THE BEAUTIFUL GEOMETRY OF APERIODIC TESSELLATIONS

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Supervised by Miroslav Lovric

WHAT IS A TESSELLATION?

A SIMPLE TESSELLATION

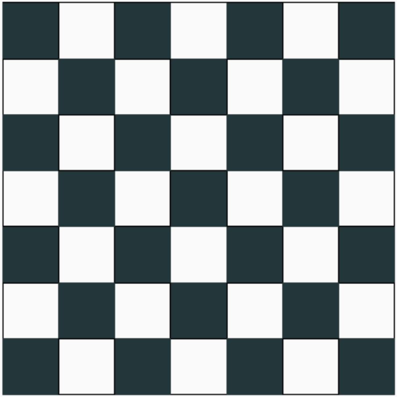


Figure 1: Checkerboard Tessellation

WHAT IS A TESSELLATION?

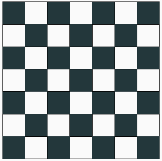
Definition:

A ***tessellation*** $\mathcal{T}$ *of the space* $\mathbb{E}^n$ *is a countable family of closed sets, T, called* tiles*:*

$$\mathcal{T} = \{T_1, T_2, \ldots\}$$

such that

1. $\mathcal{T}$ *has* ***no overlaps****:* $\mathring{T}_i \cap \mathring{T}_j = \emptyset$ *if* $i \neq j$
2. $\mathcal{T}$ *has* ***no gaps****:* $\bigcup_{i=1}^{\infty} T_i = \mathbb{E}^n$



COMPONENTS OF A TESSELLATION

Definition:

Let $\{T_1, T_2, \ldots\}$ be the set of tiles of tessellation $\mathcal{T}$, partitioned into a set of equivalence classes by ***criterion*** *$\mathcal{M}$. The set, $\mathcal{P}$, of representatives of these equivalence classes is called the* ***protoset*** *for $\mathcal{T}$ with respect to $\mathcal{M}$.*

Example:

Criterion: $\mathcal{M} = \{$*Colour of the tile. Only opposite colours may touch.*$\}$

Protoset:

$$\mathcal{P} = \{ \blacksquare , \square \}$$

PROTOSETS ADMIT TESSELLATIONS

Definition:

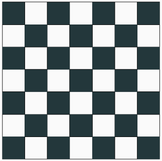
If $\mathcal{T}$ is a tessellation with protoset $\mathcal{P}$, then we say that $\mathcal{P}$ admits $\mathcal{T}$.

Example:

We say

$$\mathcal{P} = \{ \blacksquare , \square \}$$

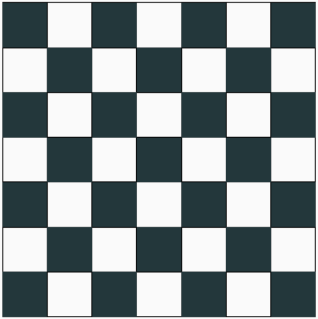
admits



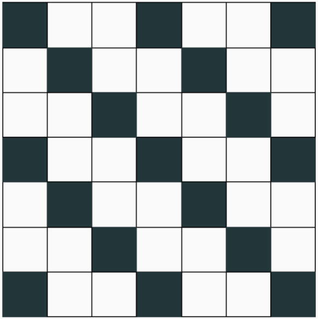
PROTOSETS CAN ADMIT MULTIPLE TESSELLATIONS

$$\mathcal{P} = \{ \blacksquare , \square \}$$

admits both



and



MATCHING RULES CORRESPOND TO DEFORMED PROTOSETS

Edge deformations can force matching rules.

$\mathcal{P} = \{$  ,  $\}$

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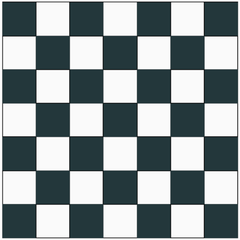

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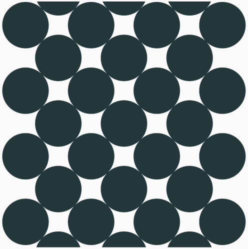


Matching Rules $\implies$ Deformed Protoset

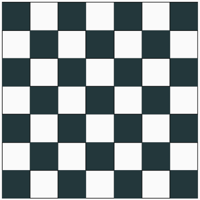
DESCRIBING TESSELLATIONS

Definition:

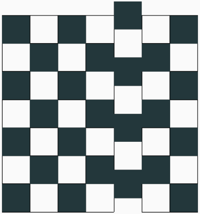
A tessellation is said to be ***periodic*** *if it admits translational symmetry in two directions.*

Definition:

A tessellation is said to be ***non-periodic*** *if it admits no translational symmetries.*



Periodic



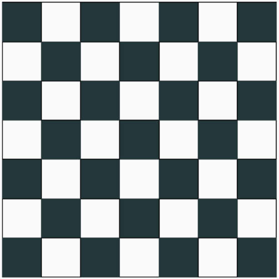
Non-Periodic

THE APERIODIC QUESTION

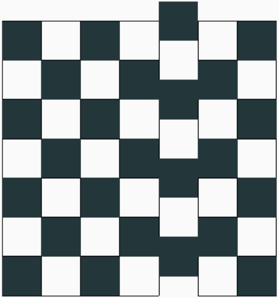
Checkerboard protoset,

$$\mathcal{P} = \{ \blacksquare , \square \}$$

admits both **periodic** and **non-periodic** tessellations.



Periodic



Non-Periodic

Checkerboard protoset,

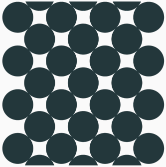
$$\mathcal{P} = \{ \blacksquare , \square \}$$

admits both **periodic** and **non-periodic** tessellations.

Some protosets,

$$\mathcal{P} = \{ \bullet , \square \}$$

admit only **periodic** tessellations.



THE APERIODIC QUESTION

Checkerboard protoset,

$$\mathcal{P} = \{ \blacksquare , \square \}$$

admits both **periodic** and **non-periodic** tessellations.

Some protosets,

$\mathcal{P} = \{ \bullet ,$  $\}$

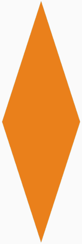
admit only **periodic** tessellations.

Are there any protosets,

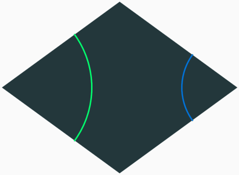
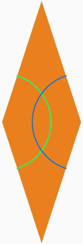
$$\mathcal{P} = \{?\}$$

that admit only **non-periodic** tessellations?

AN APERIODIC TESSELLATION

$\mathcal{P} = \{$  ,  $\}^*$

$*$ With matching rules

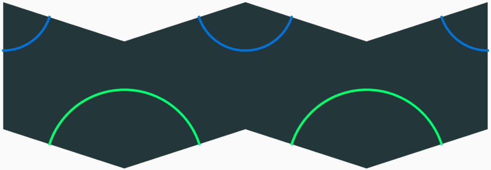
$\mathcal{P} = \{$  ,  $\}$

admits only **non-periodic** tessellations, called Penrose Tessellations.

Cannot be constructed through local procedures.

Example:

This arrangement

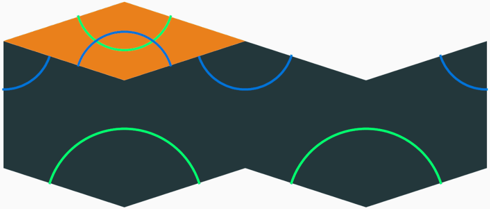


follows the matching rules.

Cannot be constructed through local procedures.

Example:

This arrangement

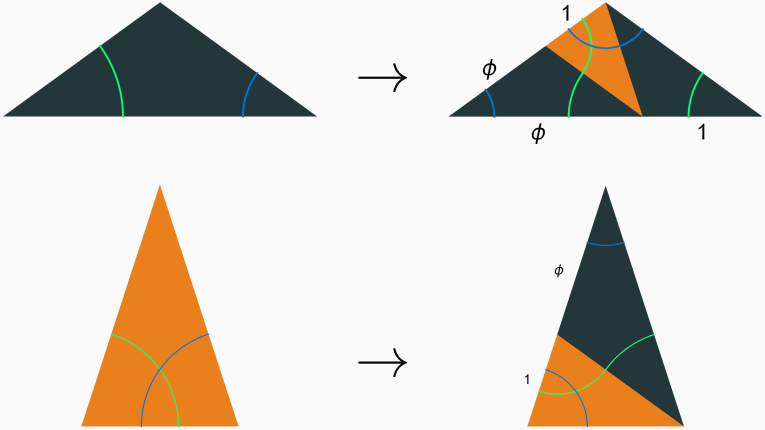


follows the matching rules, but is a mistake:

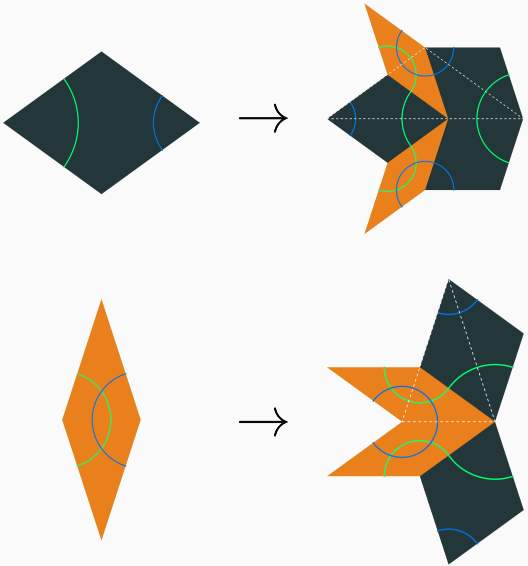
CONSTRUCTION BY SUBSTITUTION

SUBSTITUTION RULES ON ROBINSON TRIANGLES

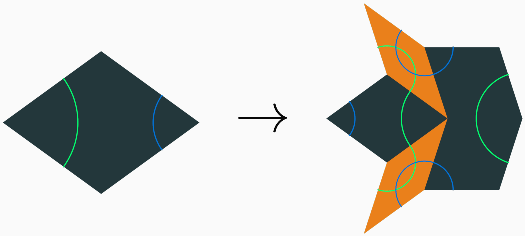
First, consider the Rhombs as joined triangles:

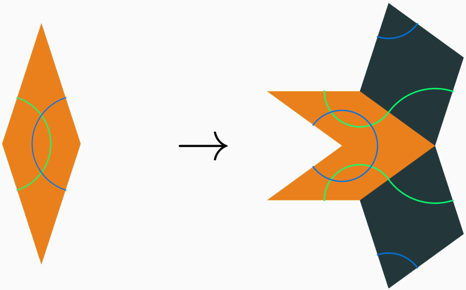


SUBSTITUTION RULES ON PENROSE RHOMBS

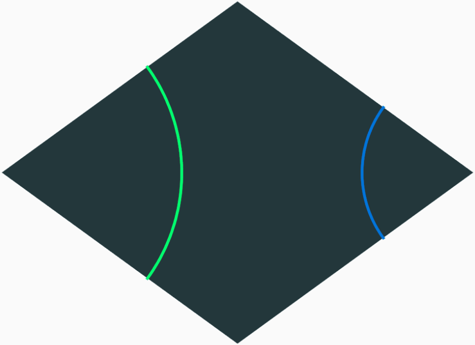


SUBSTITUTION RULES ON PENROSE RHOMBS

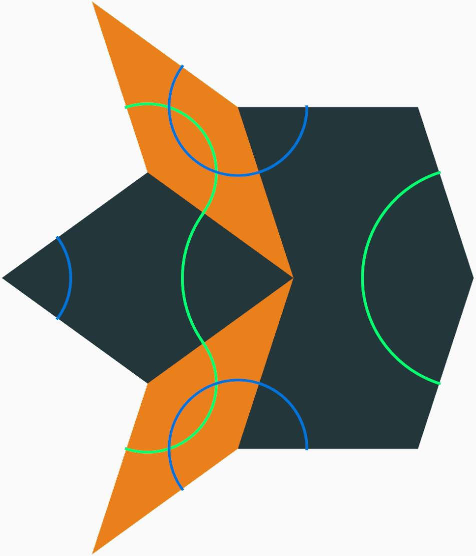




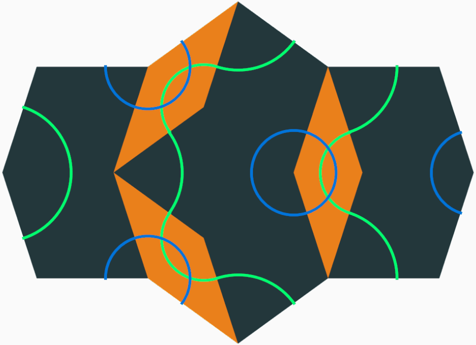
START WITH A SEED: THICK RHOMBUS



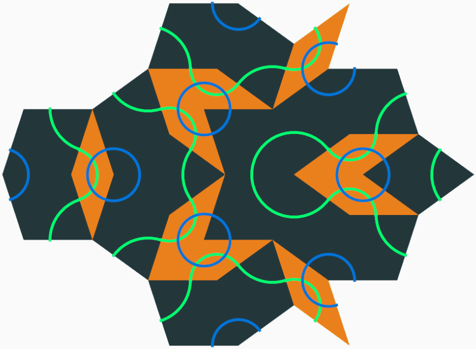
APPLY SUBSTITUTION RULES



APPLY SUBSTITUTION RULES AGAIN



APPLY SUBSTITUTION RULES AGAIN AND AGAIN



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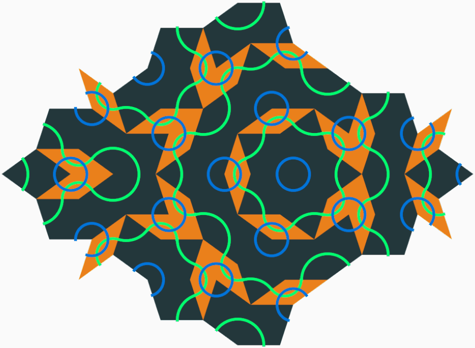

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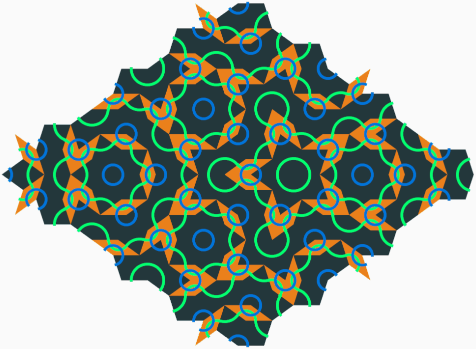
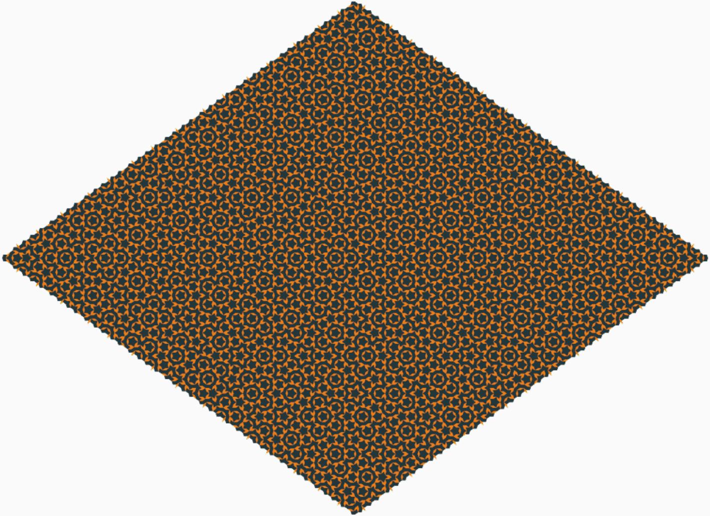


APPLY SUBSTITUTION RULES 10 TIMES

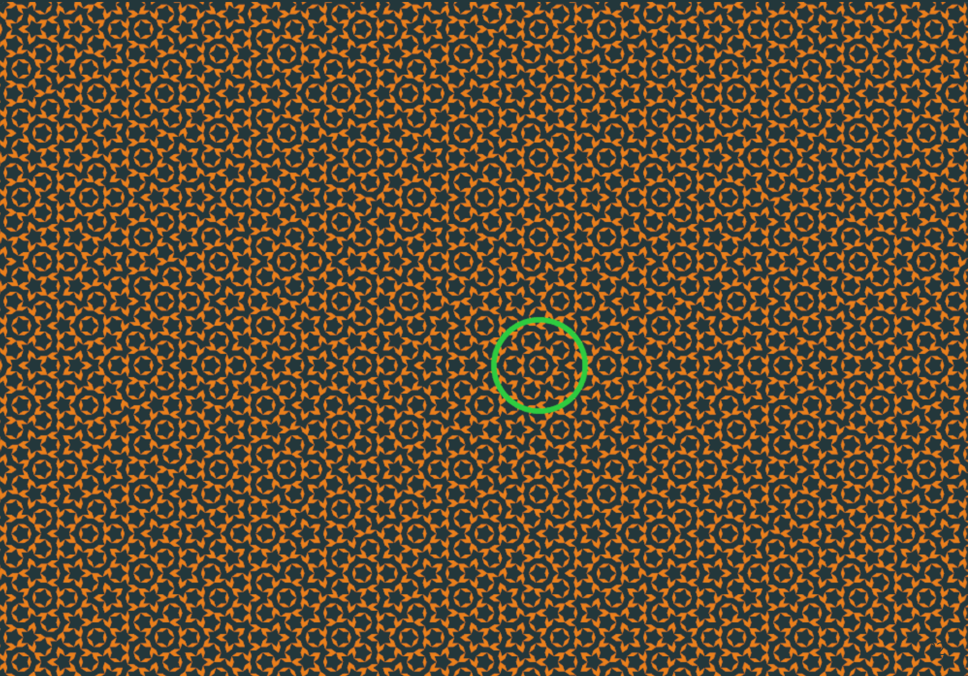


APPLY SUBSTITUTION RULES 11 TIMES

PENROSE TESSELLATION FEATURES

Any pattern with diameter d will begin repeating within $2d\phi$ from the perimeter.

DENSITY OF PATTERNS



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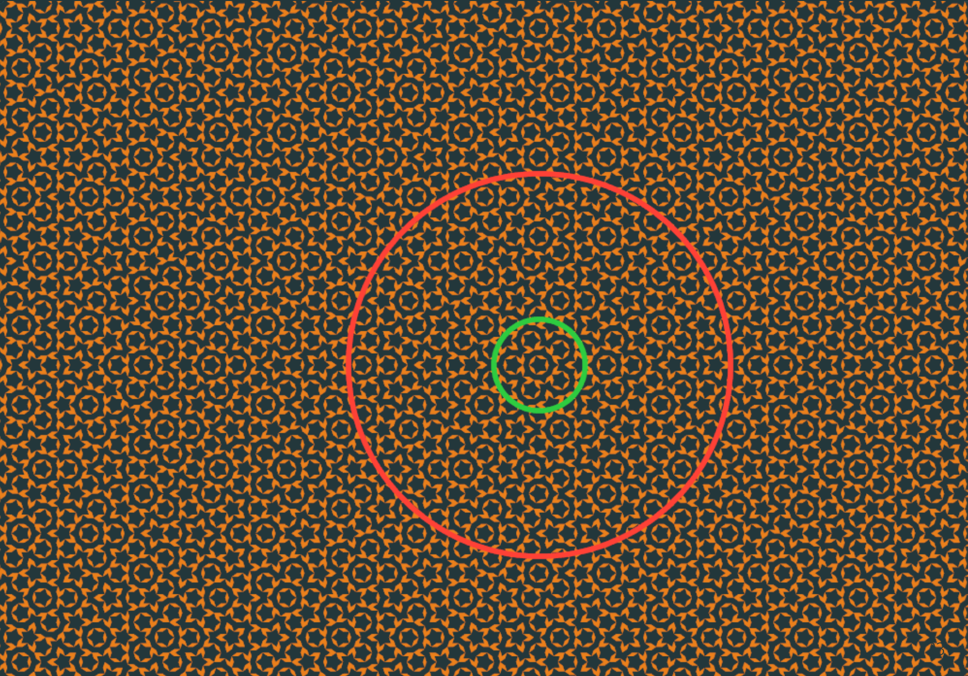

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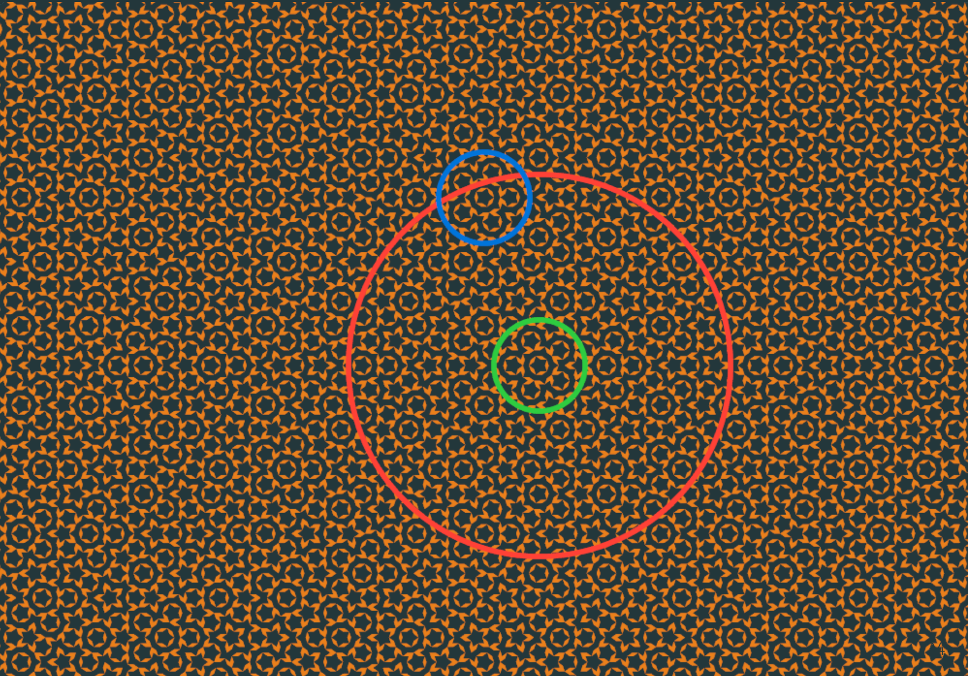

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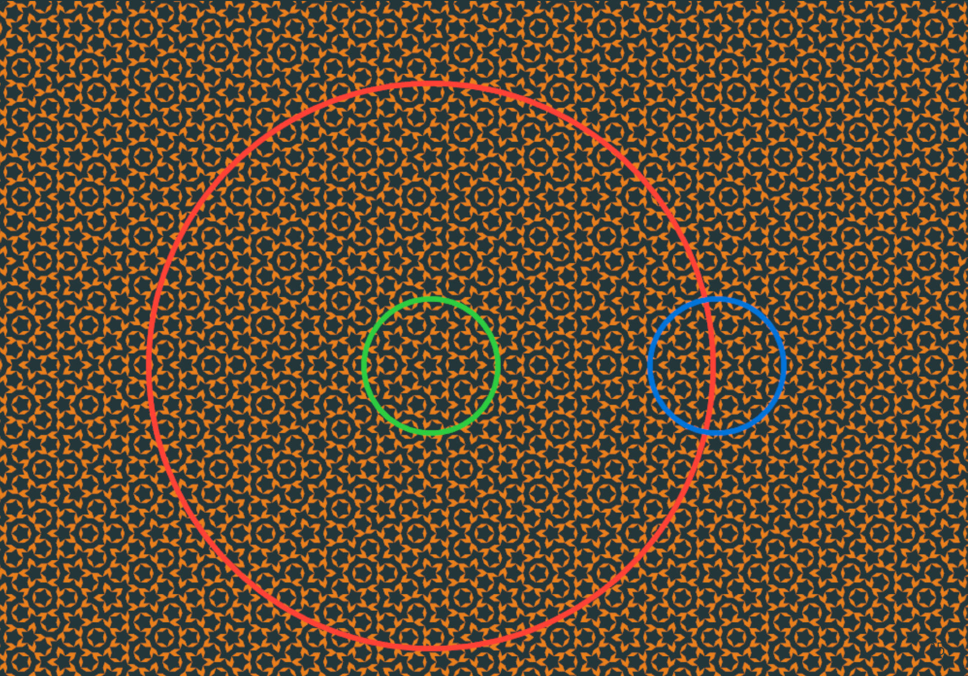

Penrose Tessellations can admit five-fold rotational symmetry.
(Impossible for periodic tessellations)