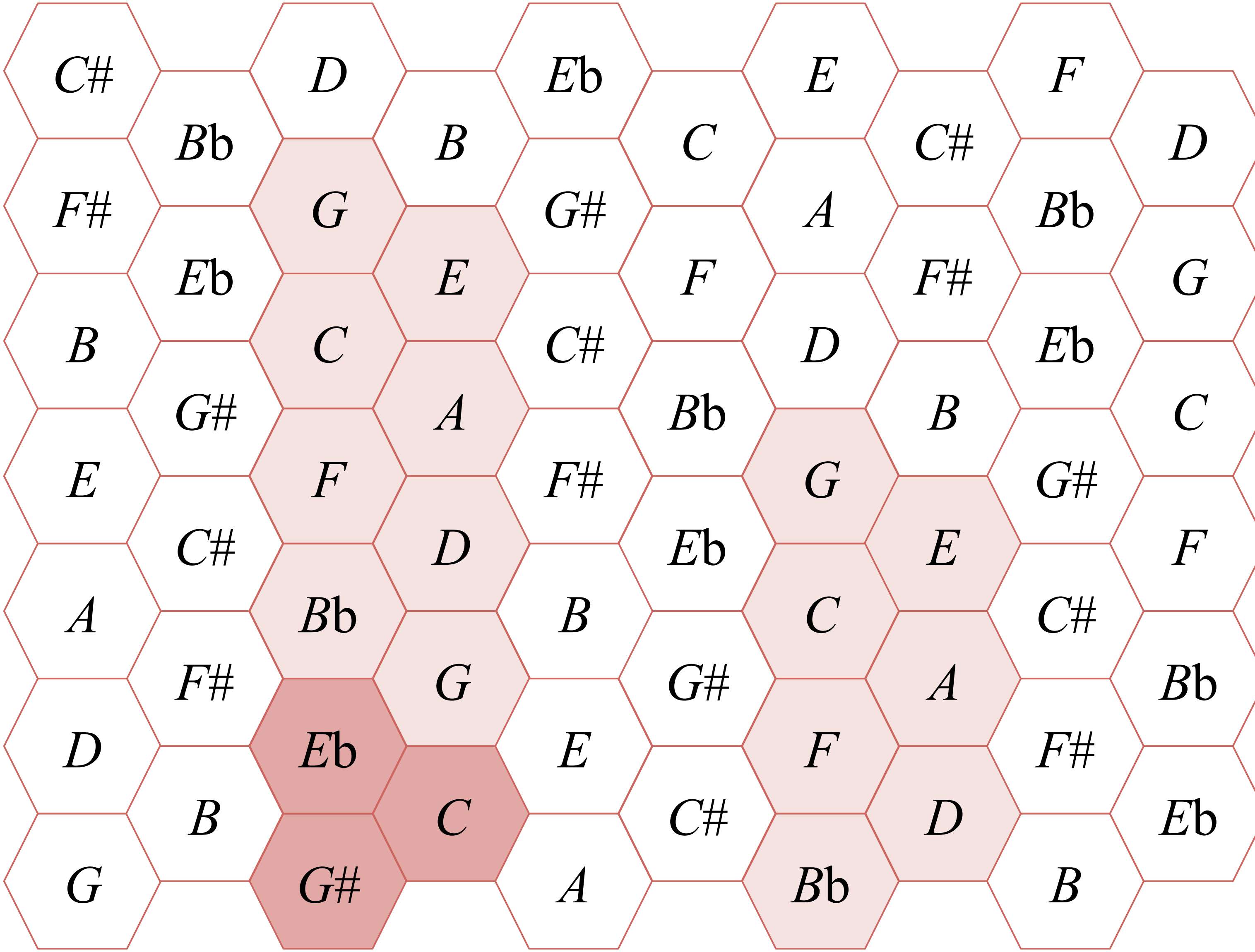
Extract of the 2nd movement of the Symphony No. 9 (L. van Beethoven)



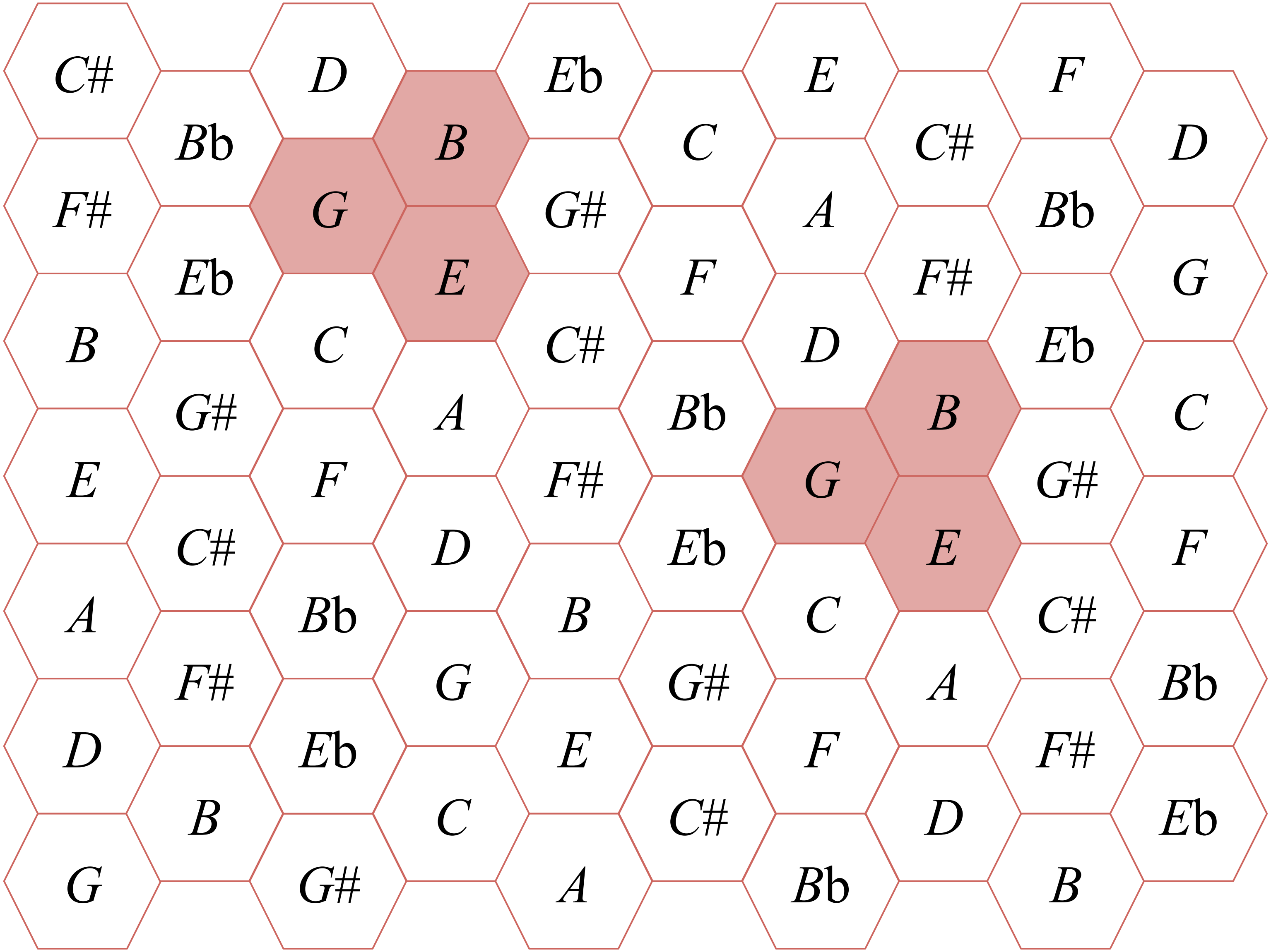
Extract of the 2nd movement of the Symphony No. 9 (L. van Beethoven)



Extract of the 2nd movement of the Symphony No. 9 (L. van Beethoven)



Extract of the Prelude Op.28 N.4
(F. Chopin)



Extract of the Prelude Op.28 N.4
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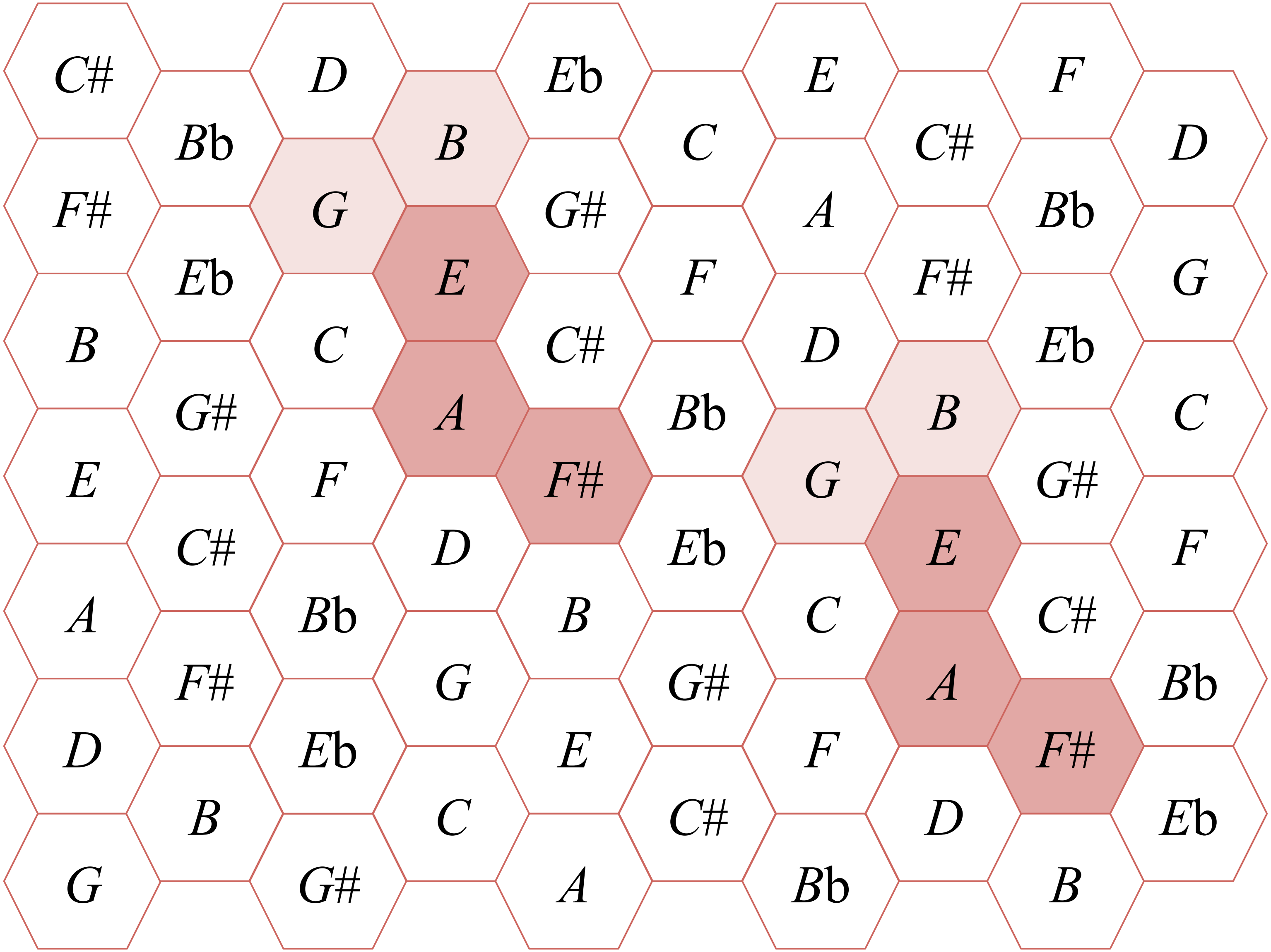

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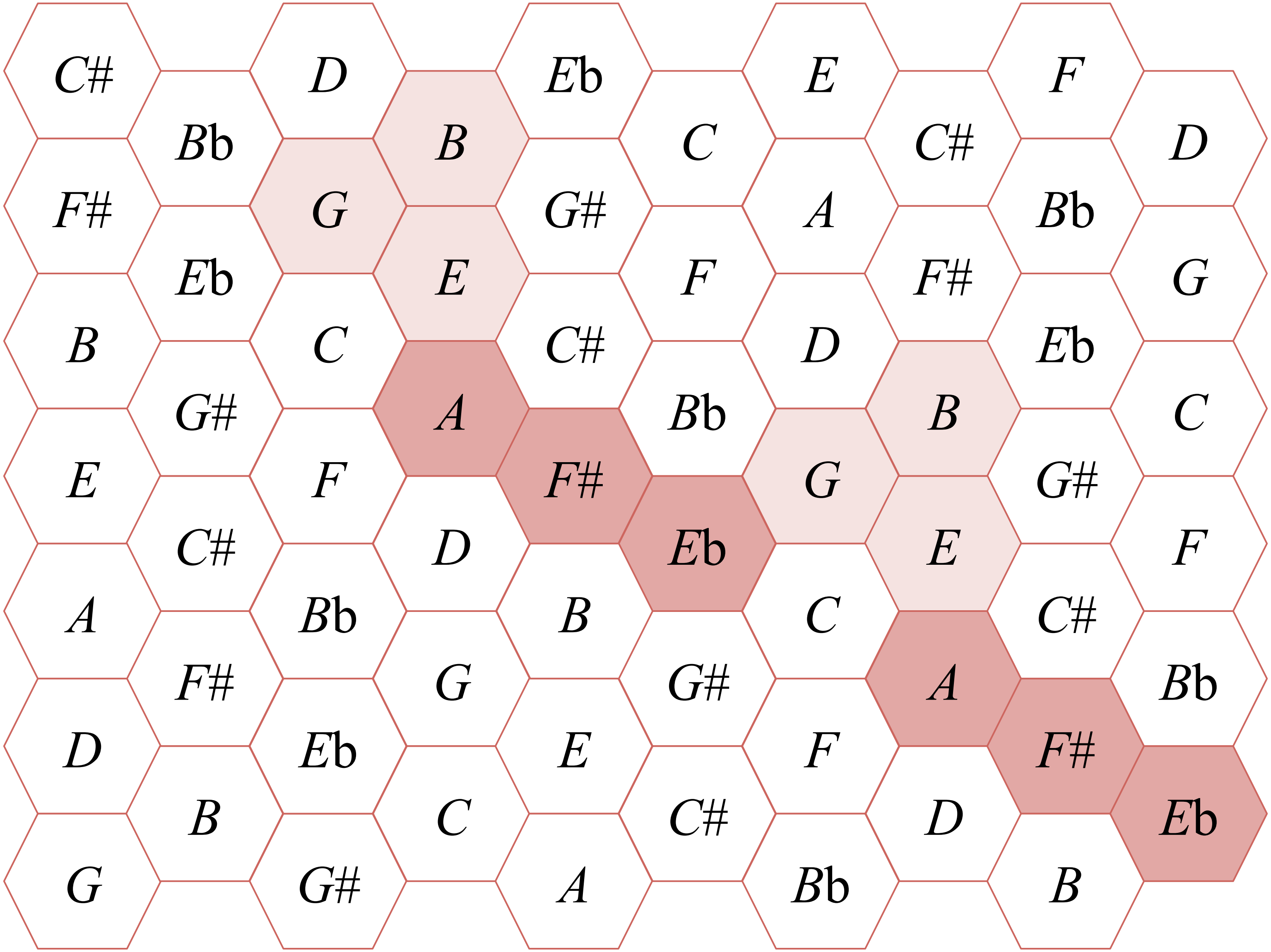
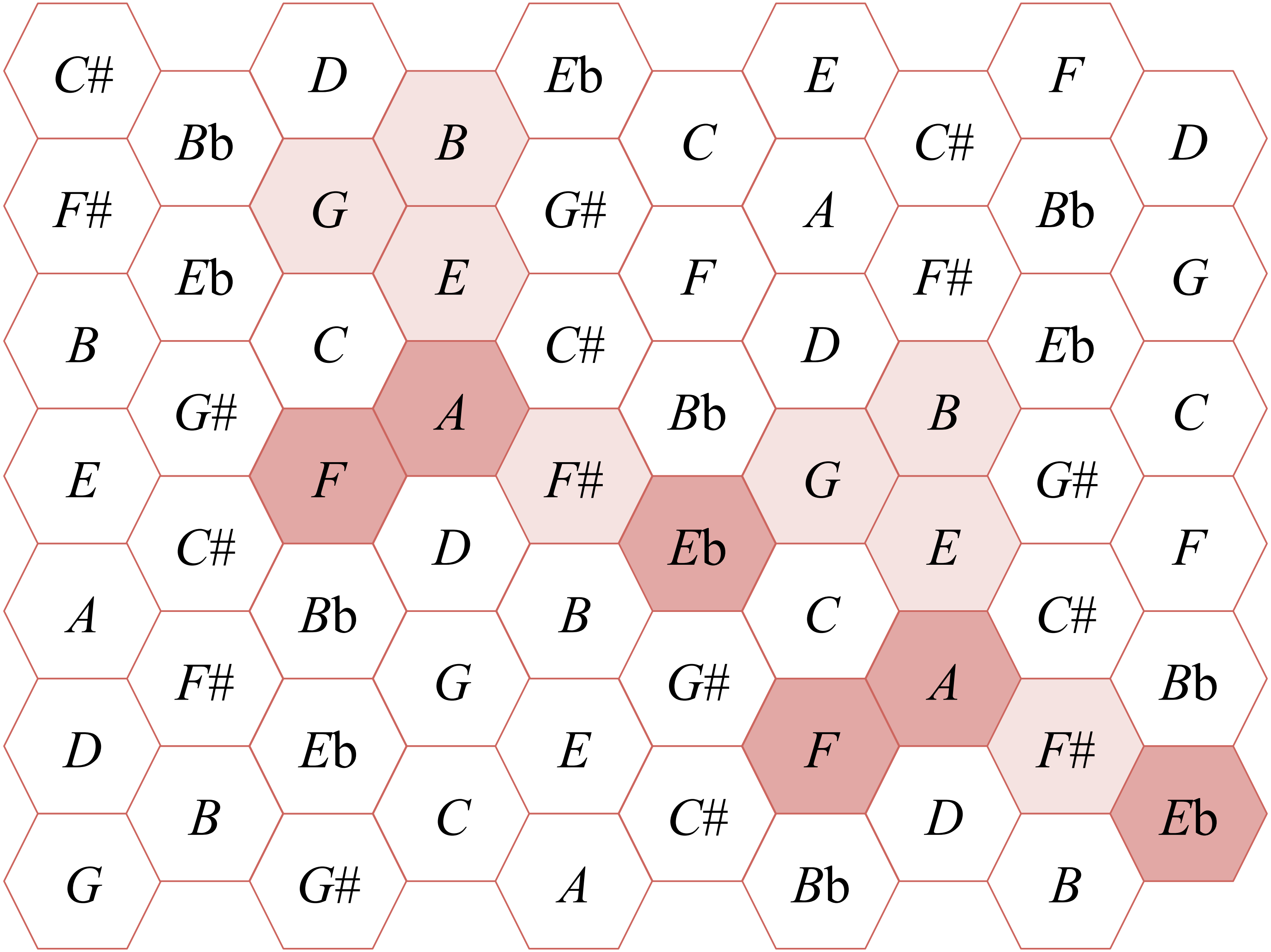


Extract of the Prelude Op.28 N.4
(F. Chopin)



Extract of the Prelude Op.28 N.4
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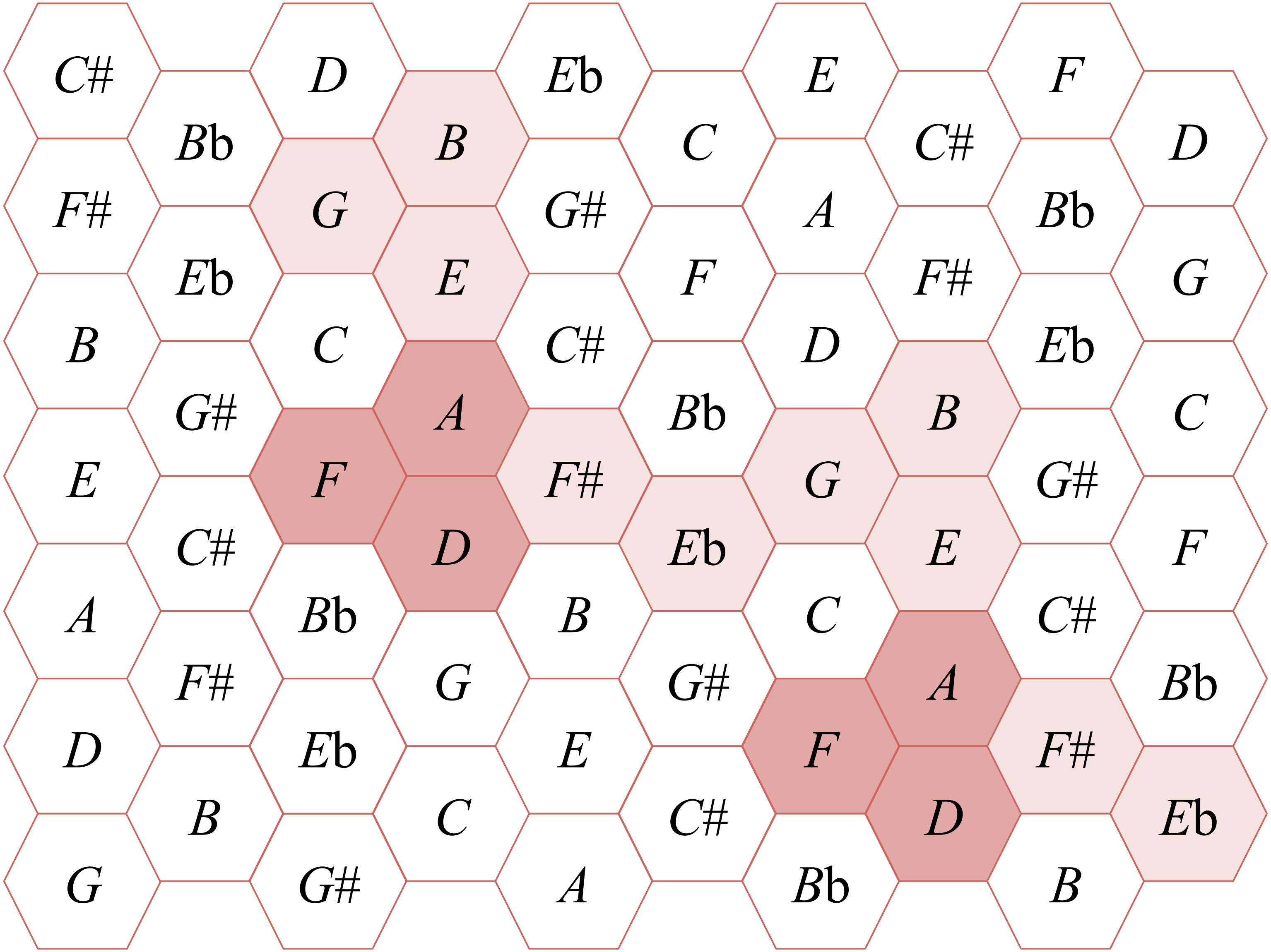

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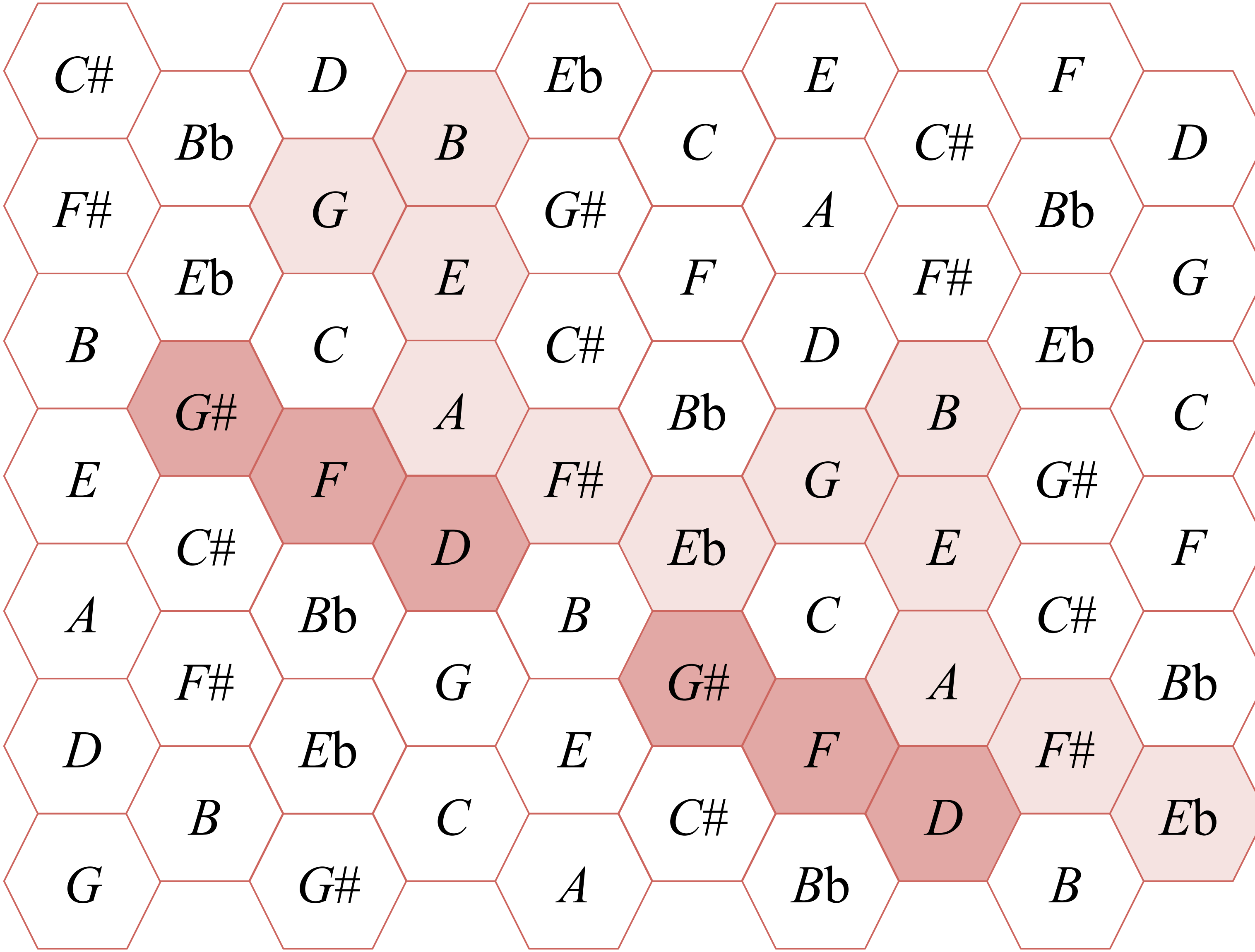

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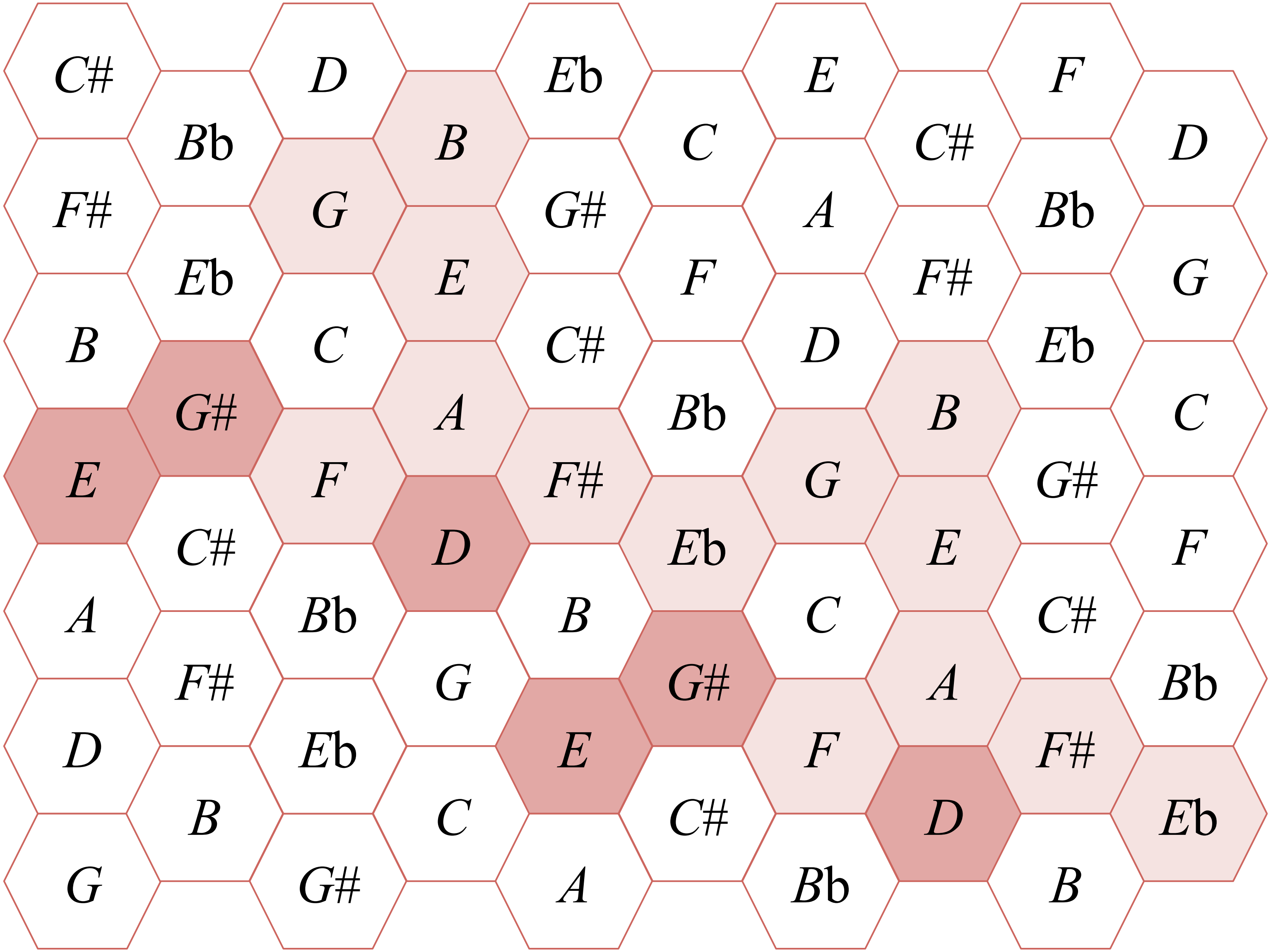

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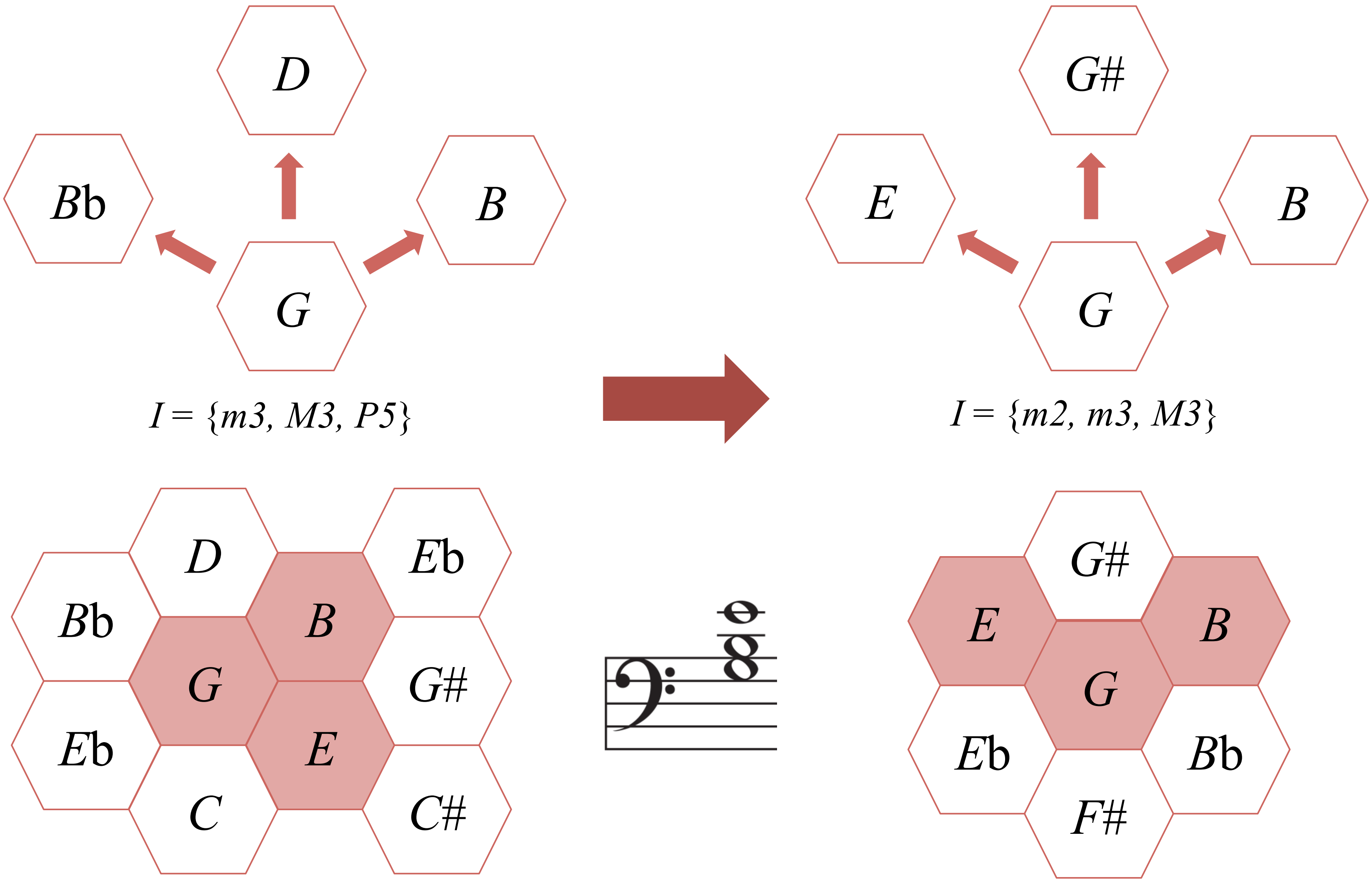

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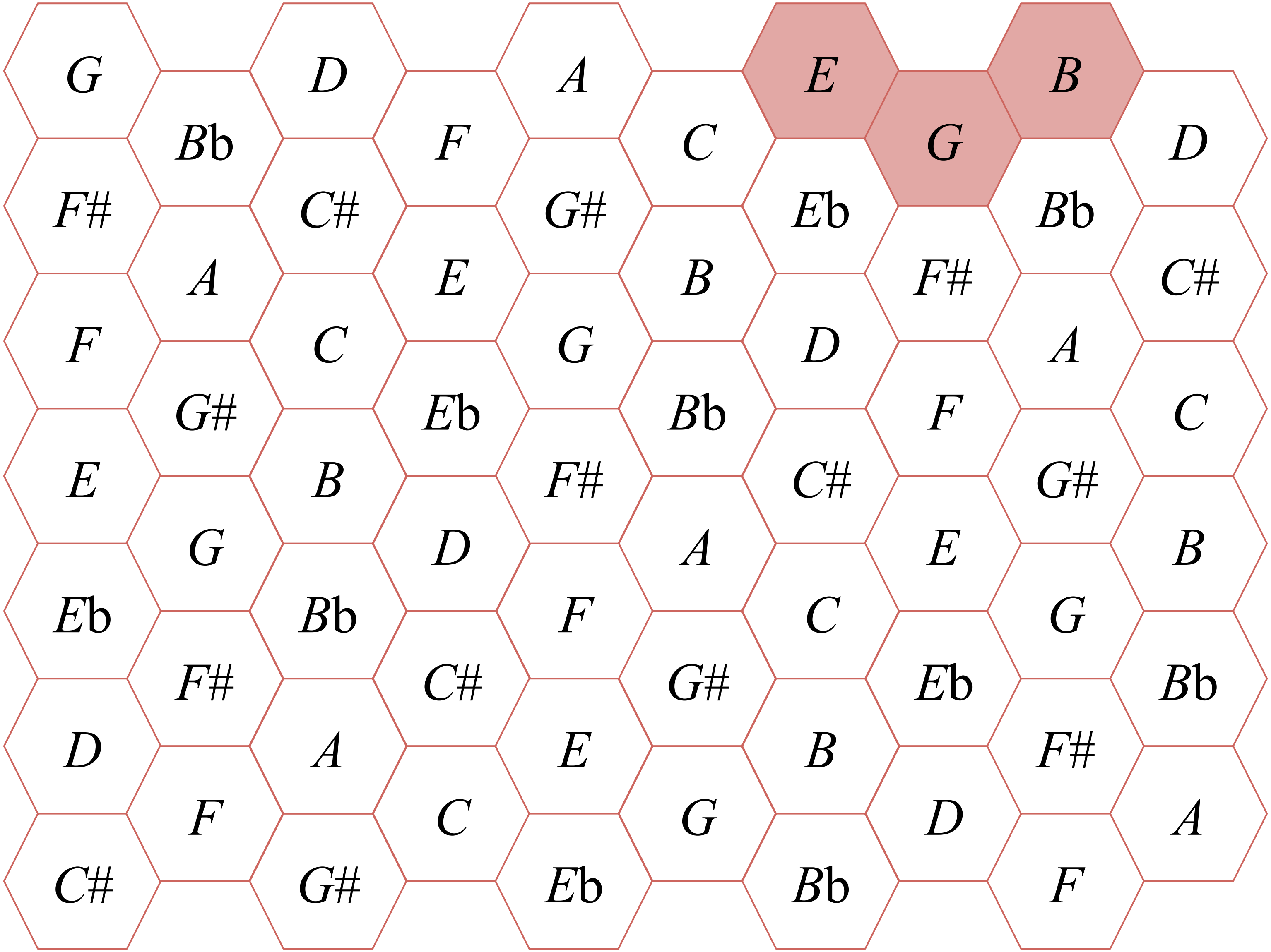

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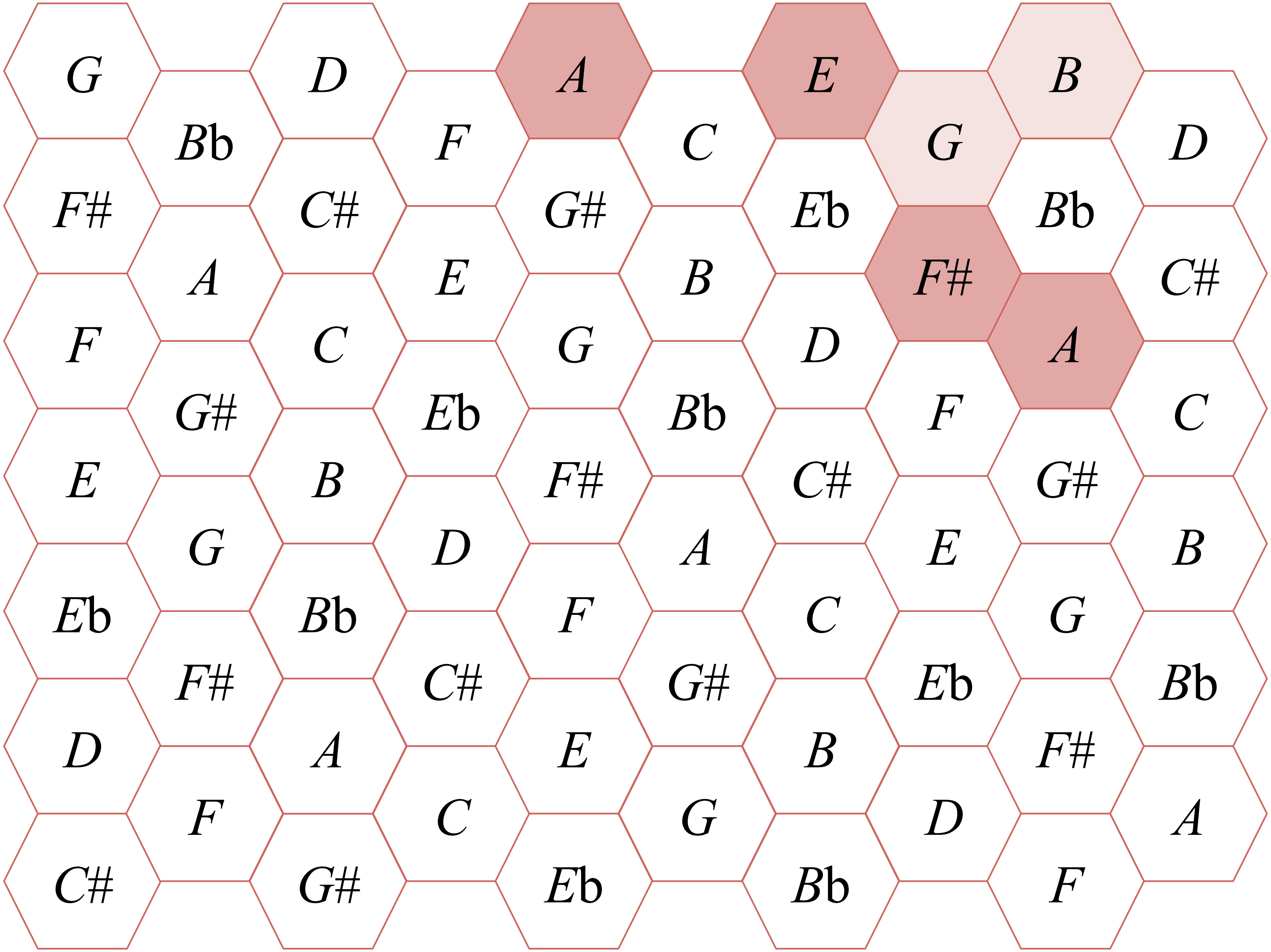

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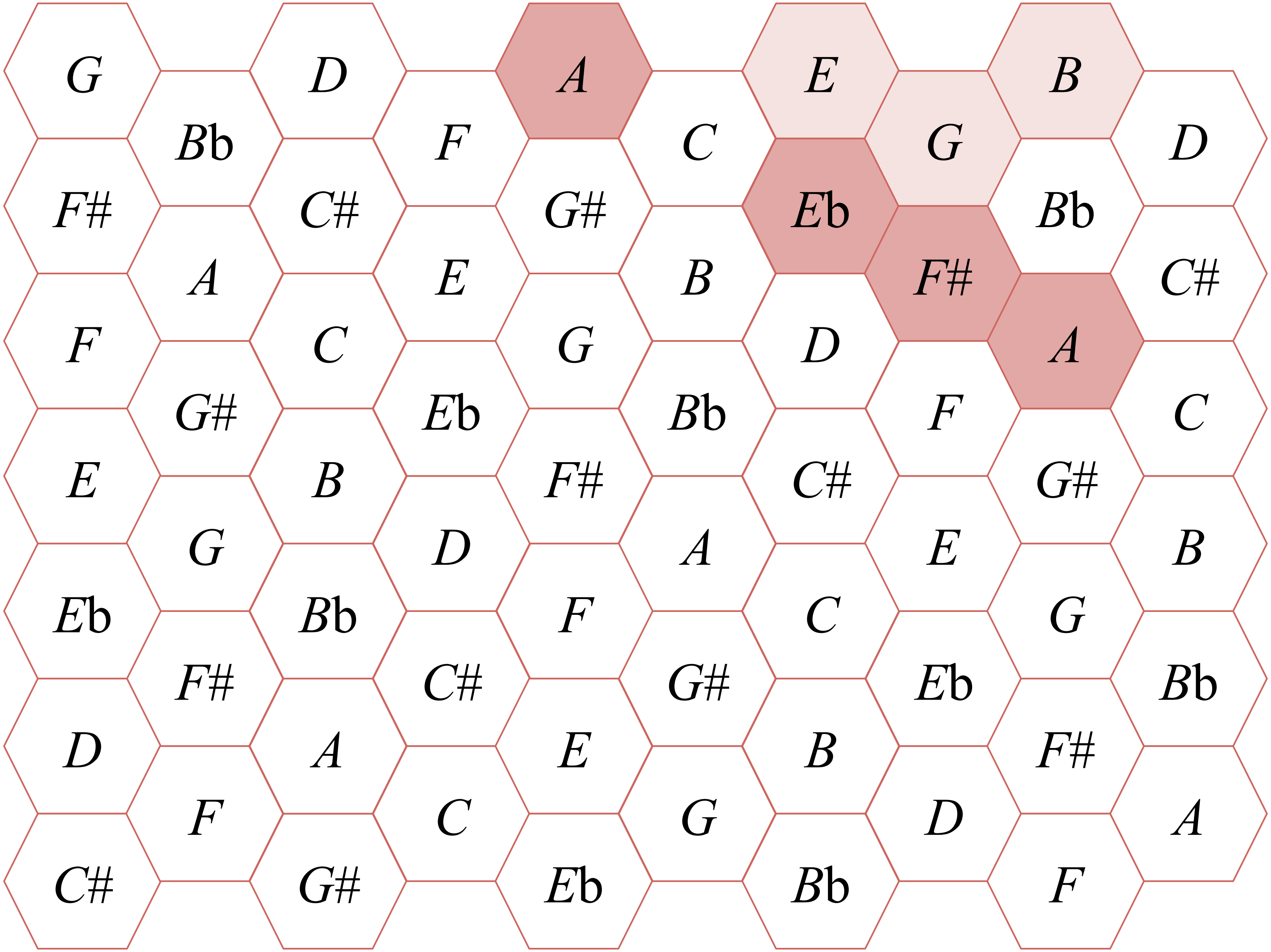

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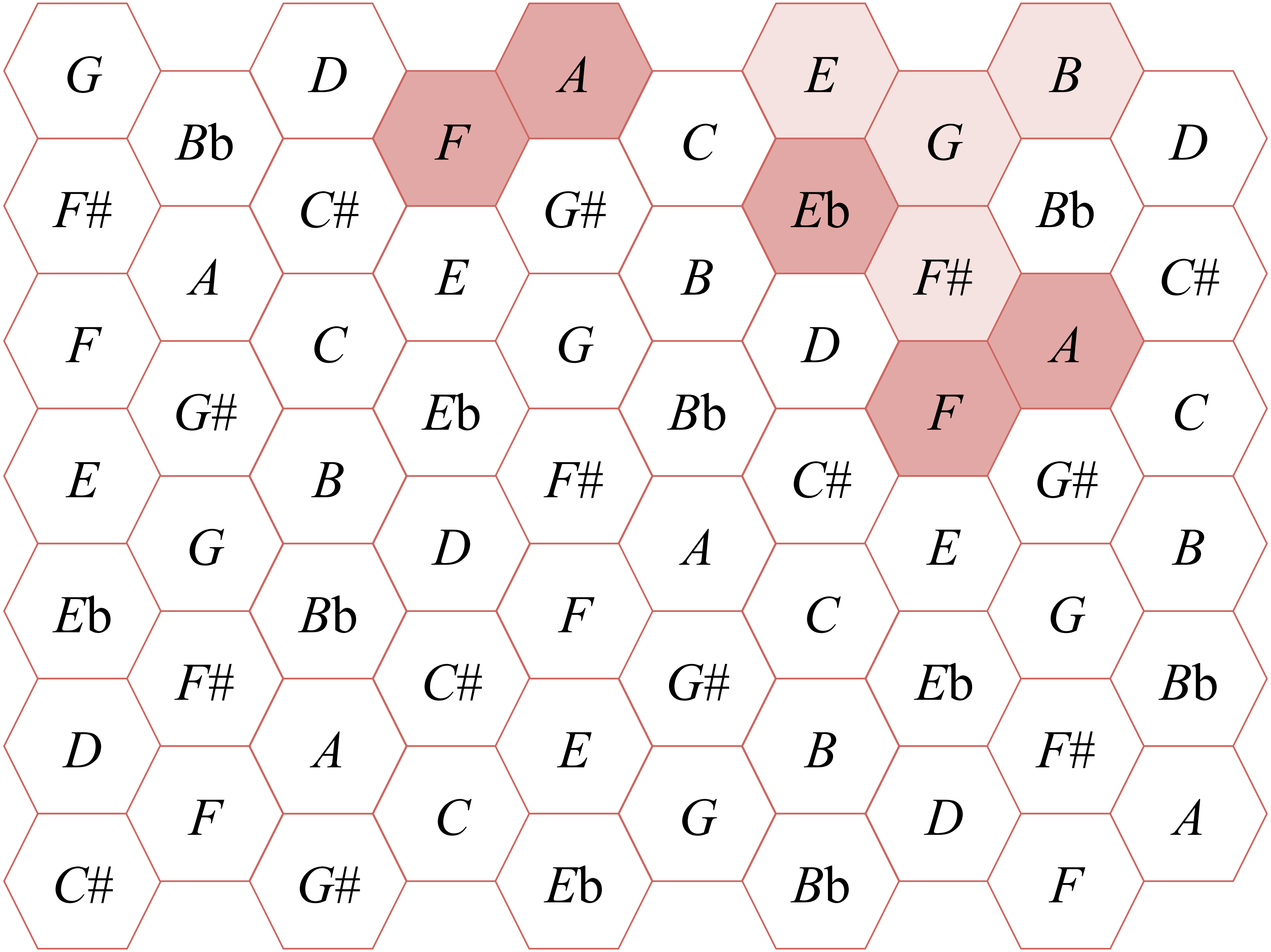

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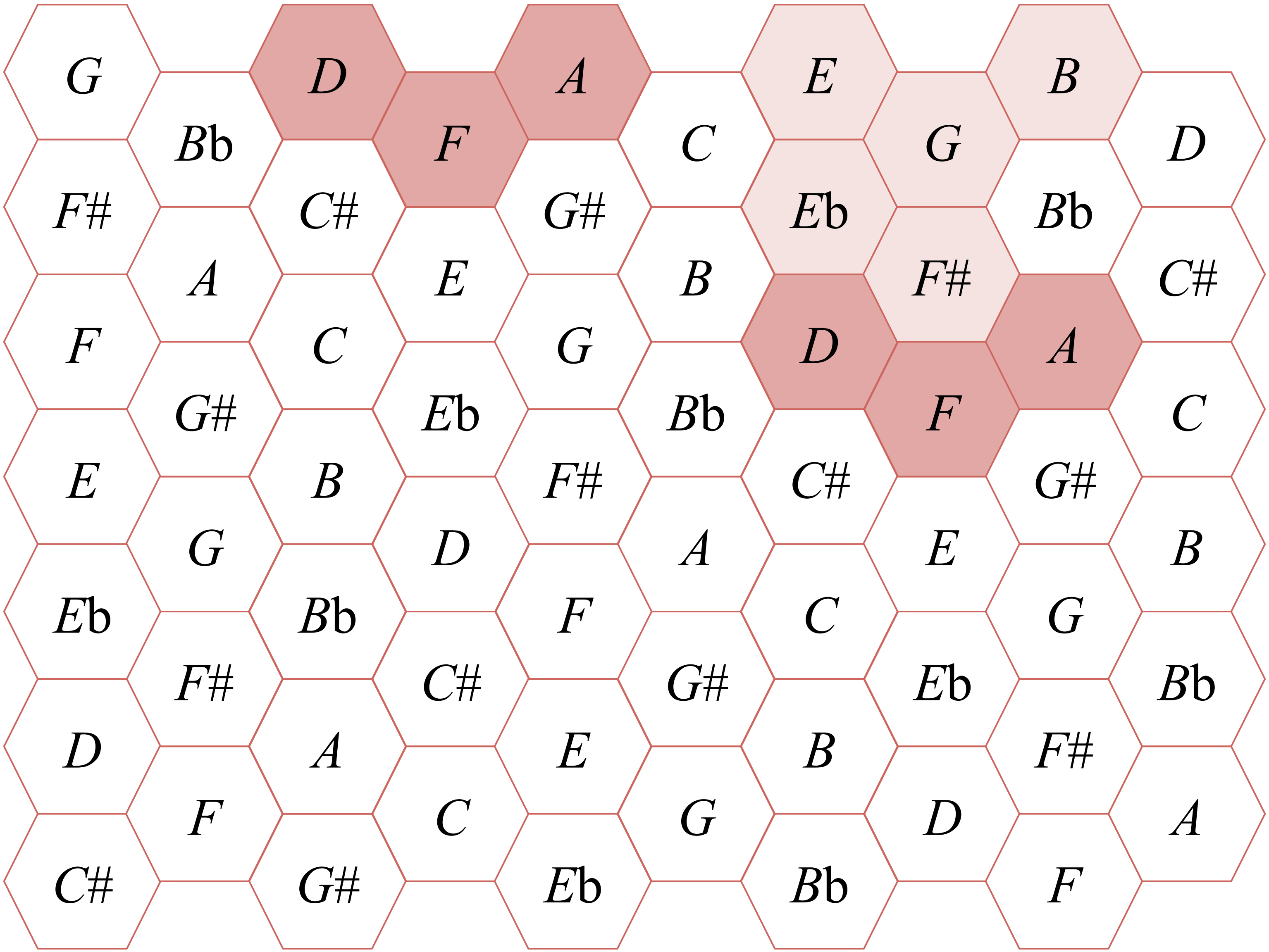

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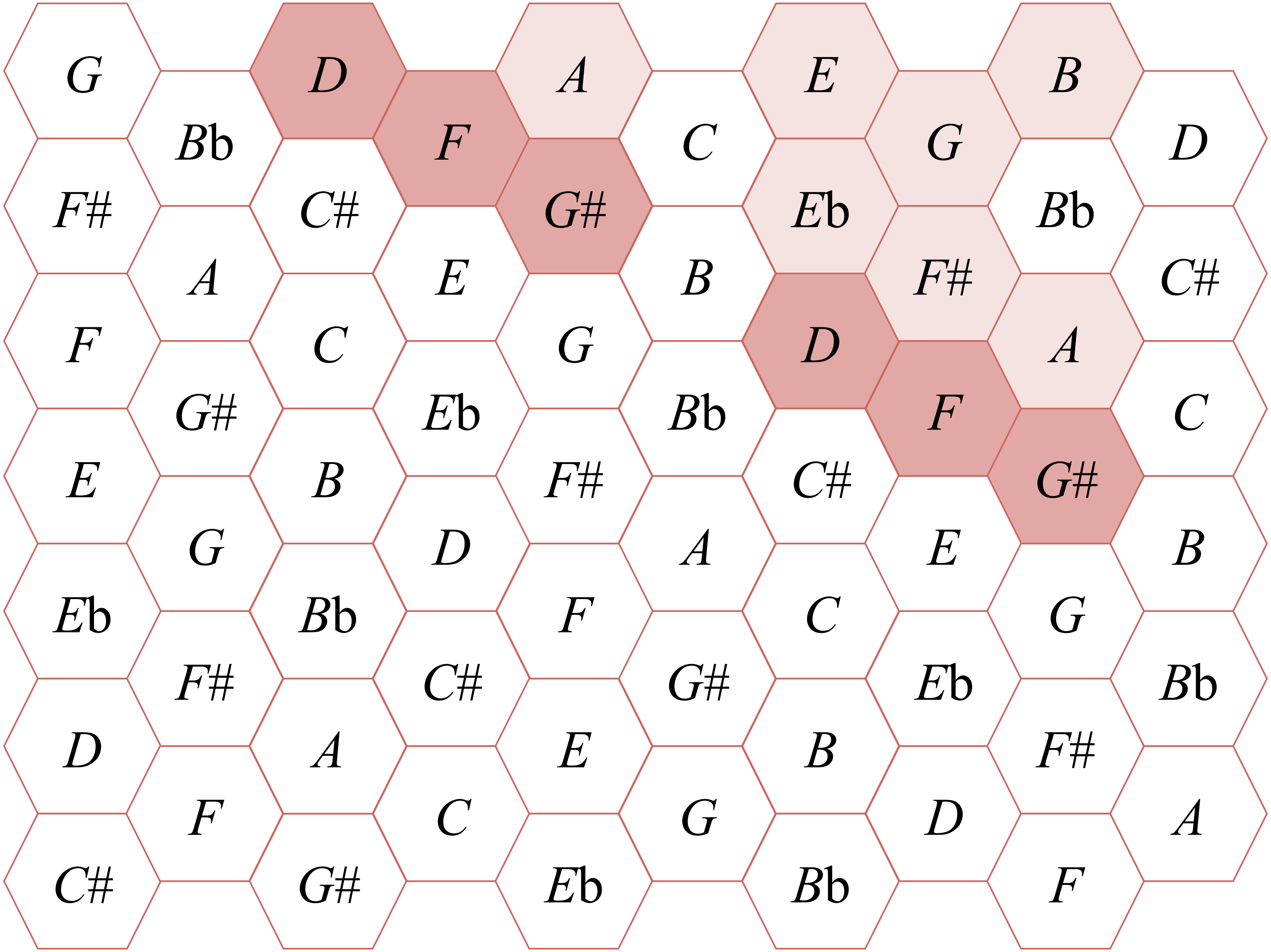

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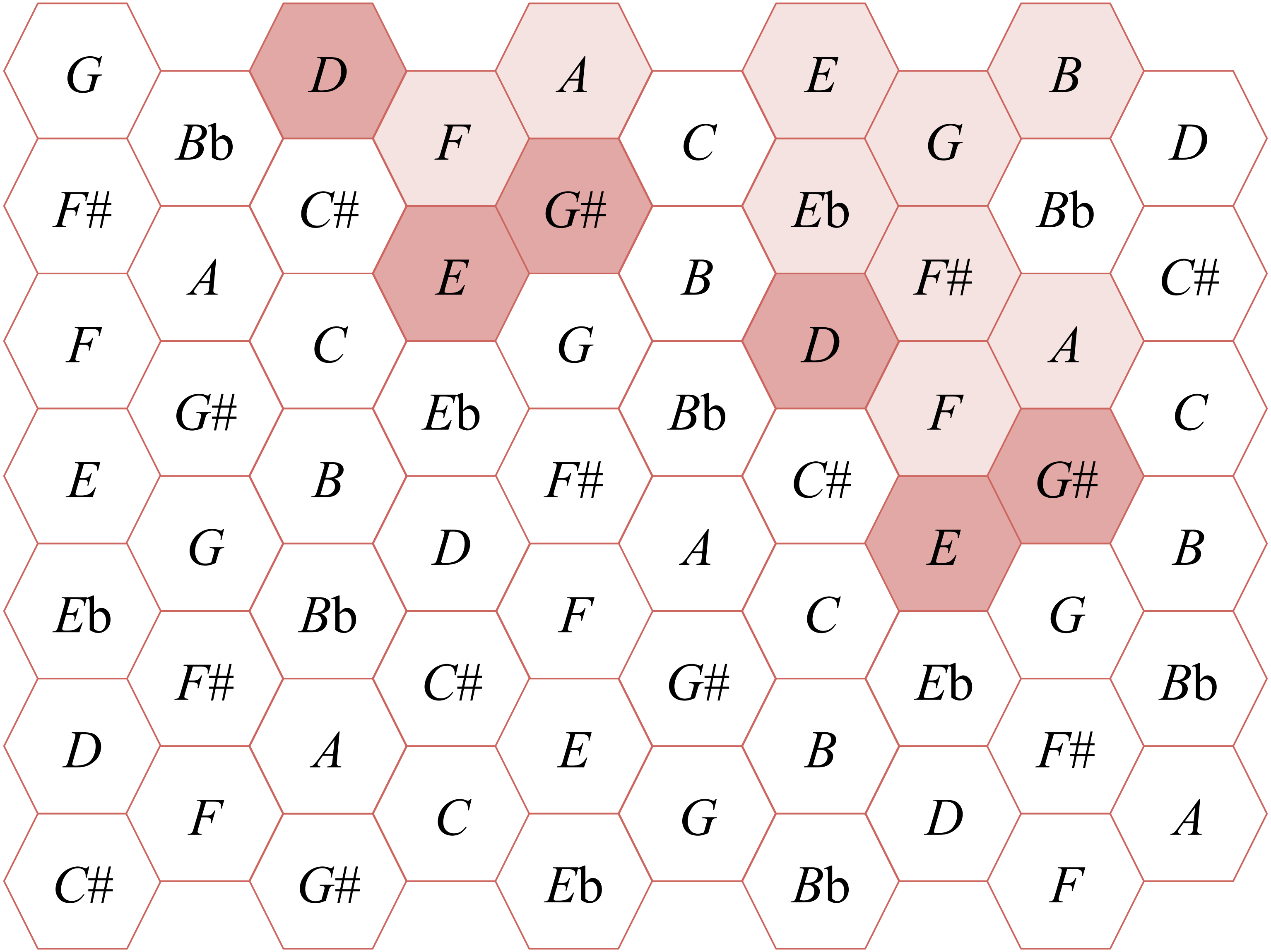

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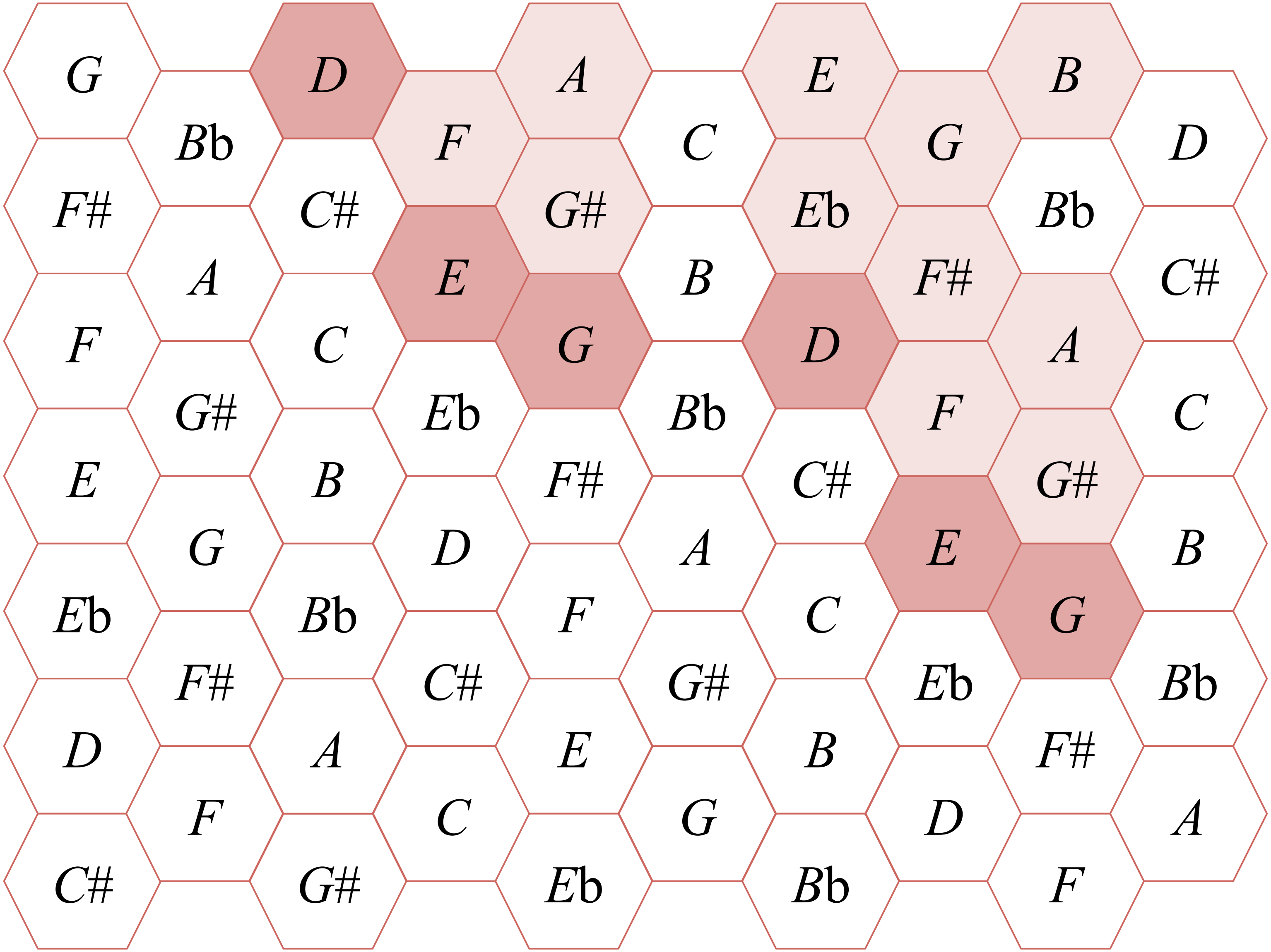

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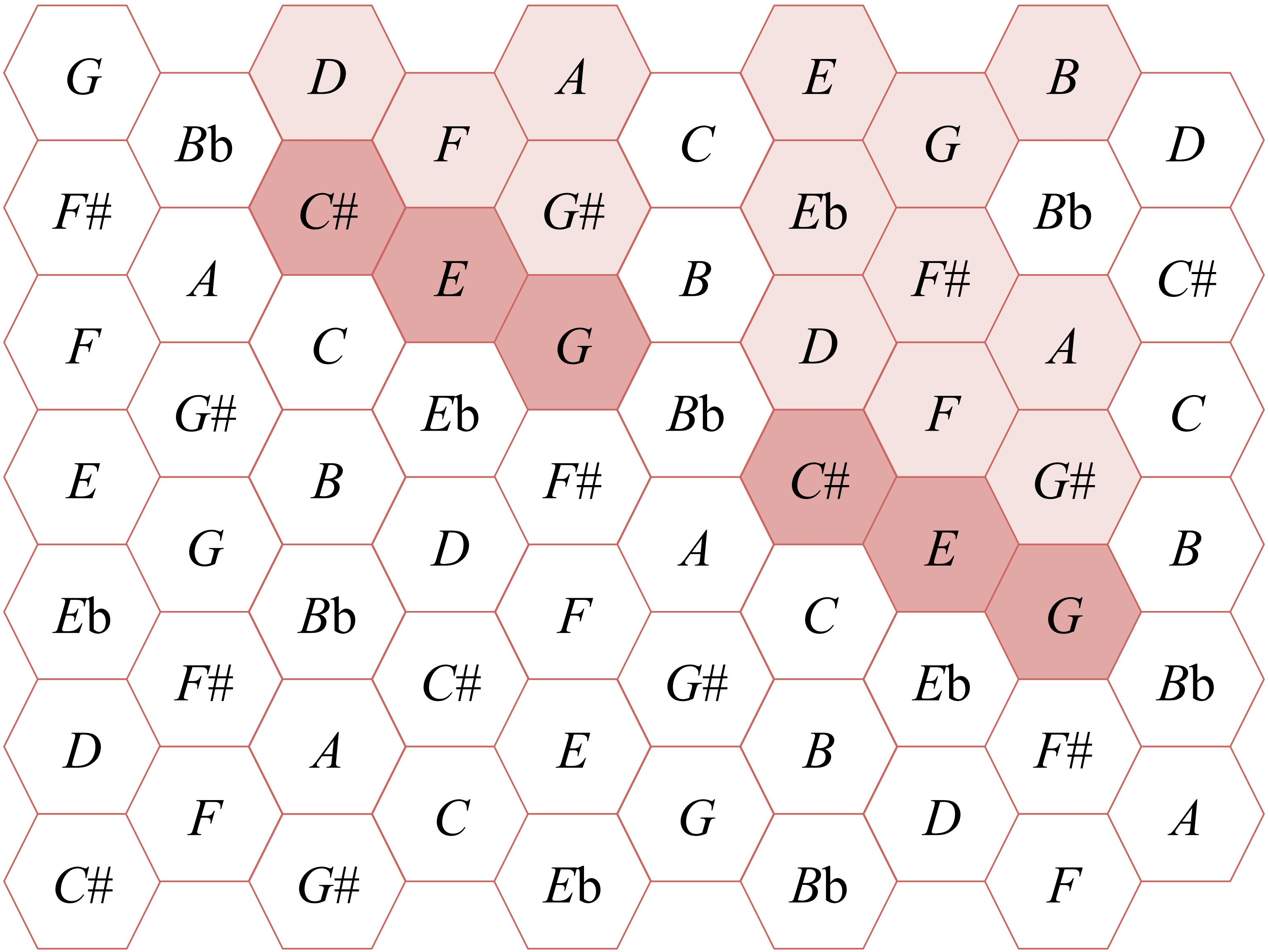

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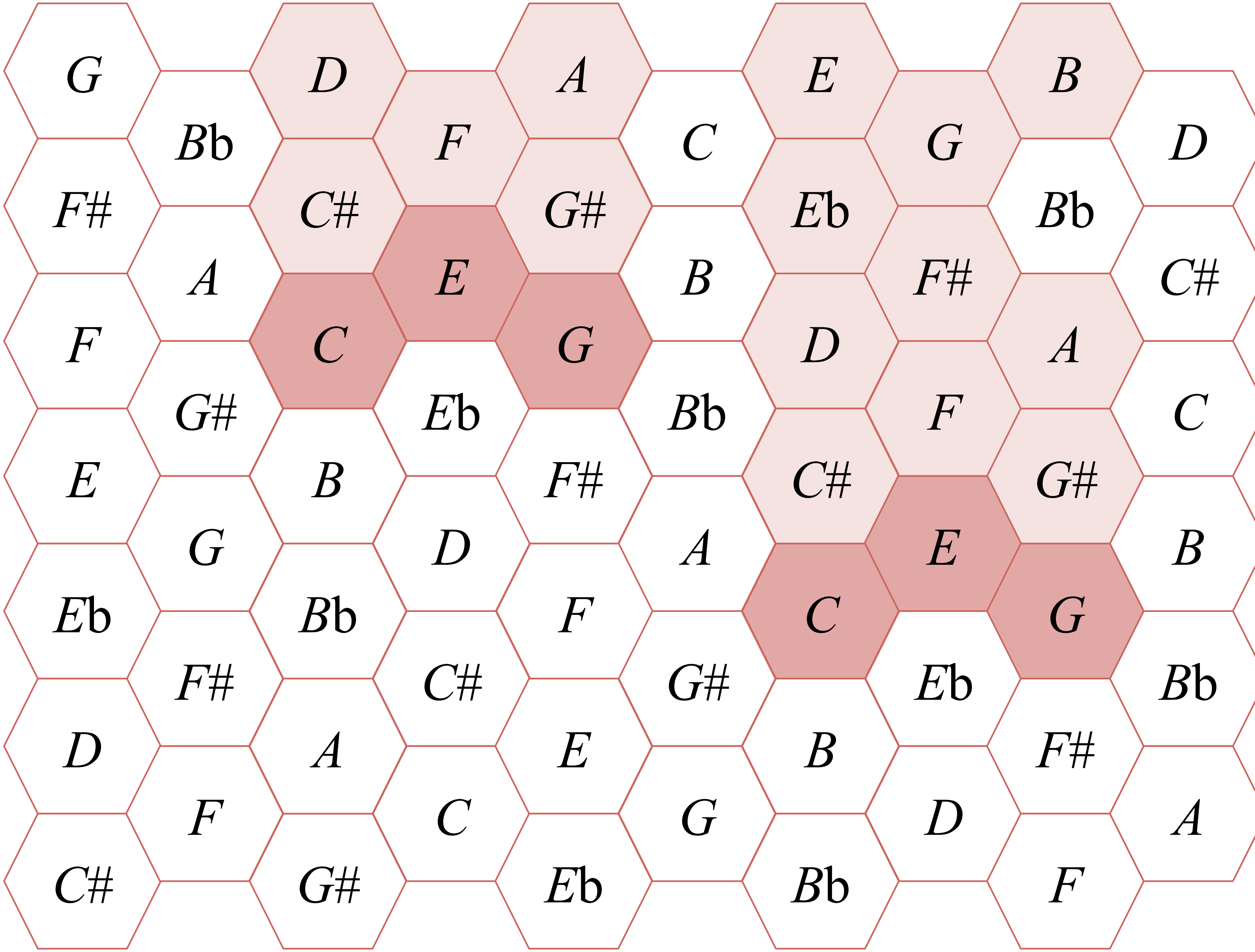

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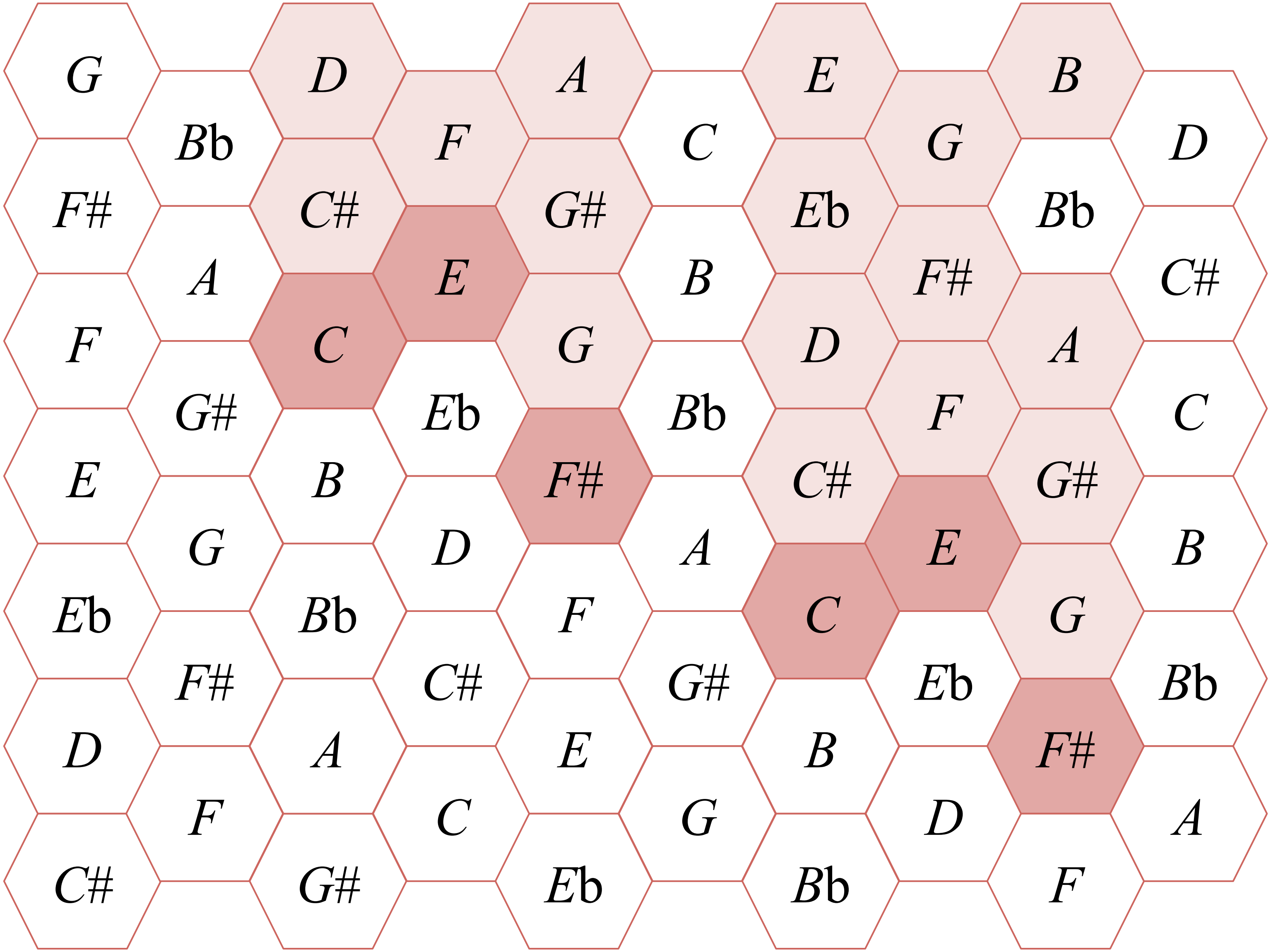

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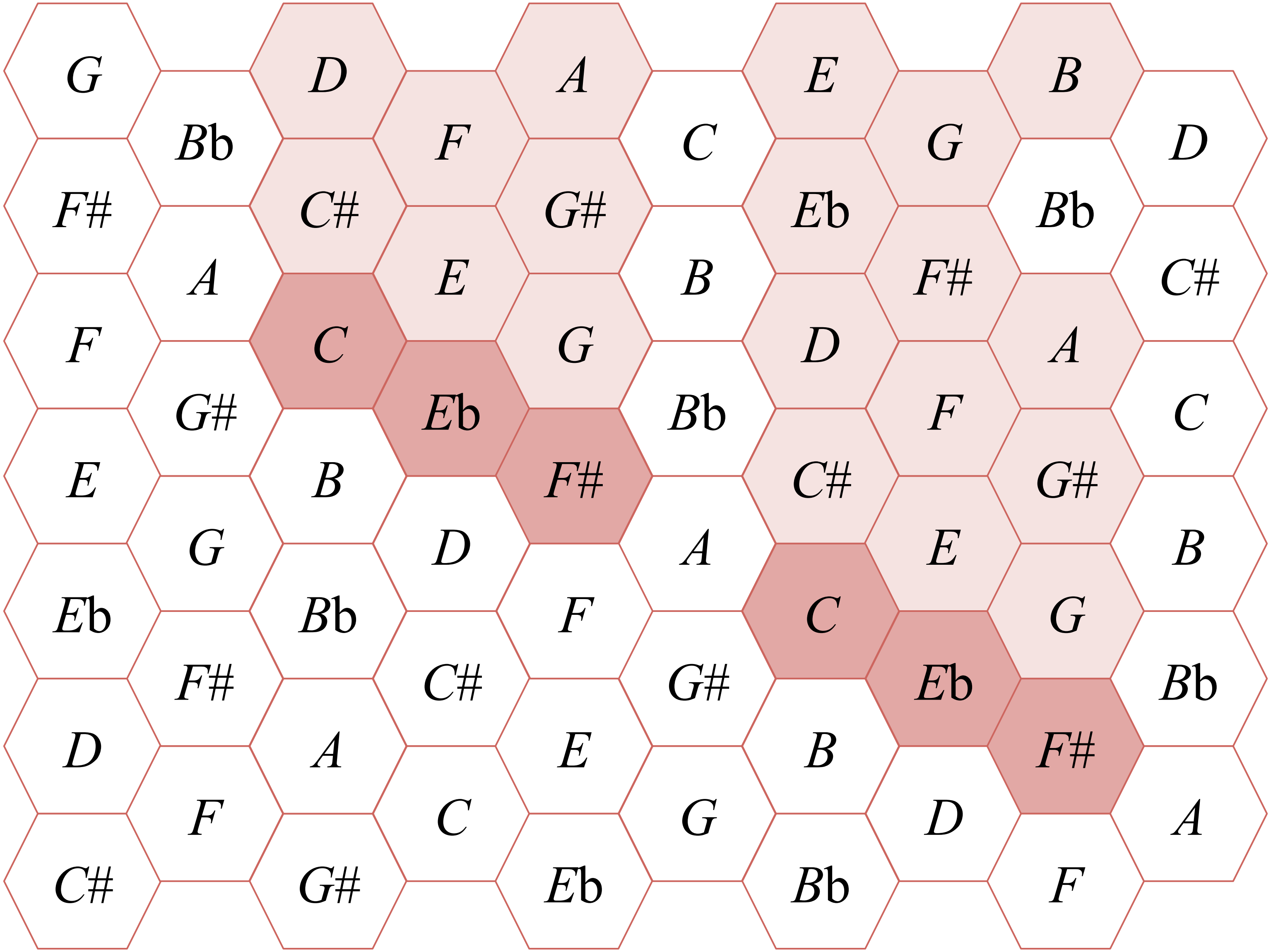

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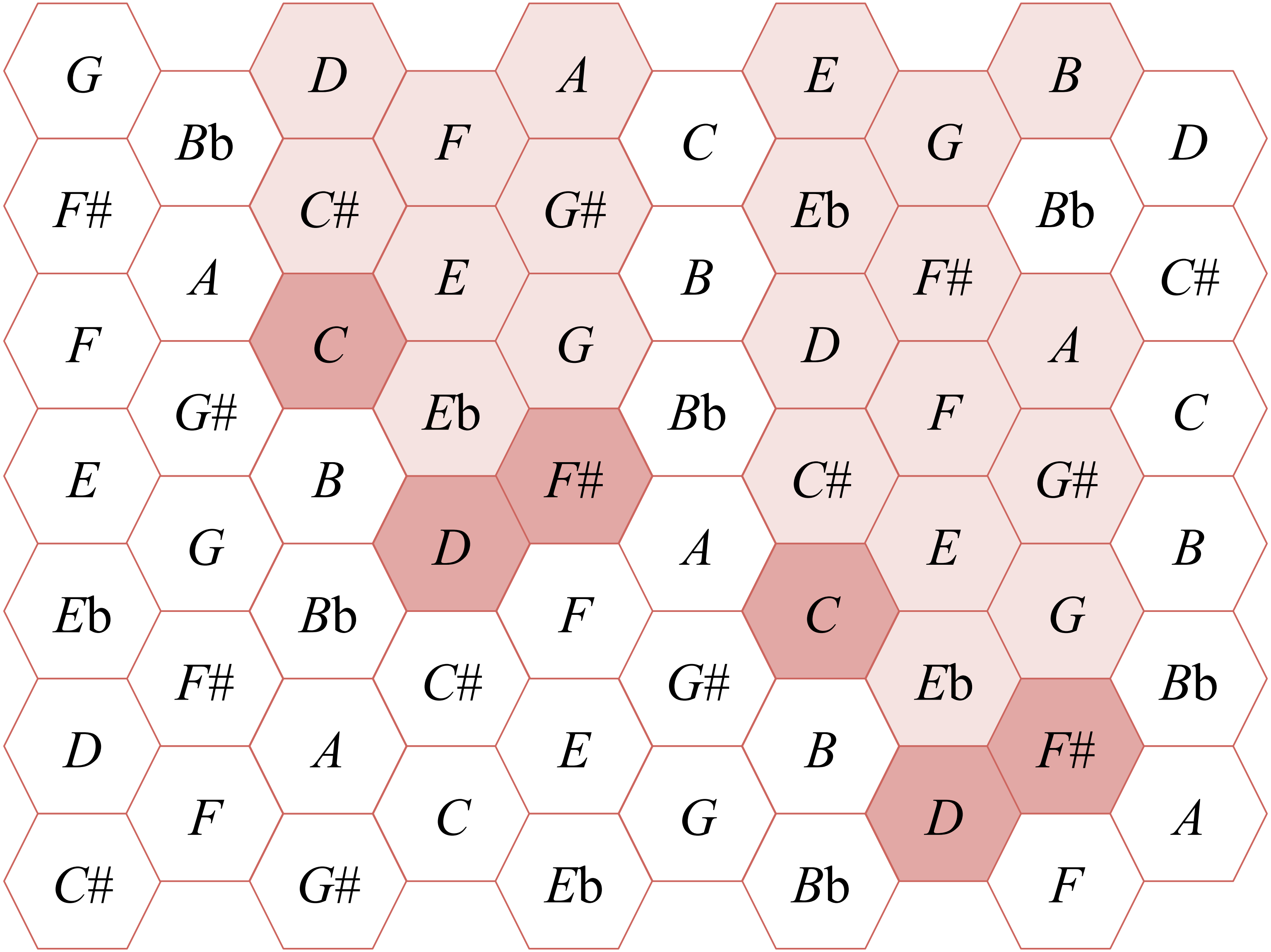

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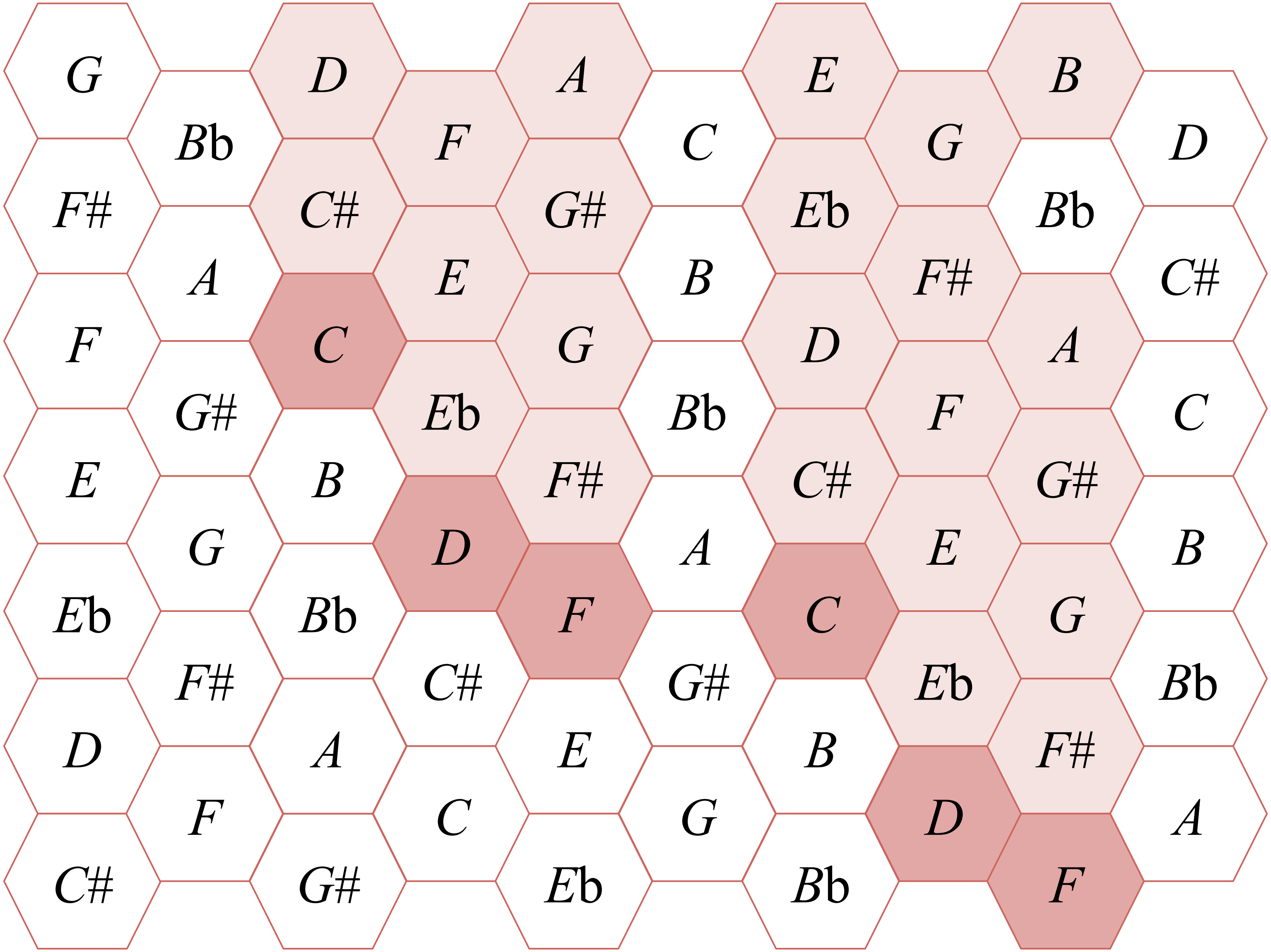

Extract of the Prelude Op.28 N.4
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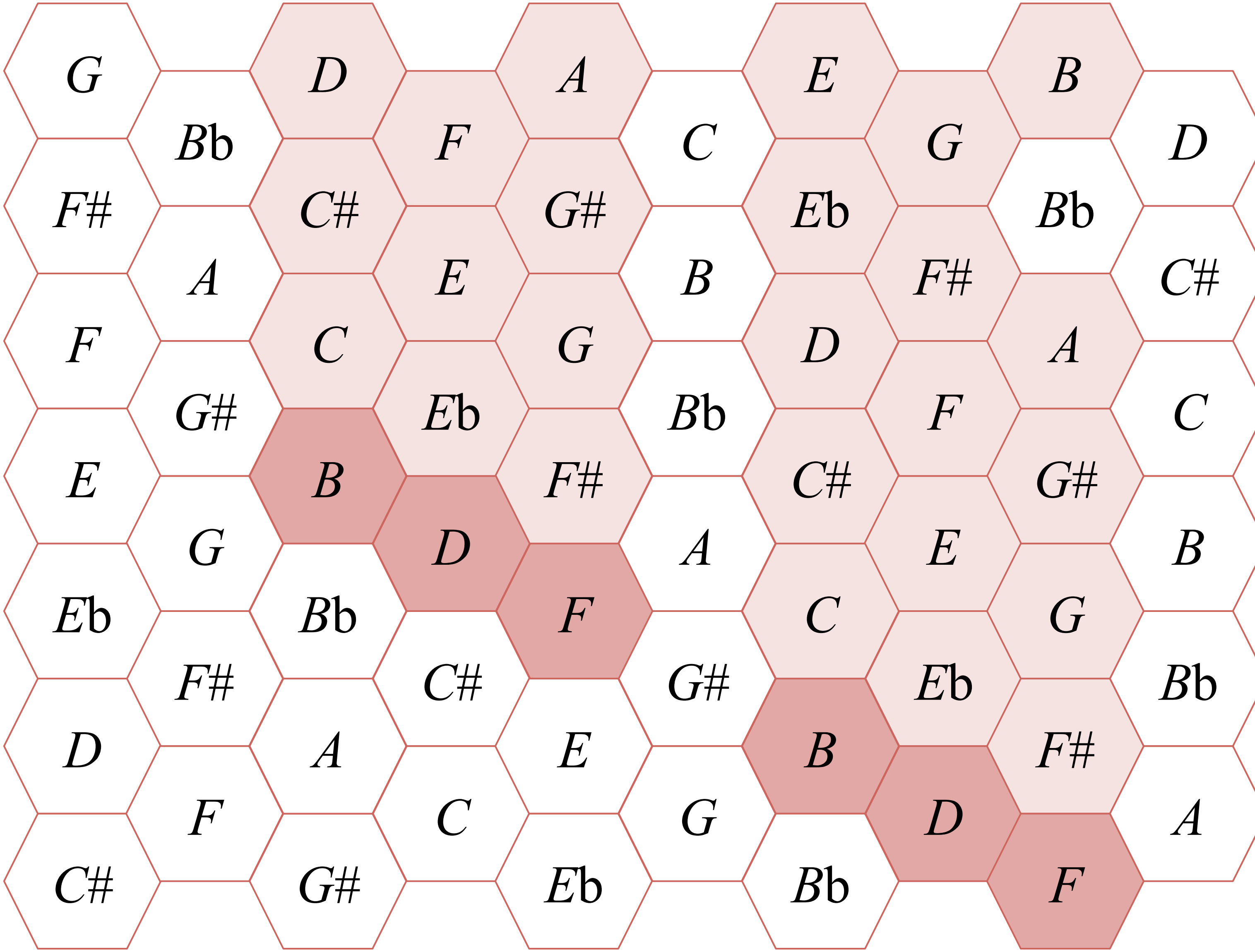

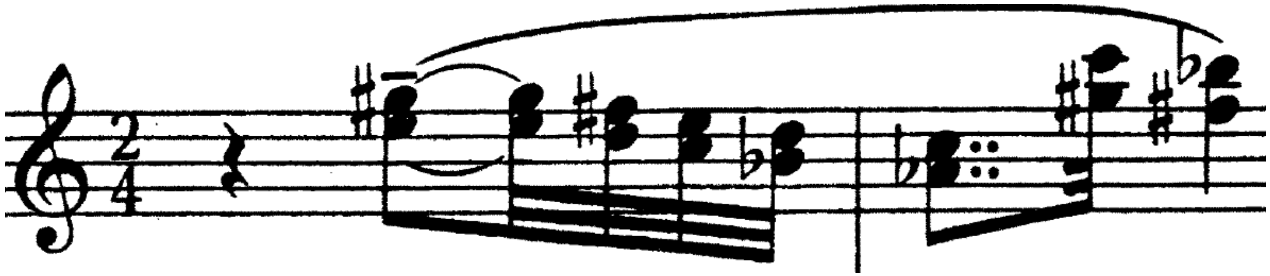

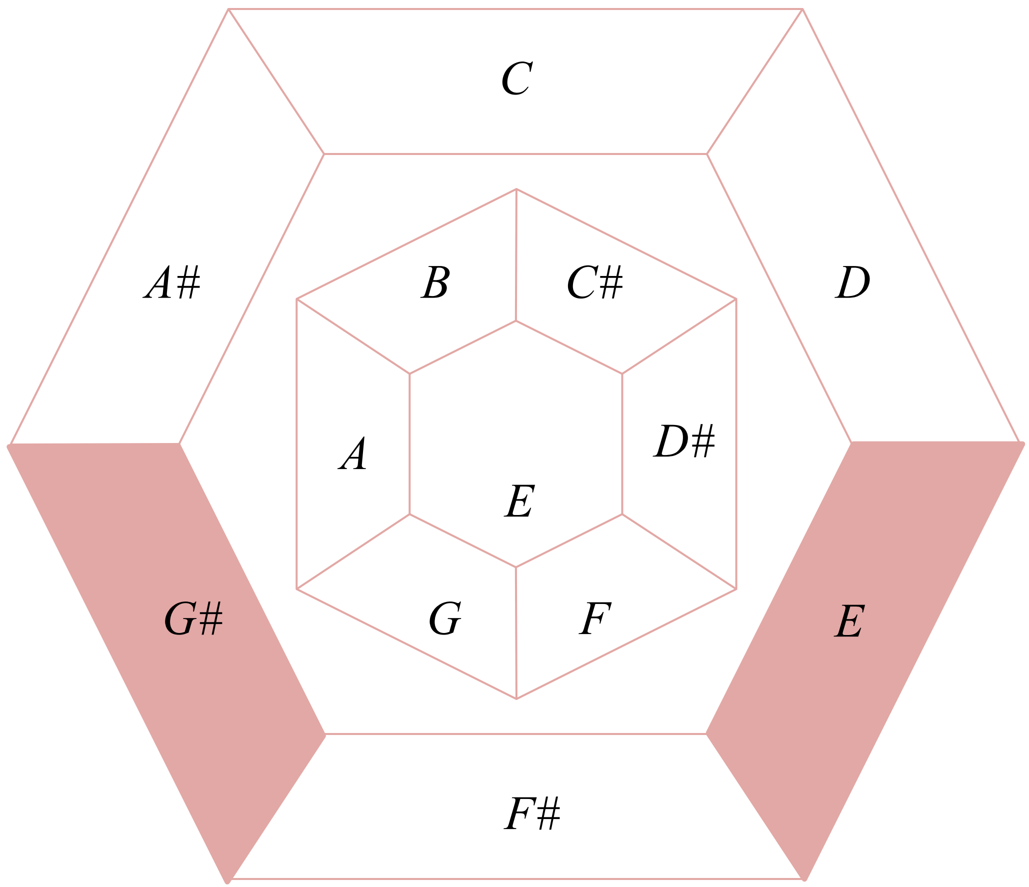
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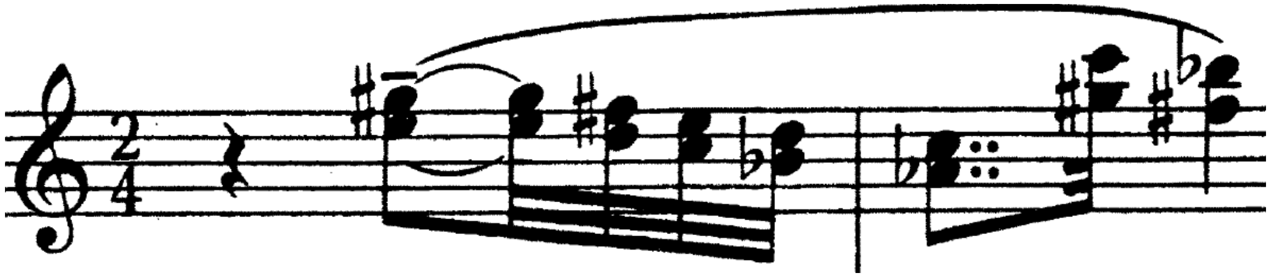

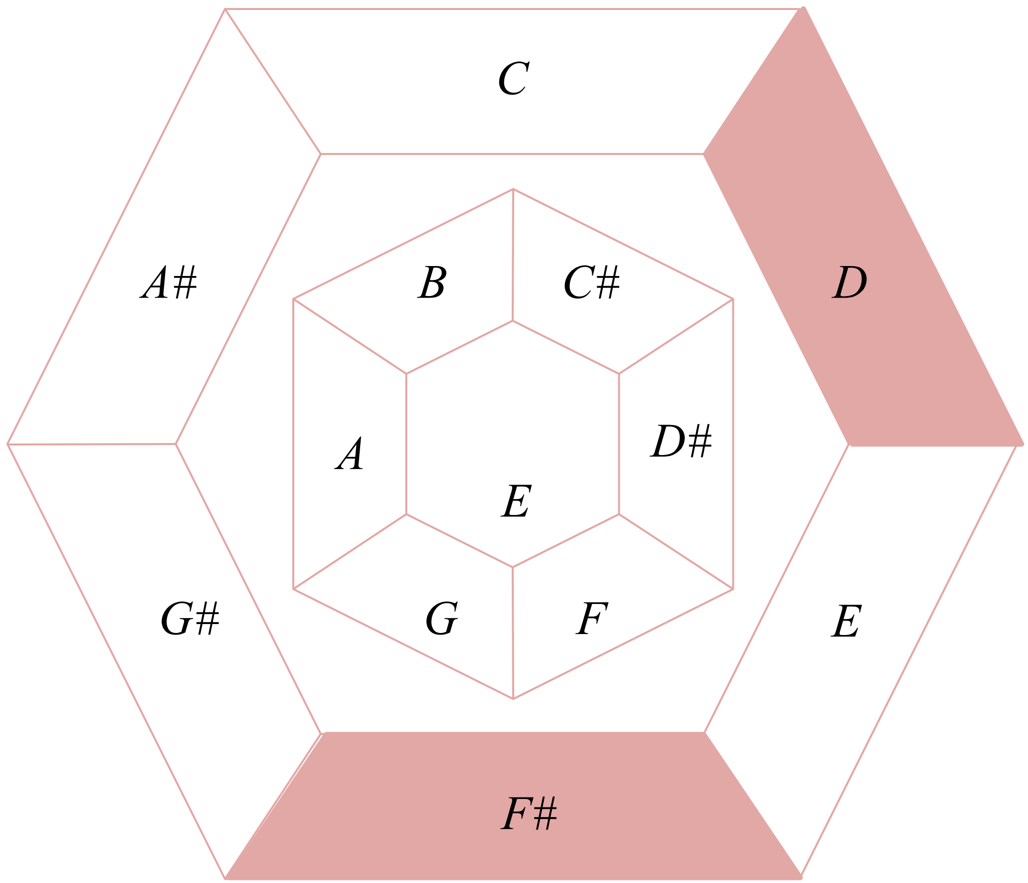
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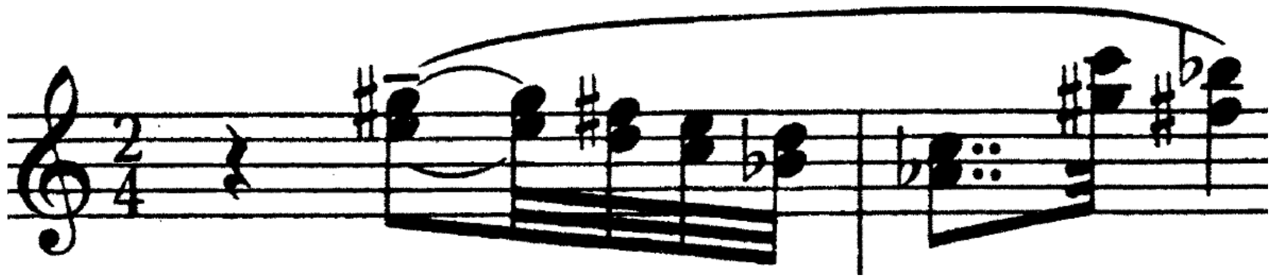

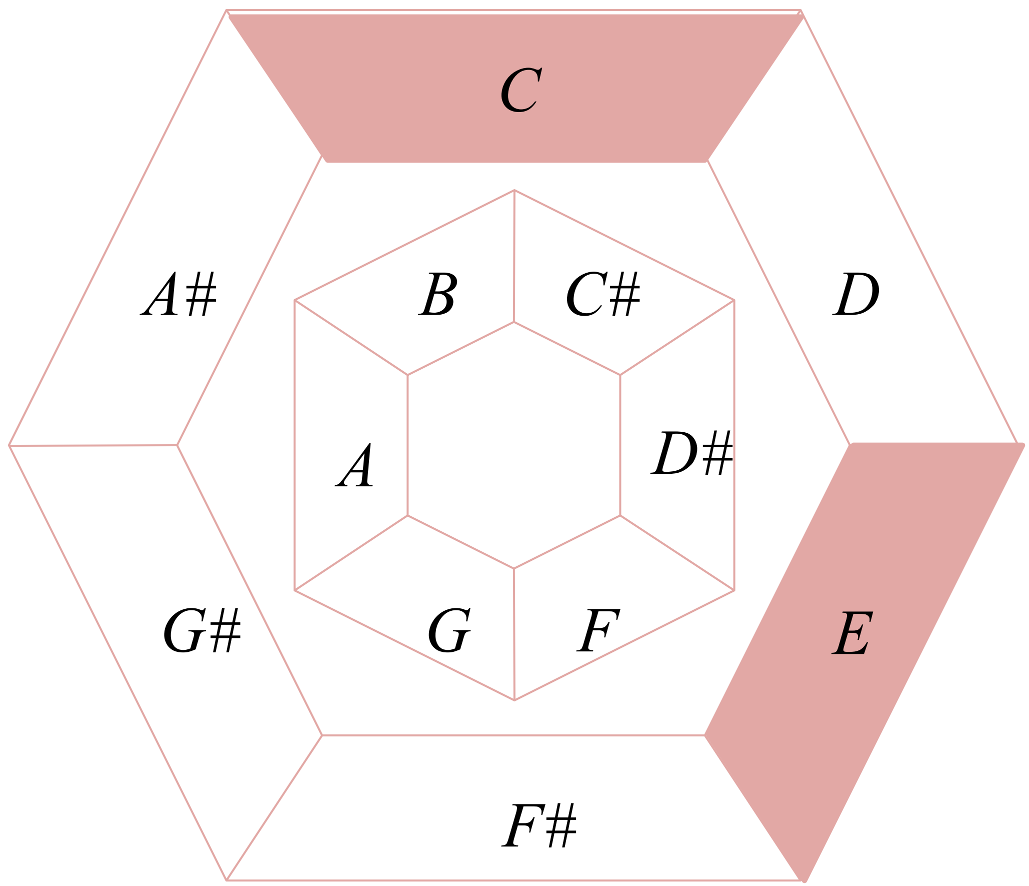
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Spatial Computing & MGS

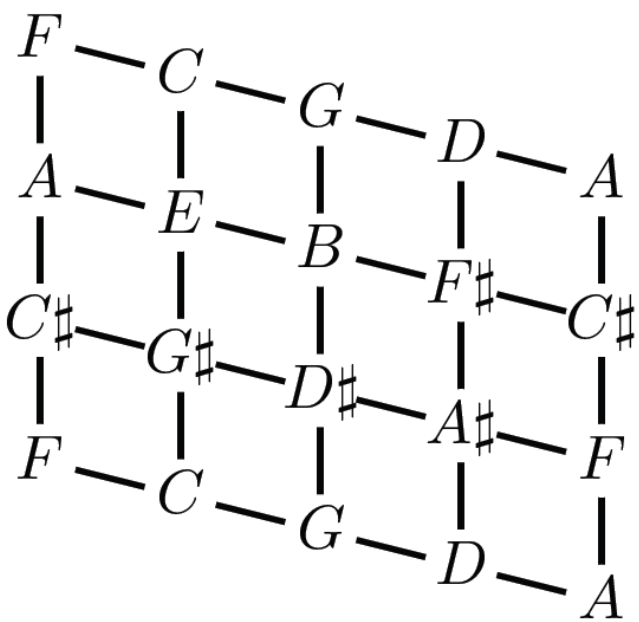
- Spatial computing
  - Compute in space
  - Compute space

- MGS: a programming language for spatial computing
  - Introduction of topological concepts in a programming language
  - Two main principles
    - Data structure: topological collection
    - Control structure: transformation

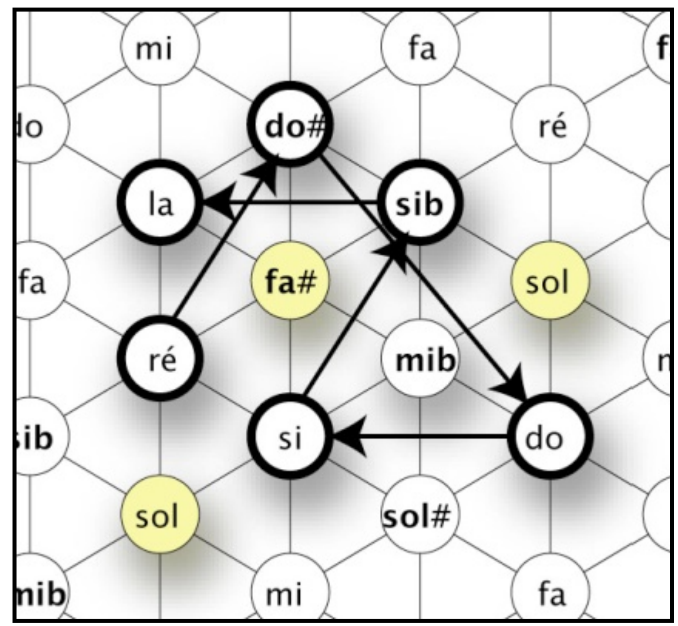
Neo-Riemannian Problematic

- Examples

  Neo-Riemannian approach for tonal music



Euler's tonnetz



Hexagonal network of notes
(J.-M. Chouvel)