

LOMBARDI DRAWINGS OF KNOTS AND LINKS

PHILIPP	KINDERMANN
STEPHEN	KOBOUROV
MAARTEN	LÖFFLER
MARTIN	NÖLLENBURG
ANDRÉ	SCHULZ
BIRGIT	VOGTENHUBER





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23rd International Symposium on
 Graph Drawing & Network Visualization
 September 24-26, Los Angeles, CA

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KNOTS



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KNOTS

A **KNOT** IS A CLOSED CURVE
EMBEDDED IN \mathbb{R}^3



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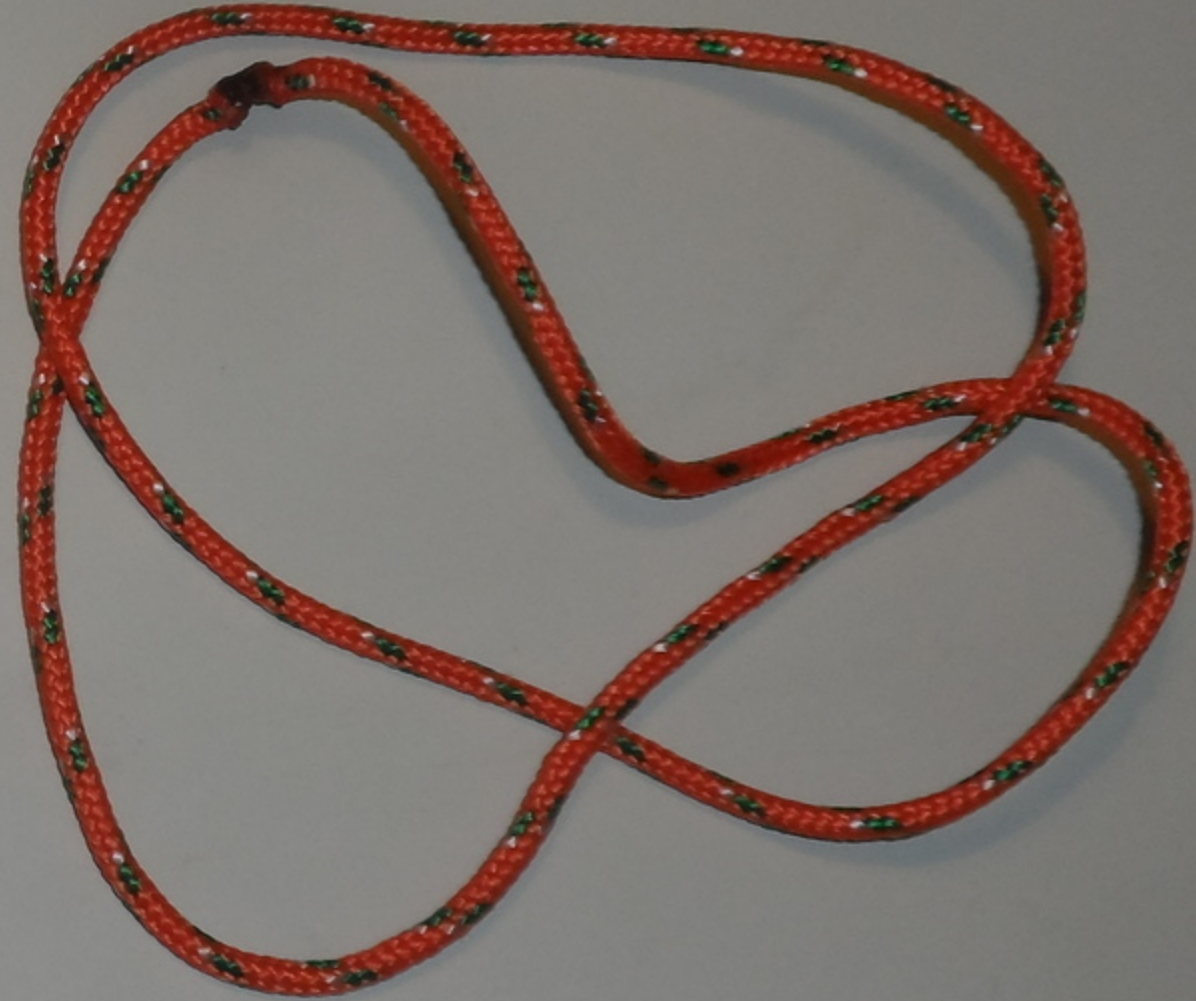
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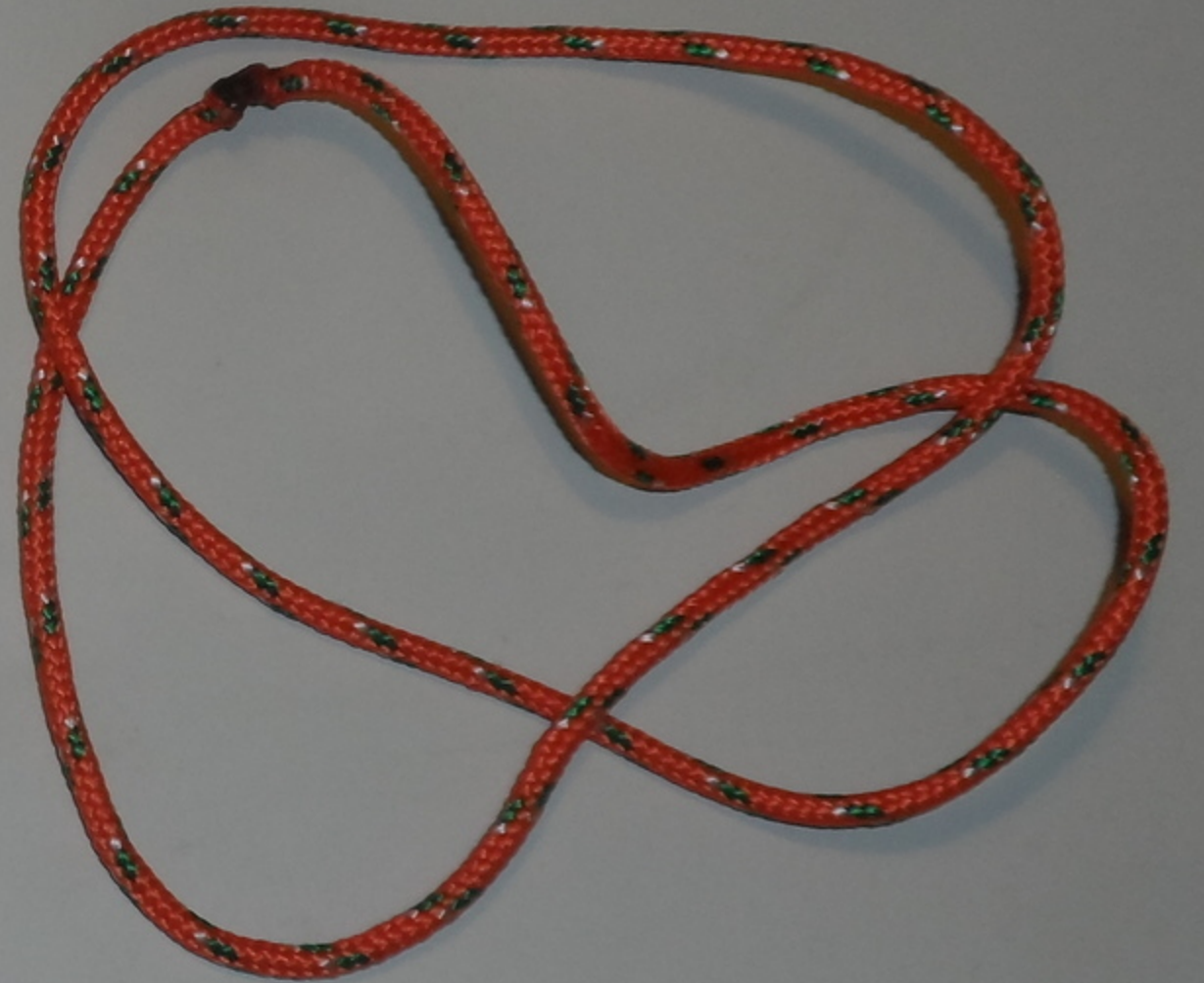
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TWO KNOTS ARE **EQUIVALENT**
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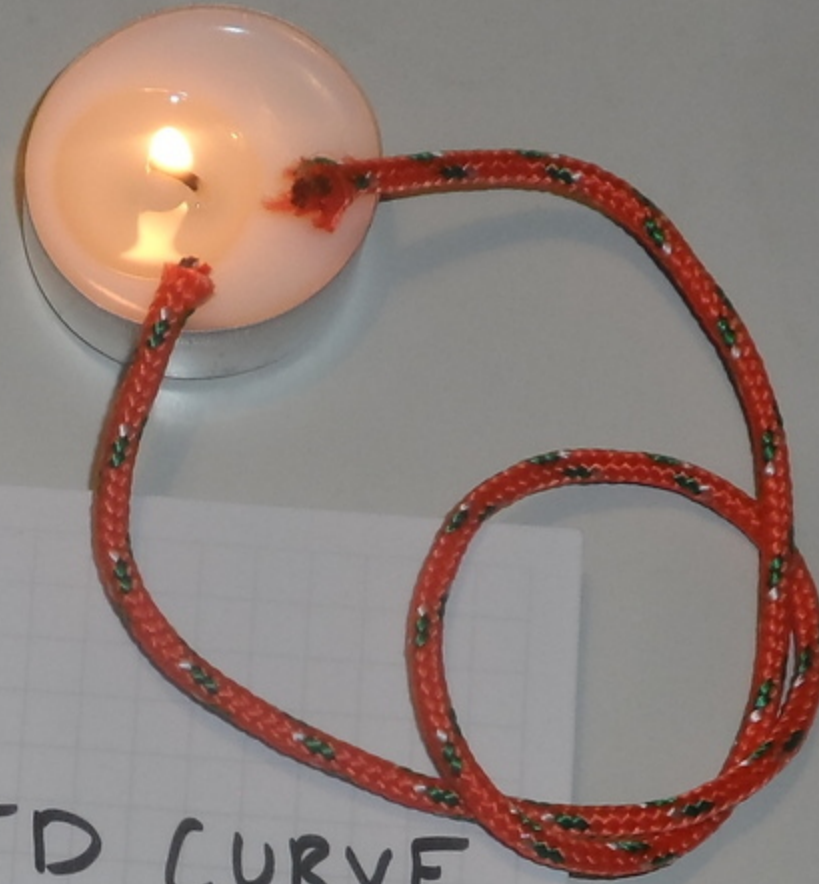
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KNOT DIAGRAMS



KNOT DIAGRAMS

A **DIAGRAM** OF A KNOT IS
A PROJECTION OF A KNOT
TO \mathbb{R}^2



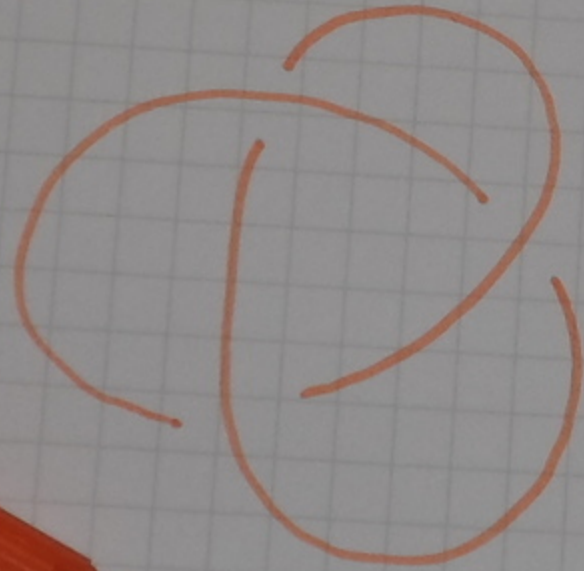
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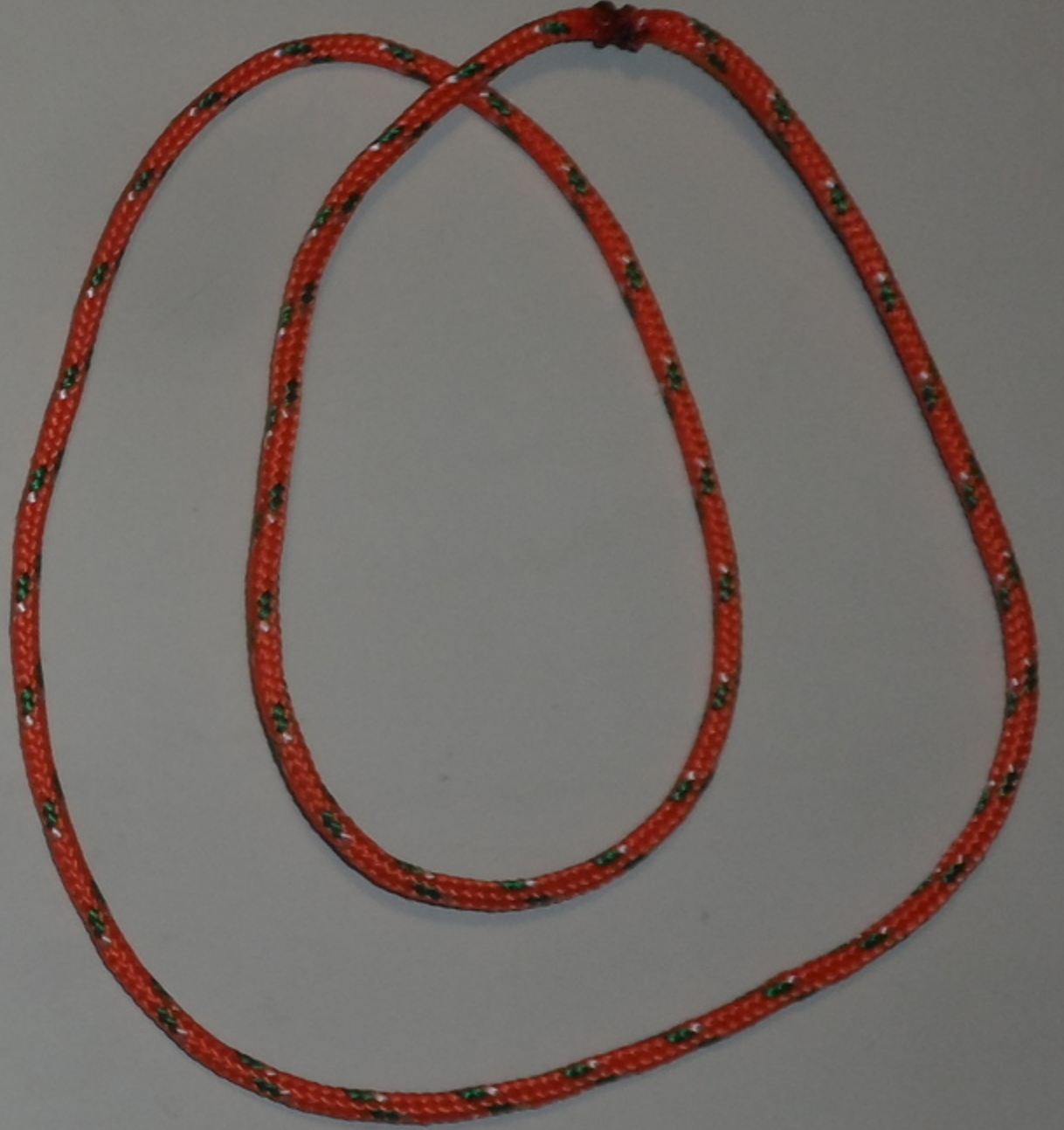
KNOT DIAGRAMS

A SINGLE KNOT CAN HAVE
DISTINCT GRAPHS AS ITS
PROJECTION



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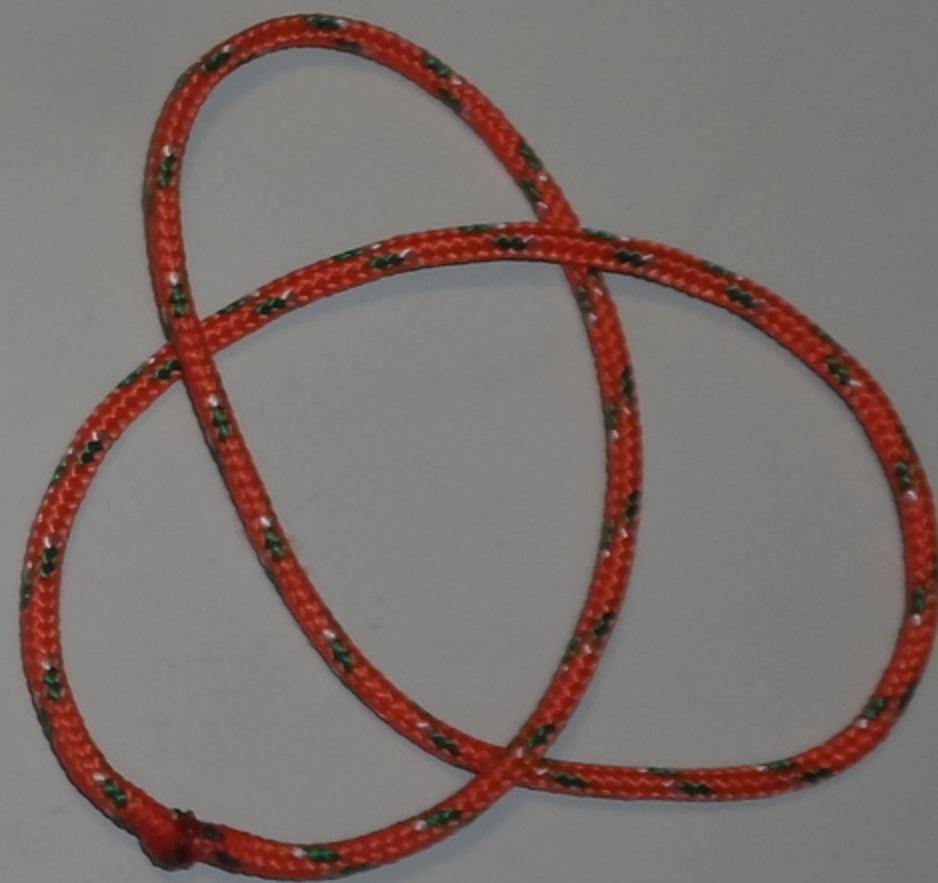


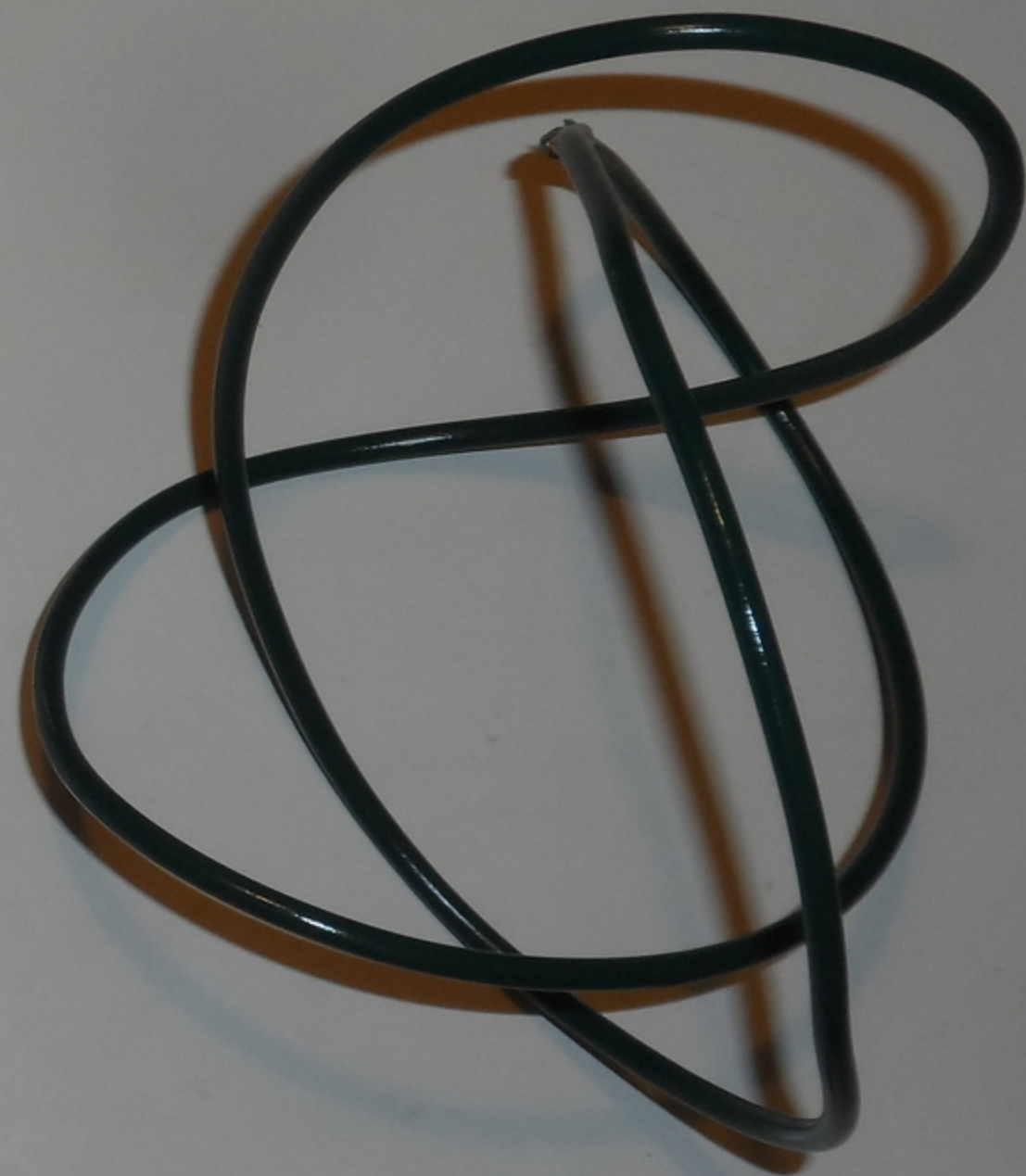


KNOT DIAGRAMS

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A **MINIMAL** DIAGRAM HAS
THE SMALLEST POSSIBLE
NUMBER OF CROSSINGS





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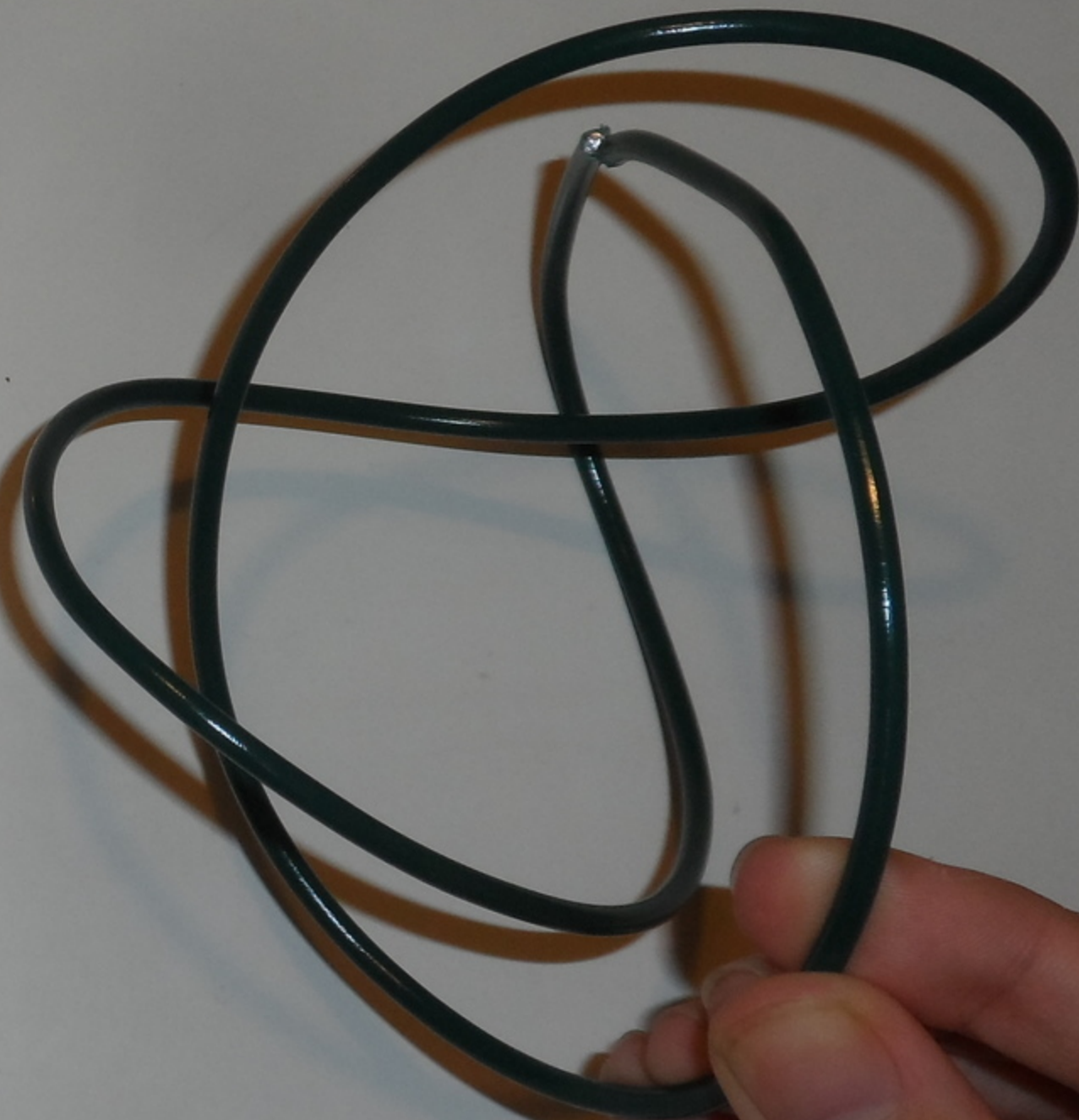
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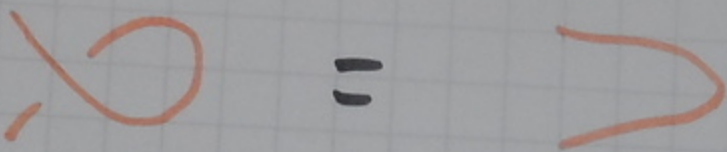
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REIDEMEISTER MOVES

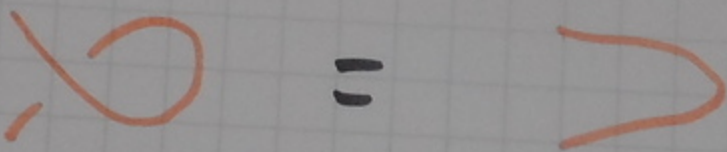
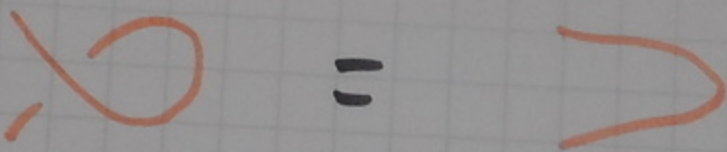


REIDEMEISTER MOVES

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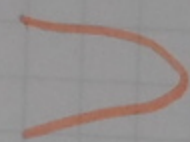


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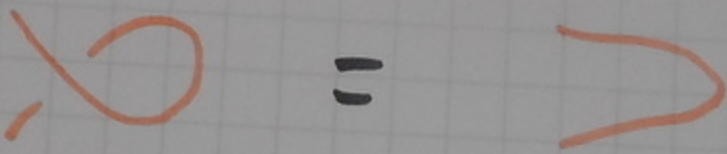


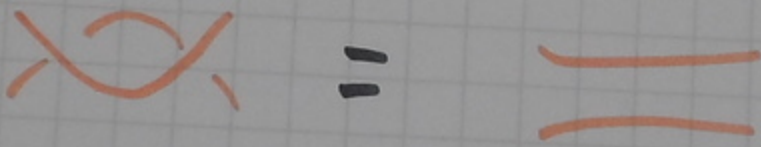
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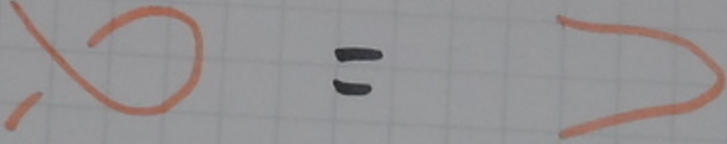
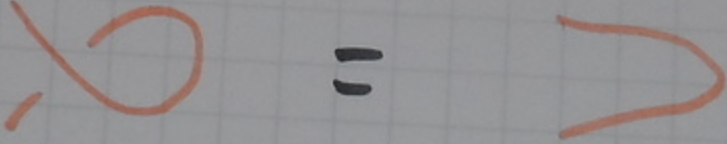
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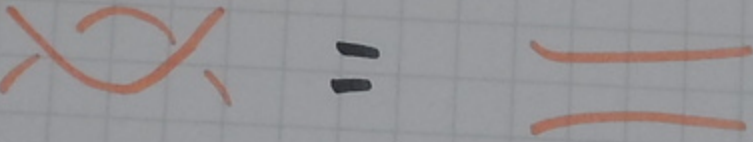
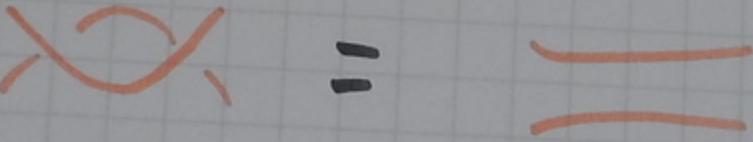
TYPE I 

TYPE II 



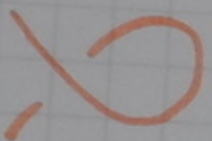
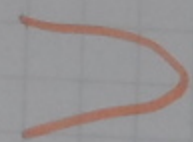
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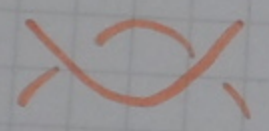
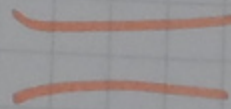
TYPE I  " 

TYPE II  " 



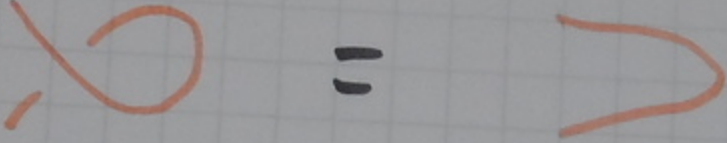
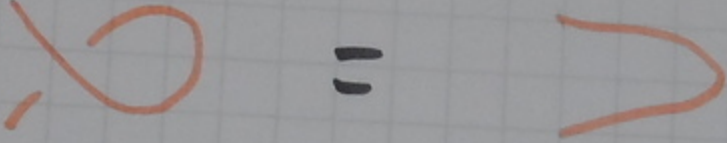
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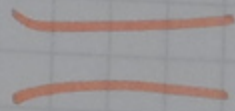
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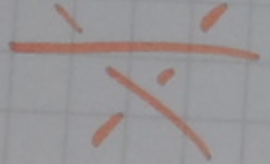
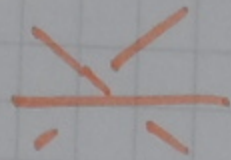
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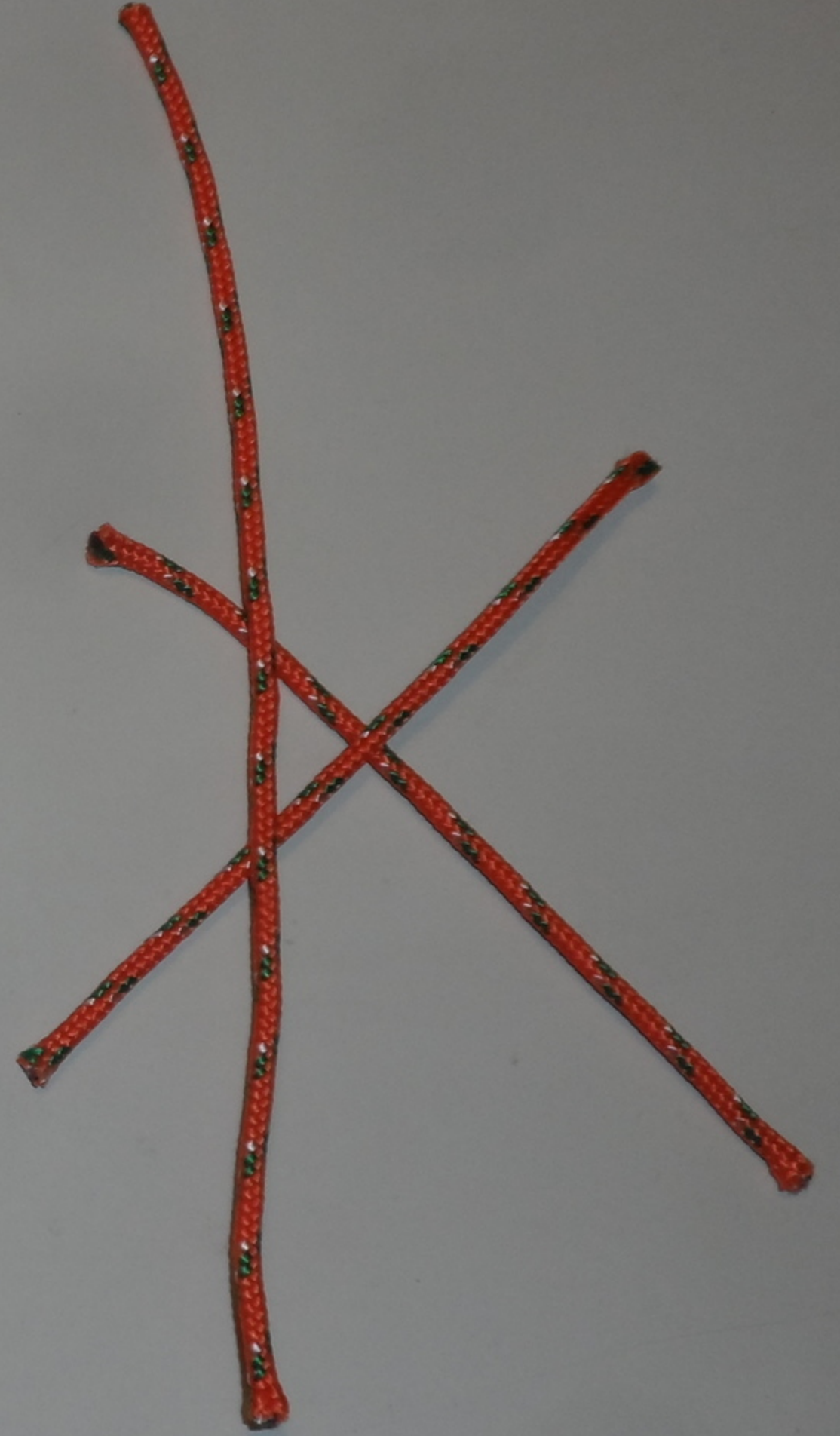


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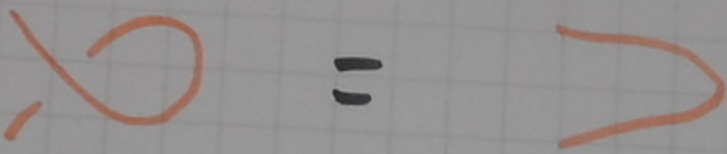
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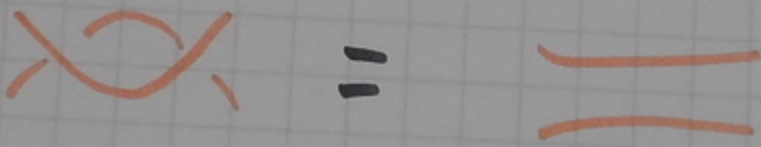
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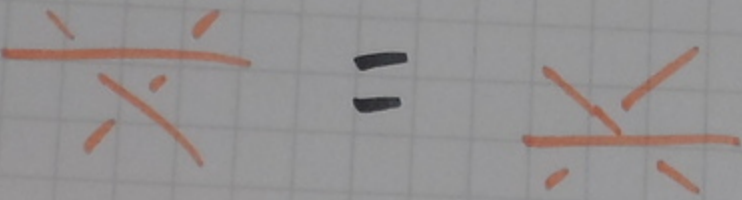
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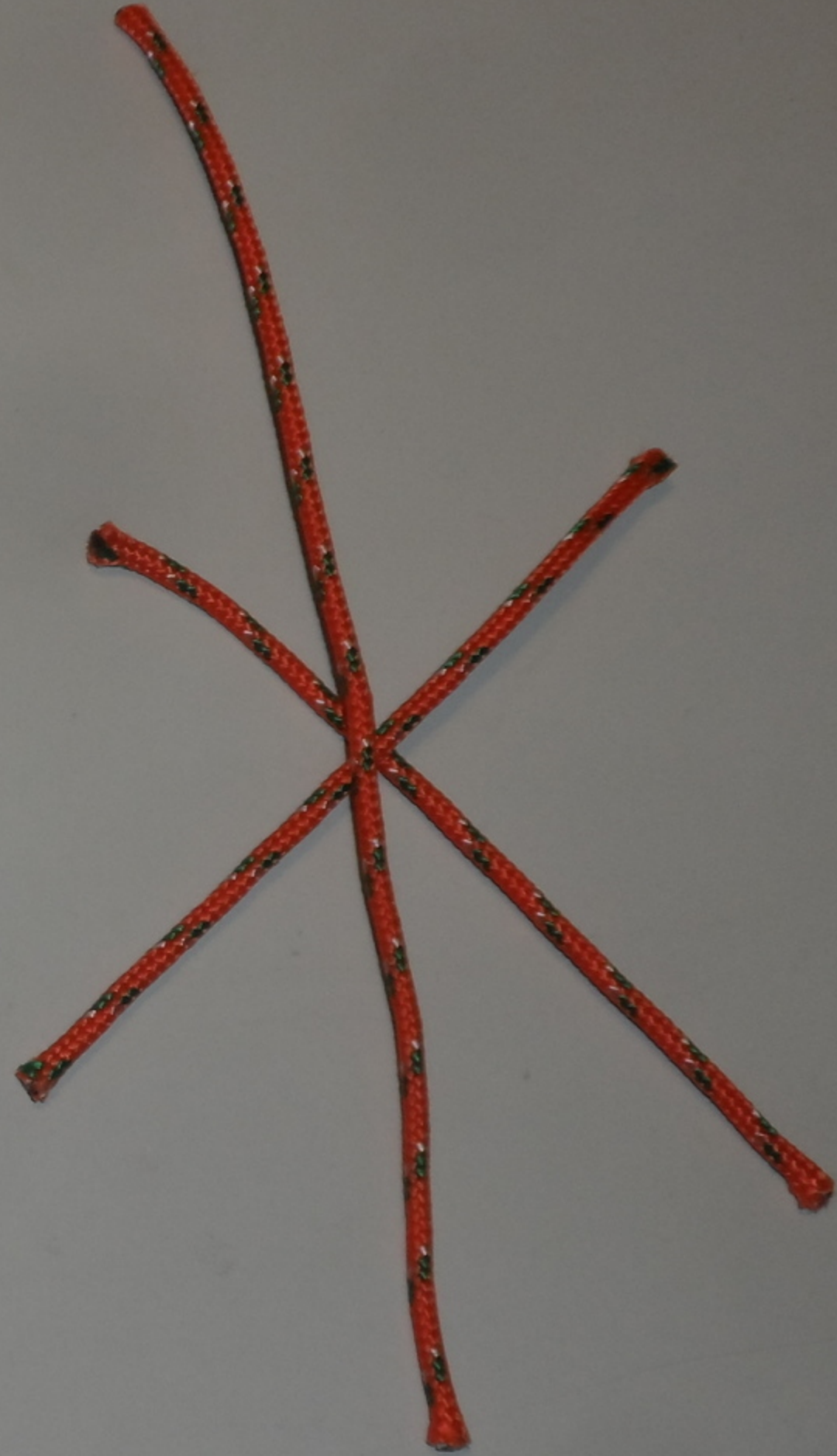


REIDEMEISTER MOVES

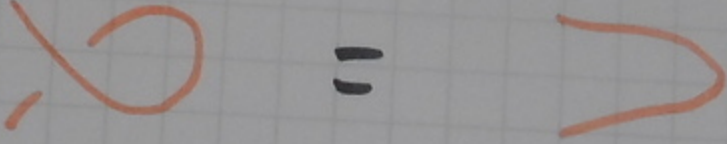
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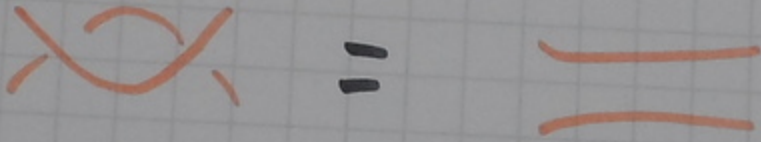
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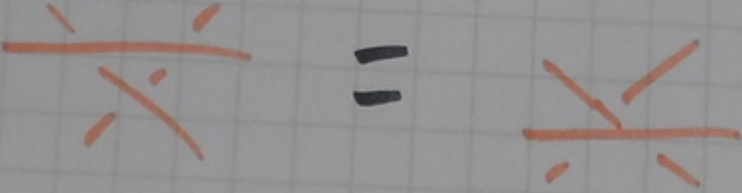
TYPE III 



REIDEMEISTER MOVES

TYPE I 

TYPE II 

TYPE III 



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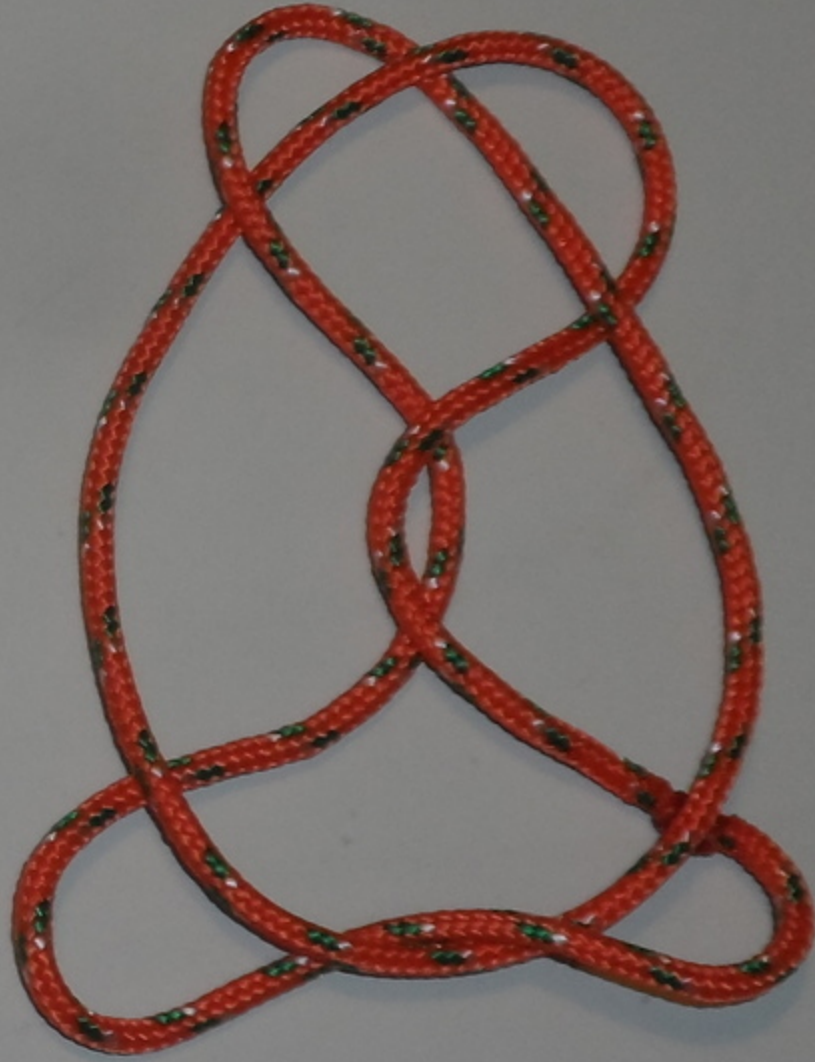
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LET K' BE A SMOOTH
IMMERSION OF A KNOT K



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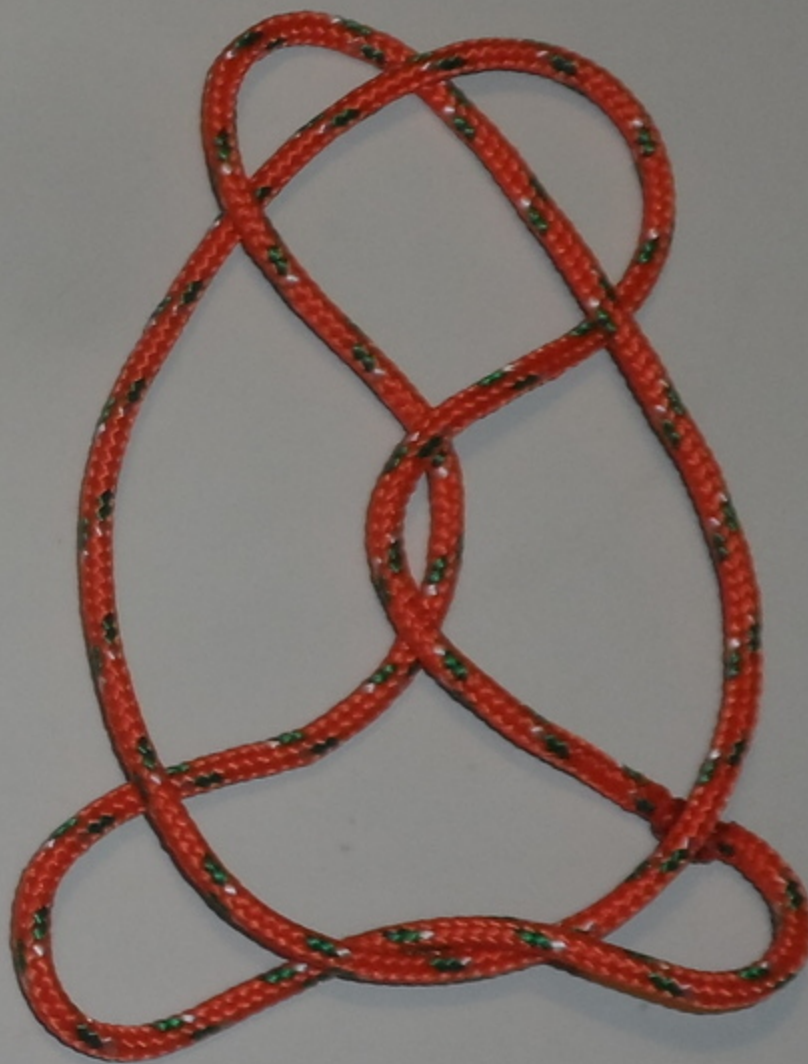
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$$V^1(K') = V(K_+) - V(K_-)$$



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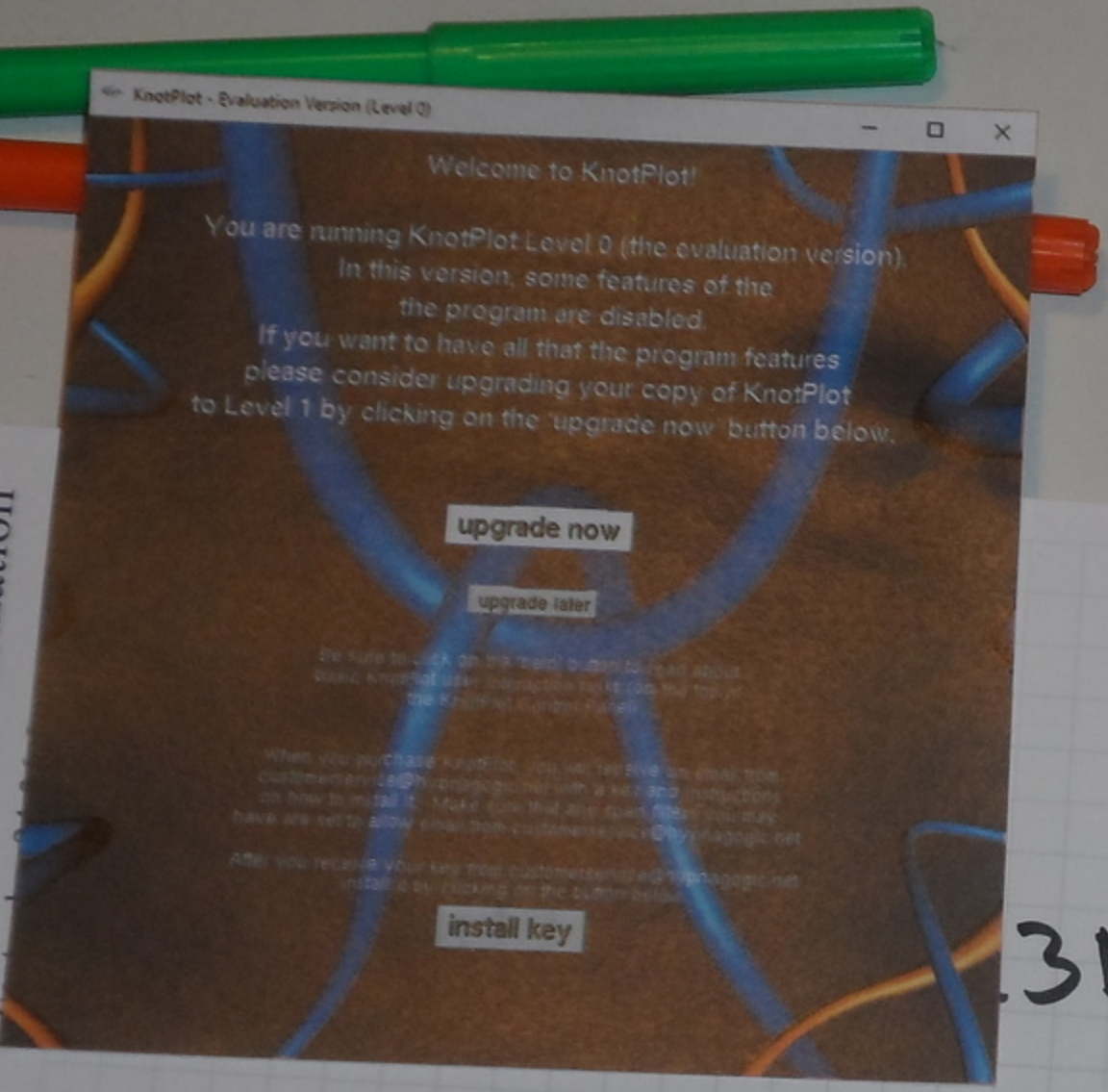
SOFTWARE

KNOTPLOT (3D)



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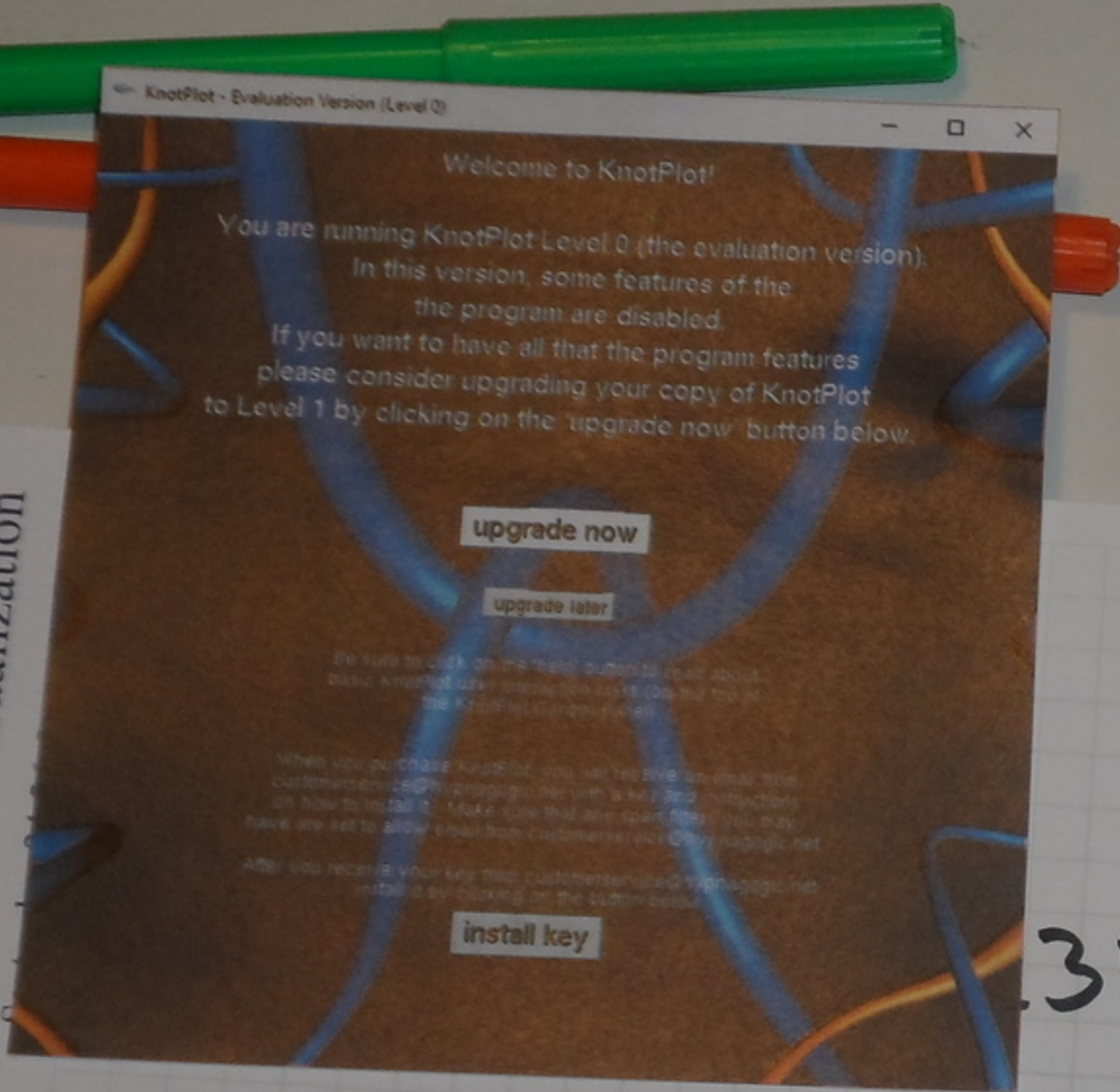


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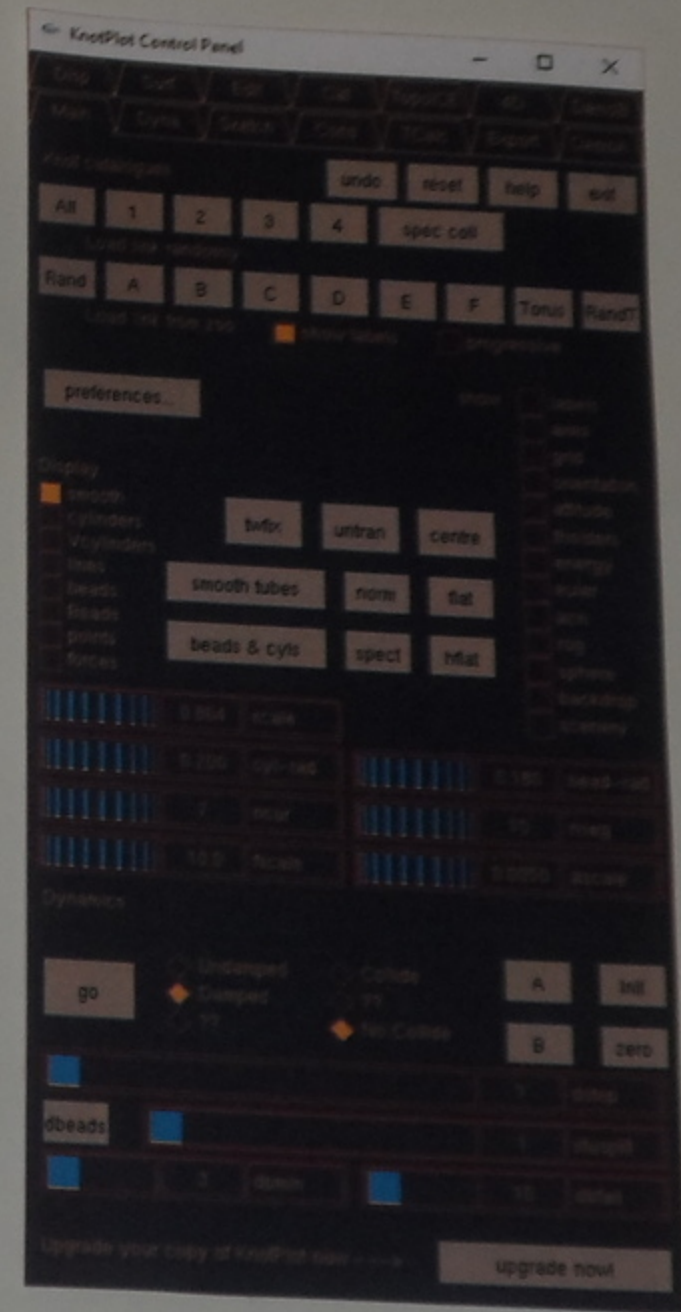


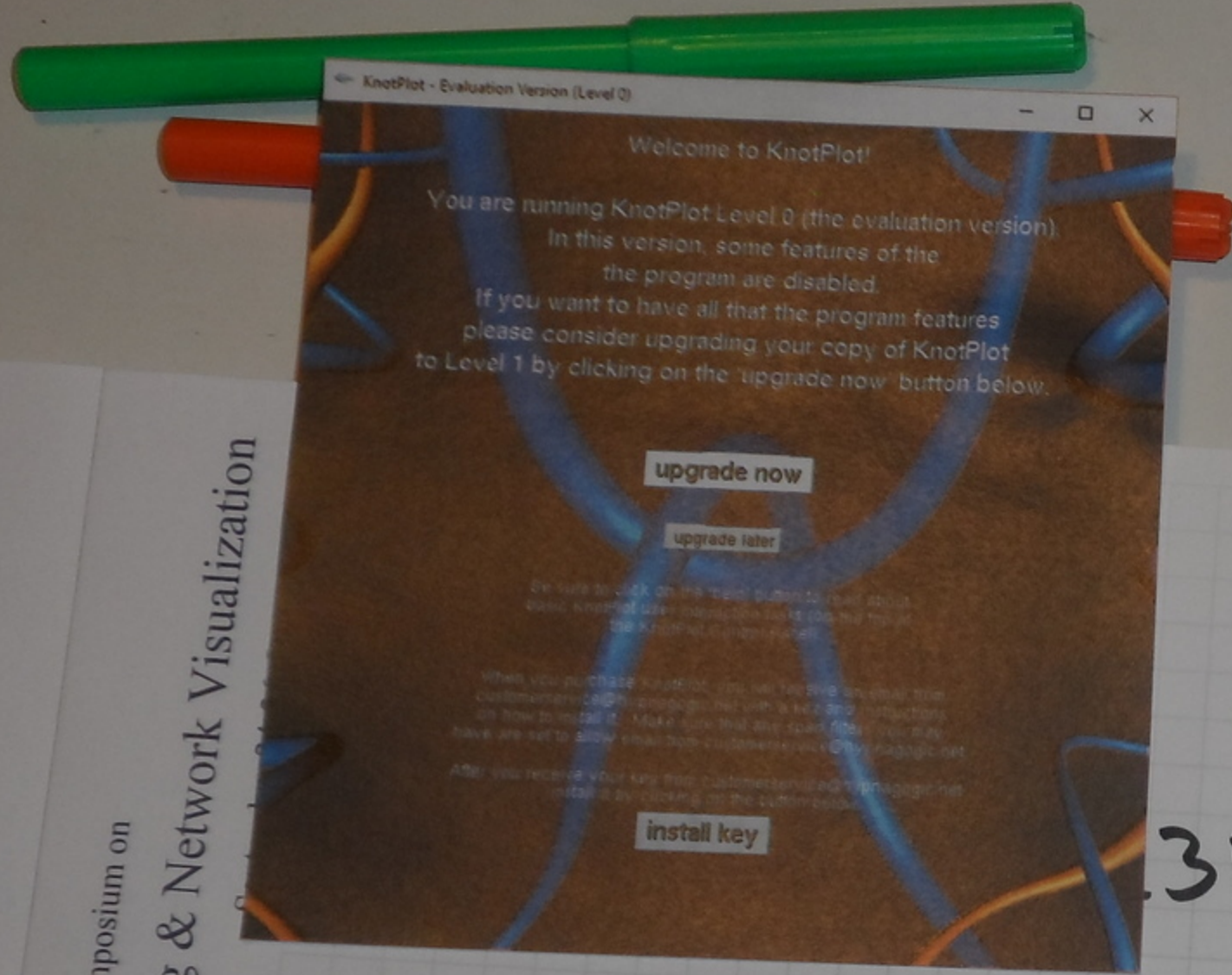
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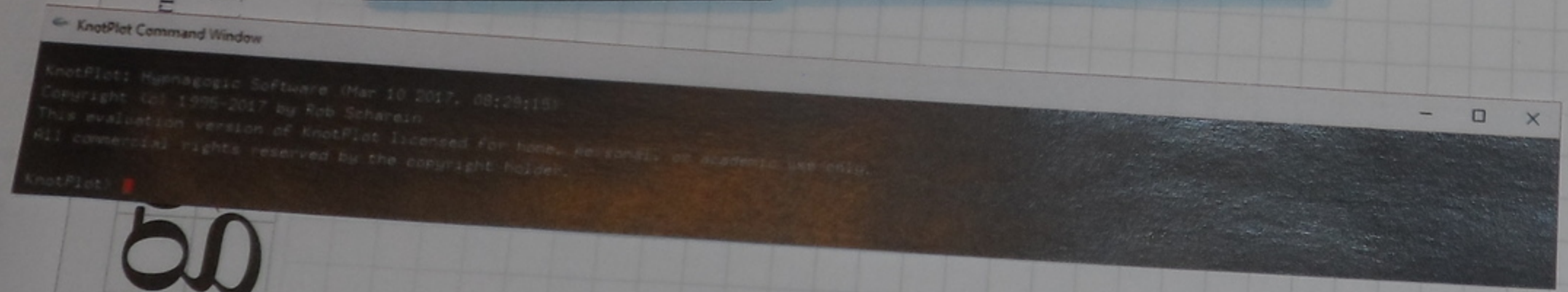




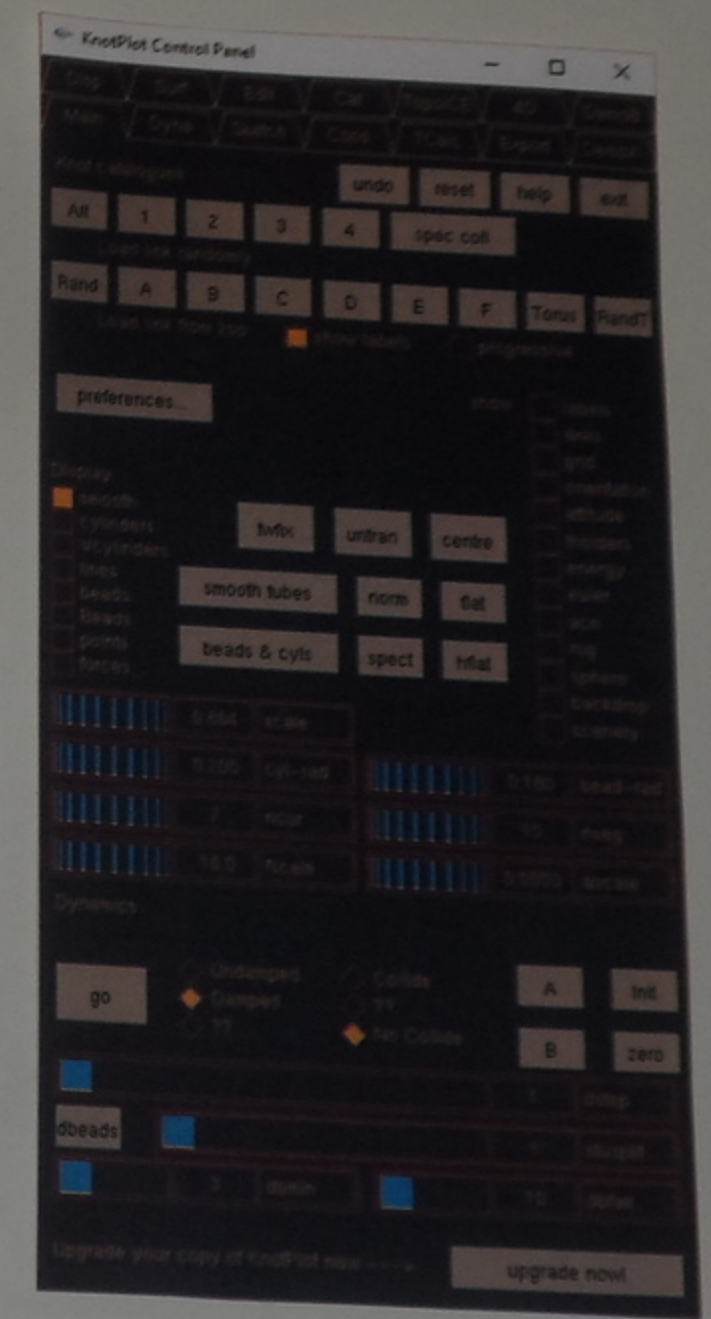
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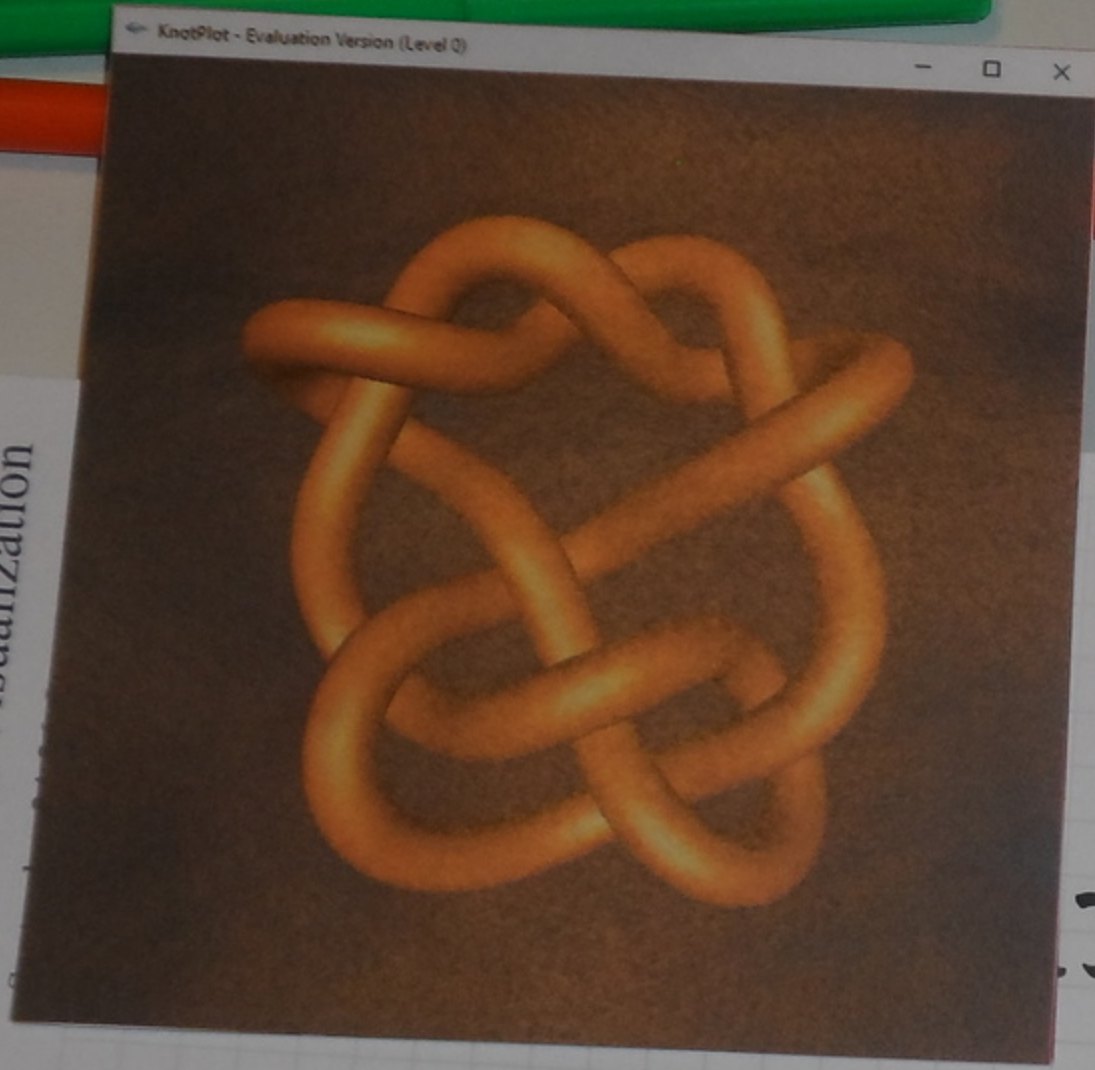
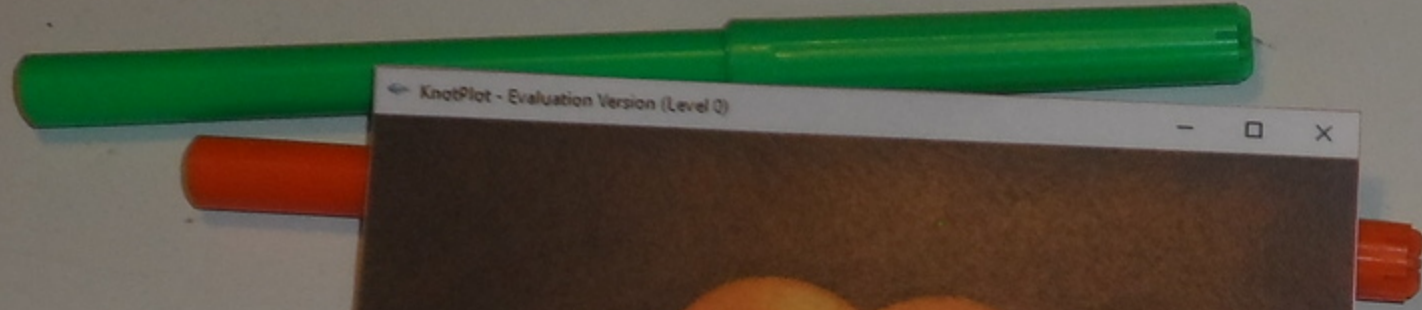
upgrade now
upgrade later
install key

(3D)



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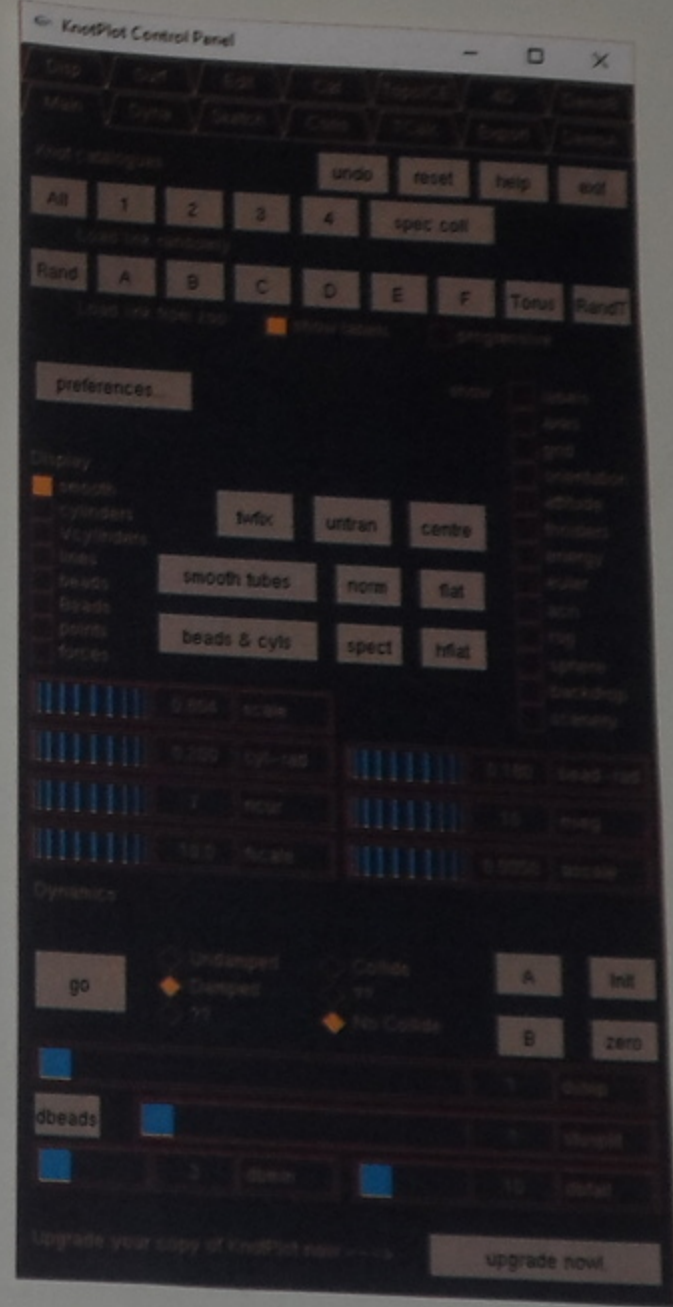
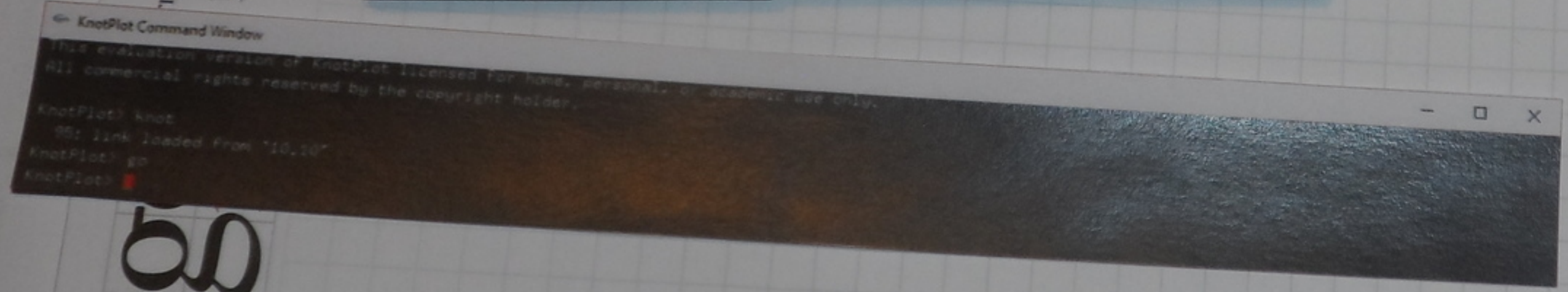


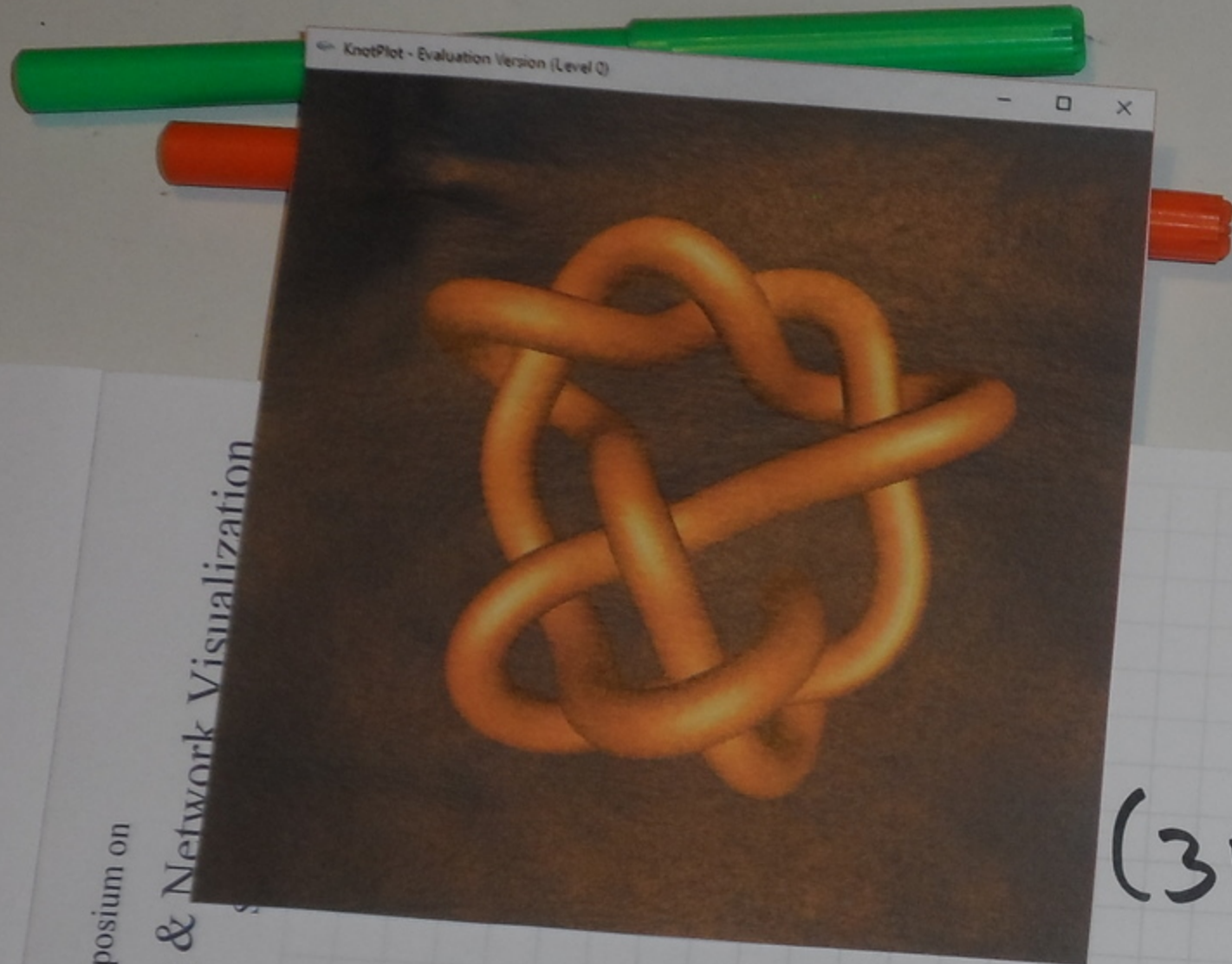


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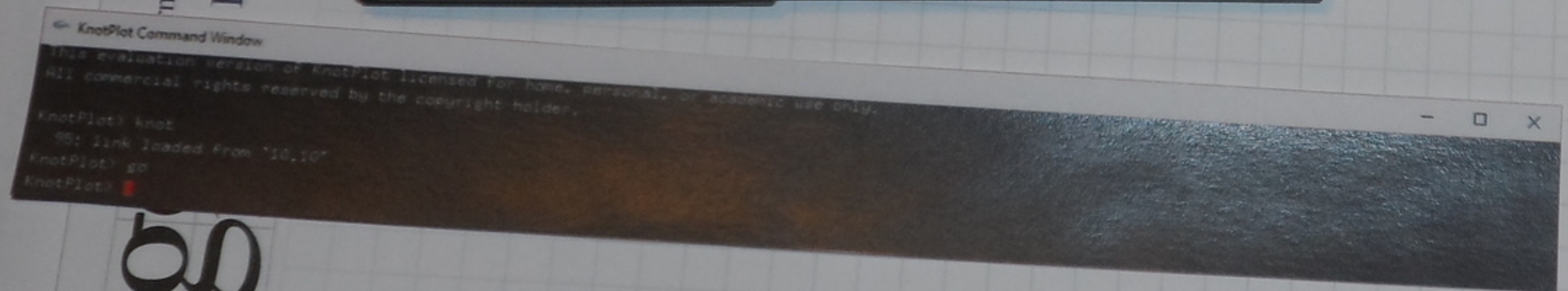
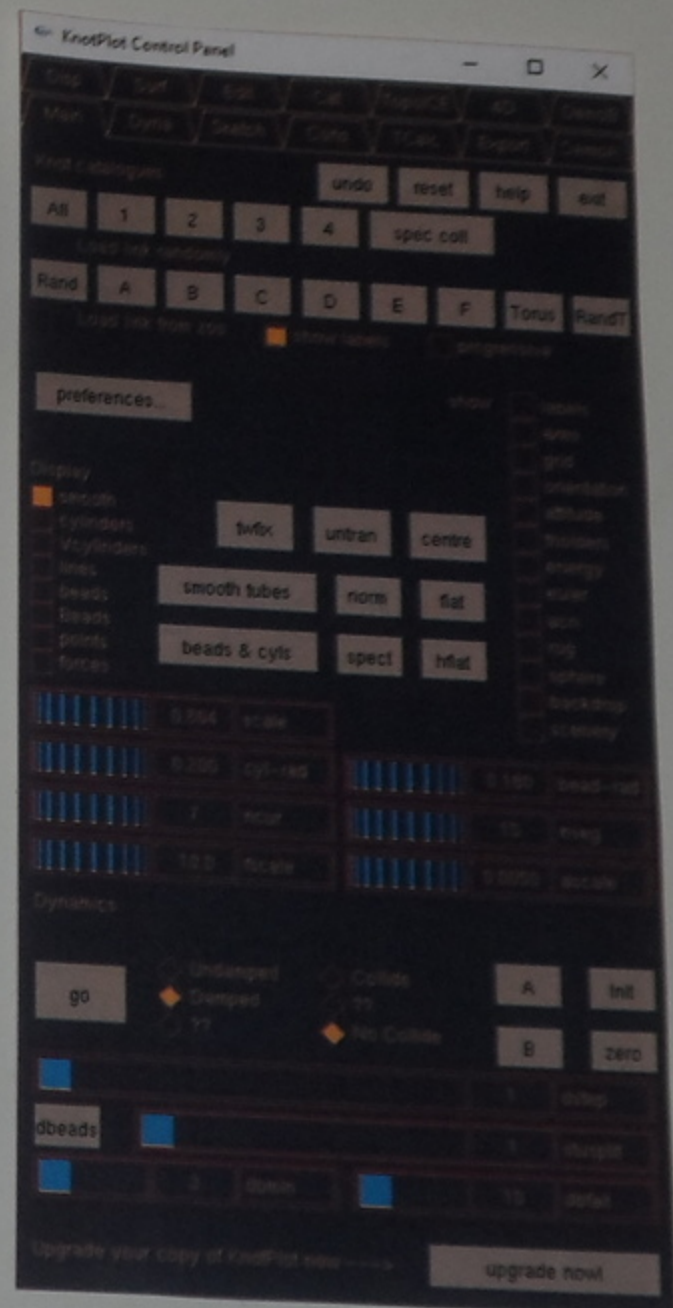


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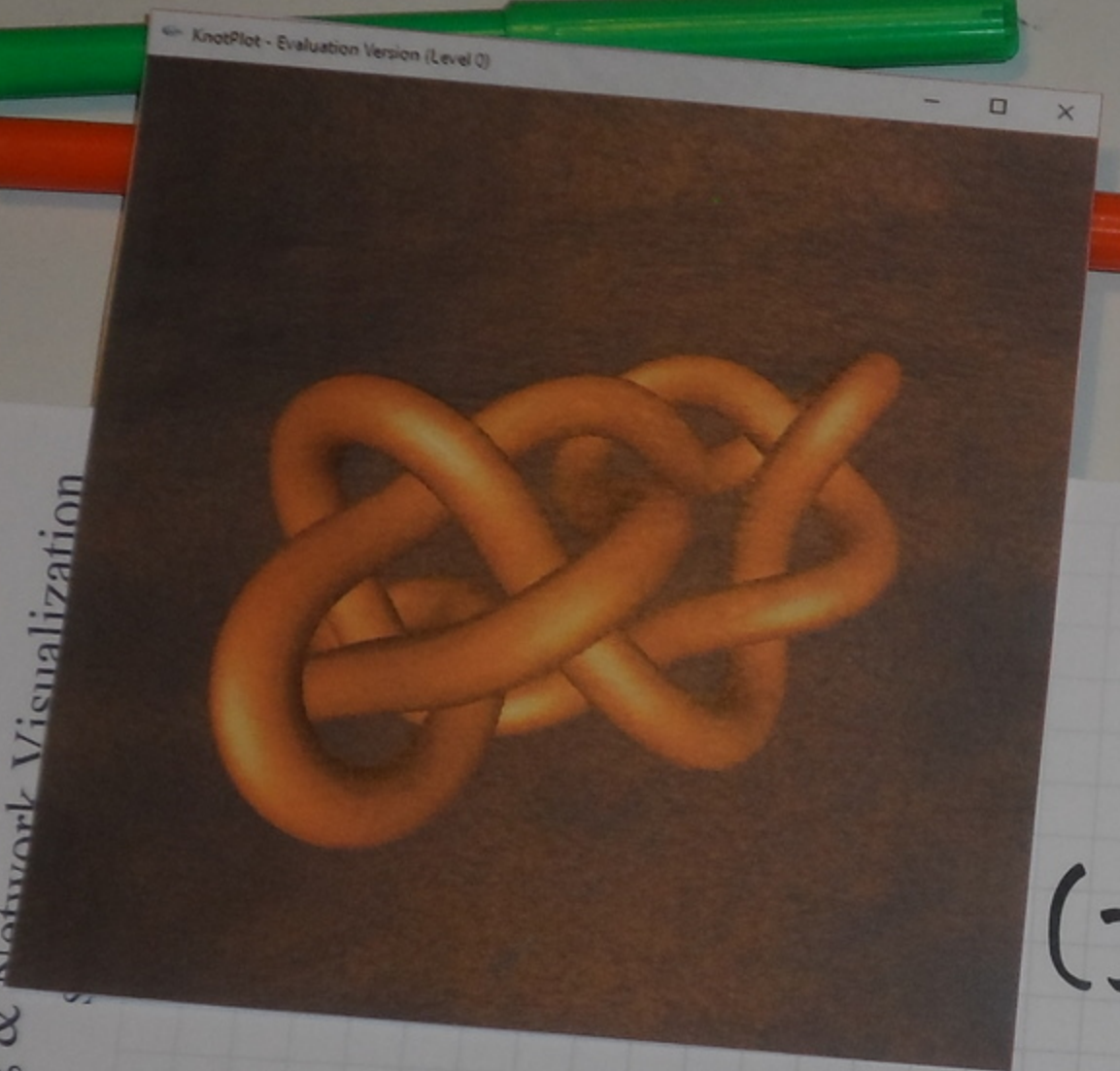
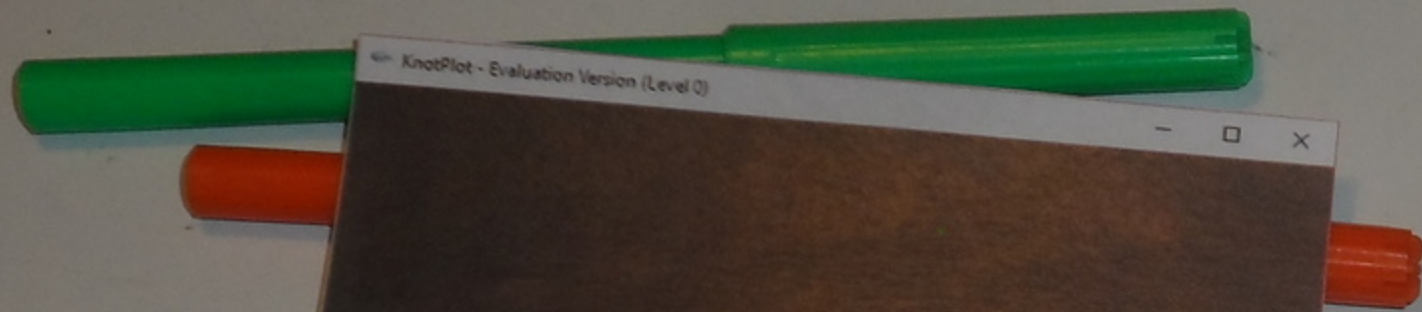


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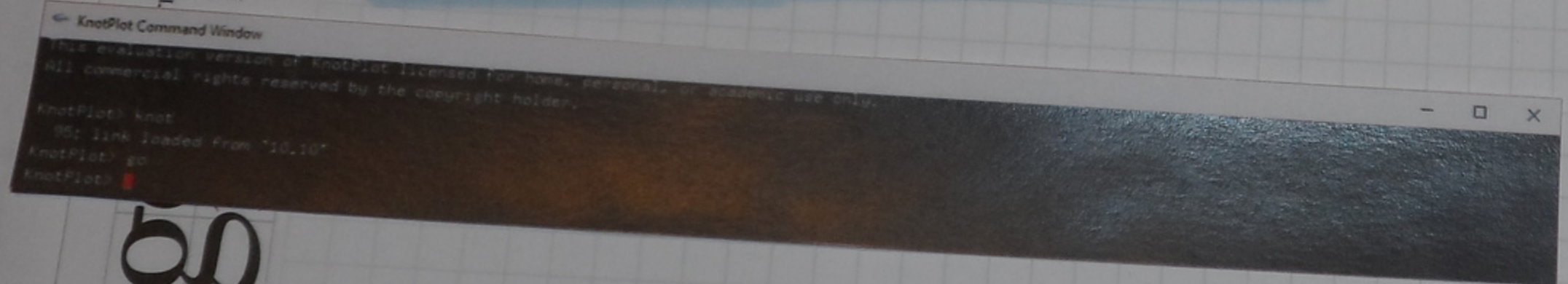


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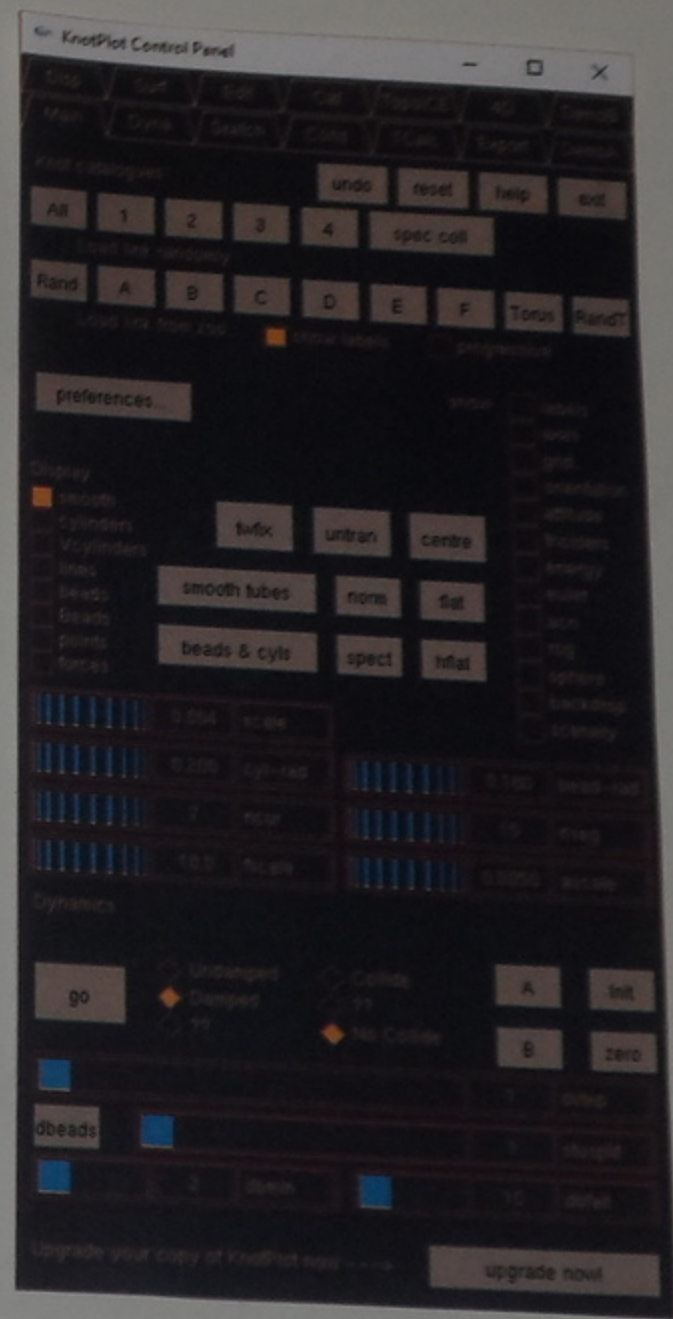
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KNOTPLOT (3D)



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KNOTPLOT (3D)

KNOTILUS (2D)





SOFTWARE

KNOTPLOT (3D)

KNOTILUS (2D)

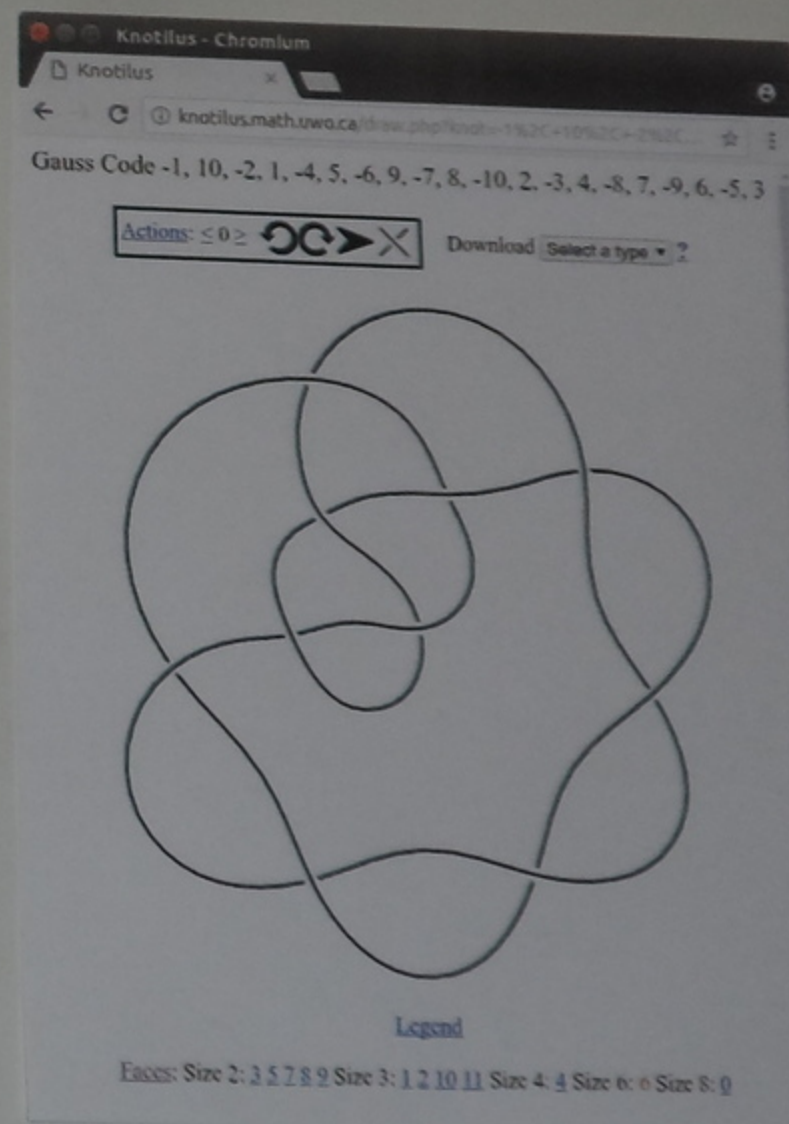


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KNOTILUS (2D)

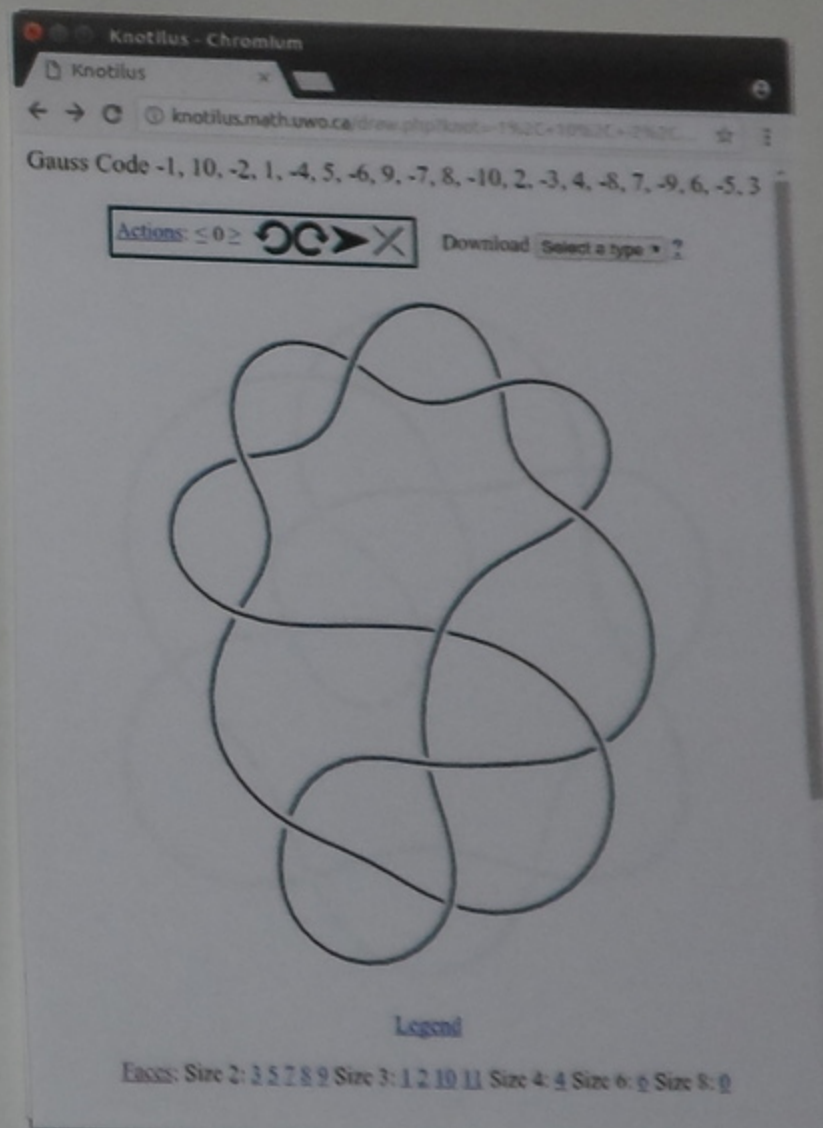


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KNOTILUS (2D)

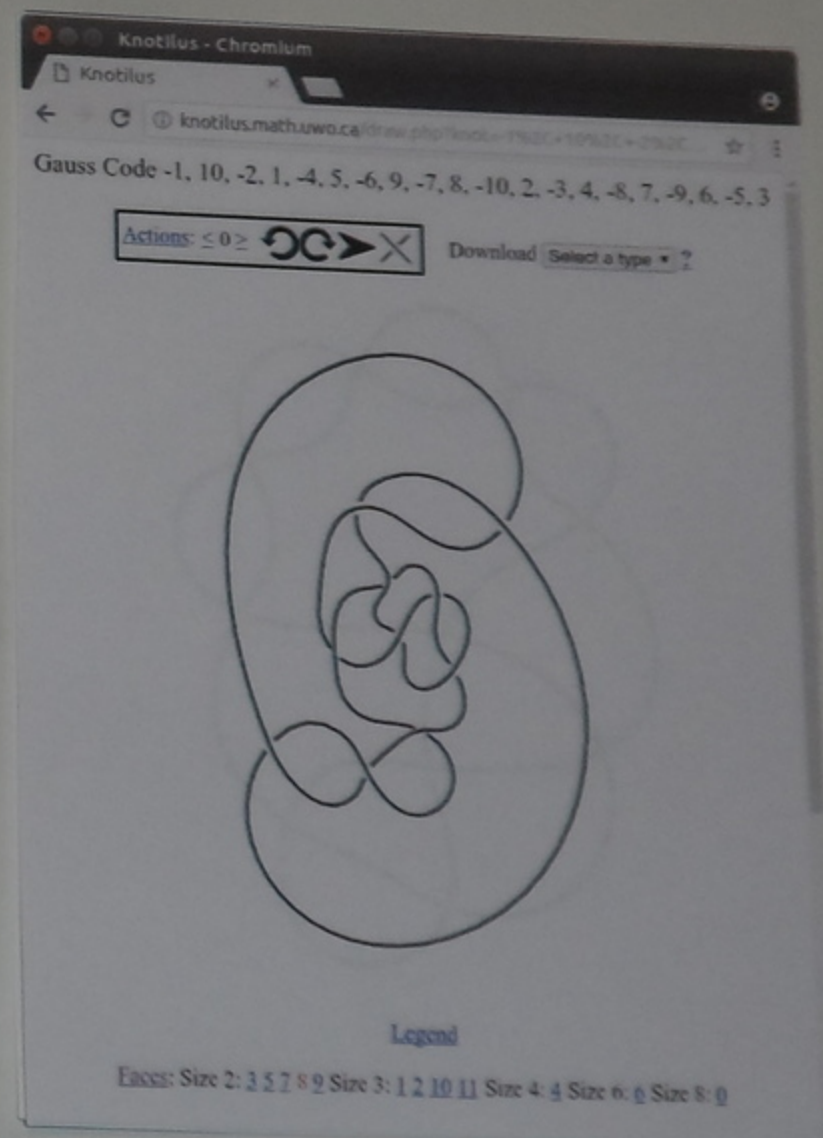


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CHALLENGE



CHALLENGE

DESIGN AN ALGORITHM
THAT CAN SMOOTHLY
TRANSITION BETWEEN
KNOT DIAGRAMS



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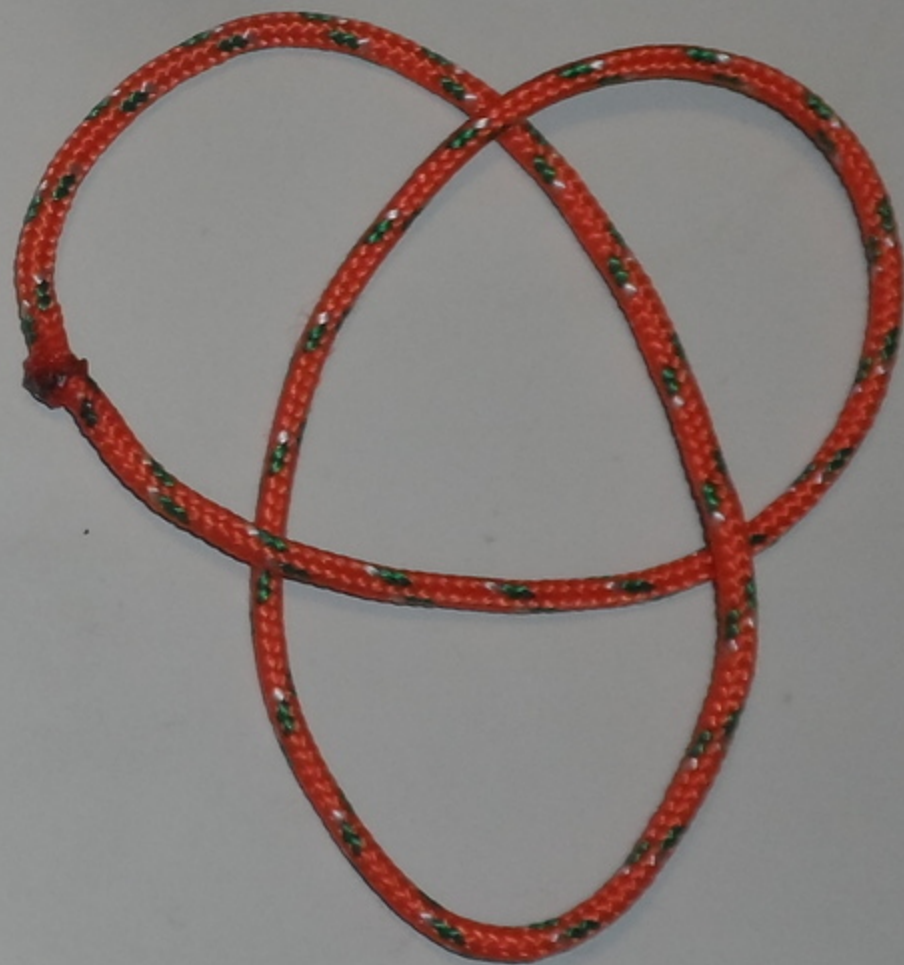
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KNOT DIAGRAMS



CHALLENGE

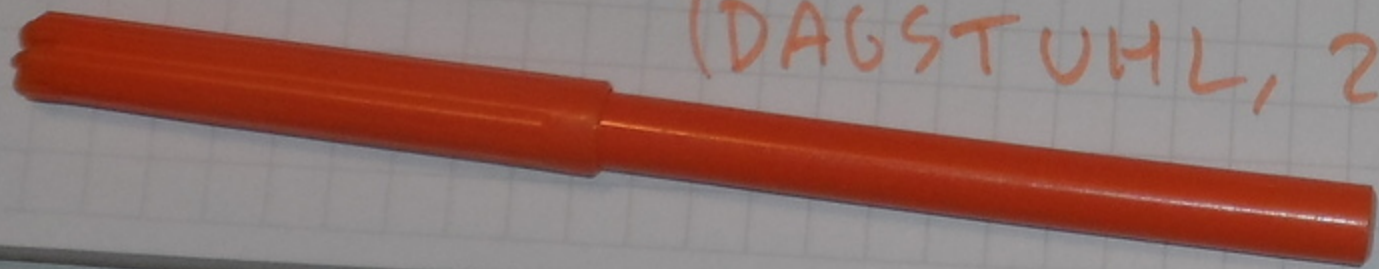
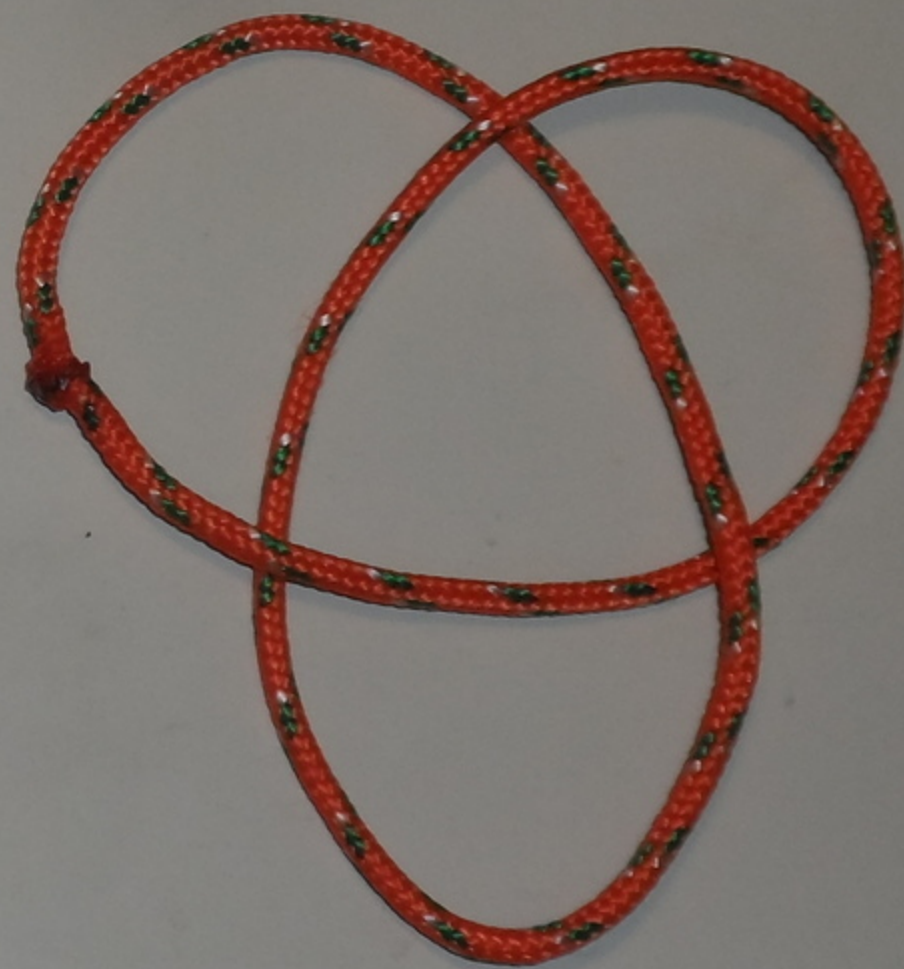
DESIGN AN ALGORITHM
THAT CAN SMOOTHLY
TRANSITION BETWEEN
KNOT DIAGRAMS



CHALLENGE

DESIGN AN ALGORITHM
THAT CAN SMOOTHLY
TRANSITION BETWEEN
KNOT DIAGRAMS

BENJAMIN BURTON
(DAGSTUHL, 2017)



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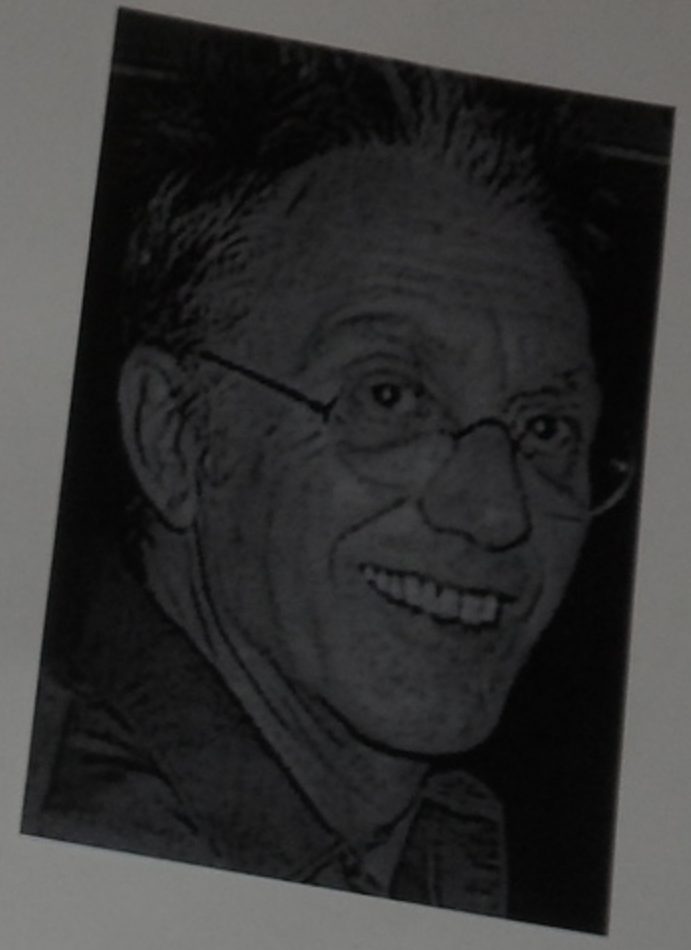
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MARK LOMBARDI





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MARK LOMBARDI



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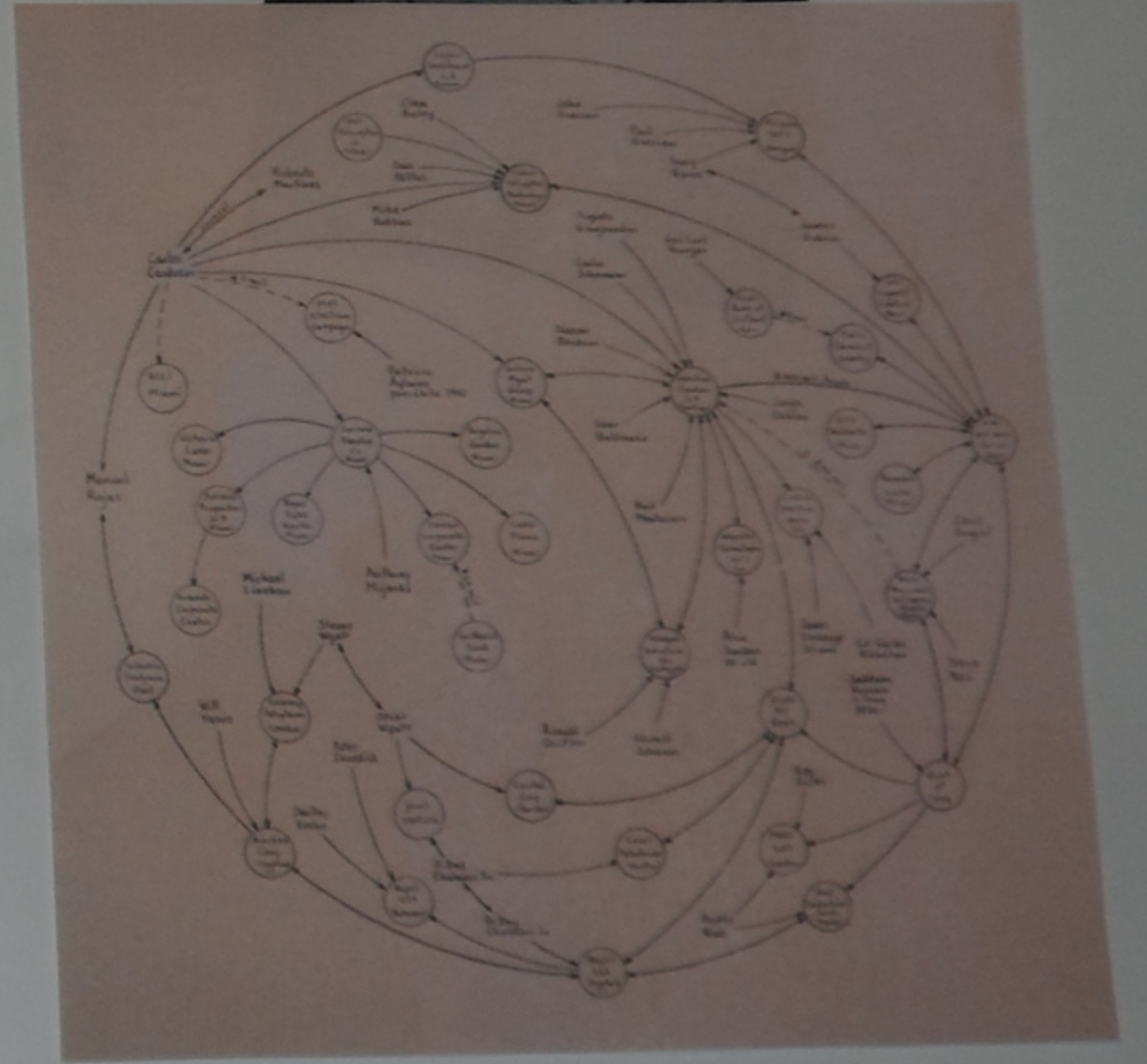
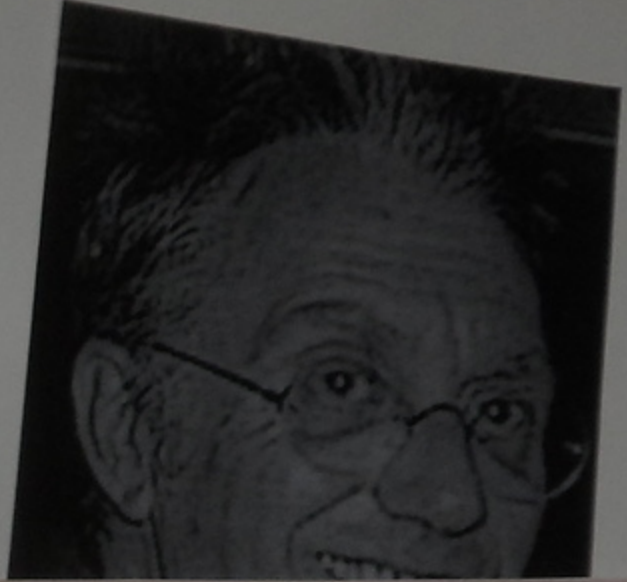
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MARK LOMBARDI

AMERICAN ARTIST
WITH DISTINCT DRAWING
STYLE



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LOMBARDI DRAWINGS





LOMBARDI DRAWINGS

EDGES ARE CIRCULAR ARCS
VERTICES HAVE PERFECT
ANGULAR RESOLUTION



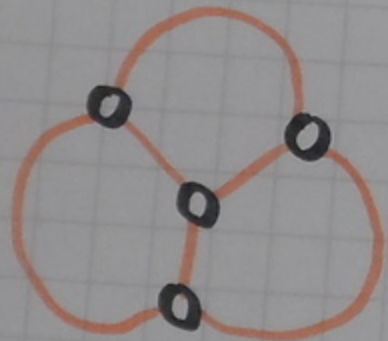
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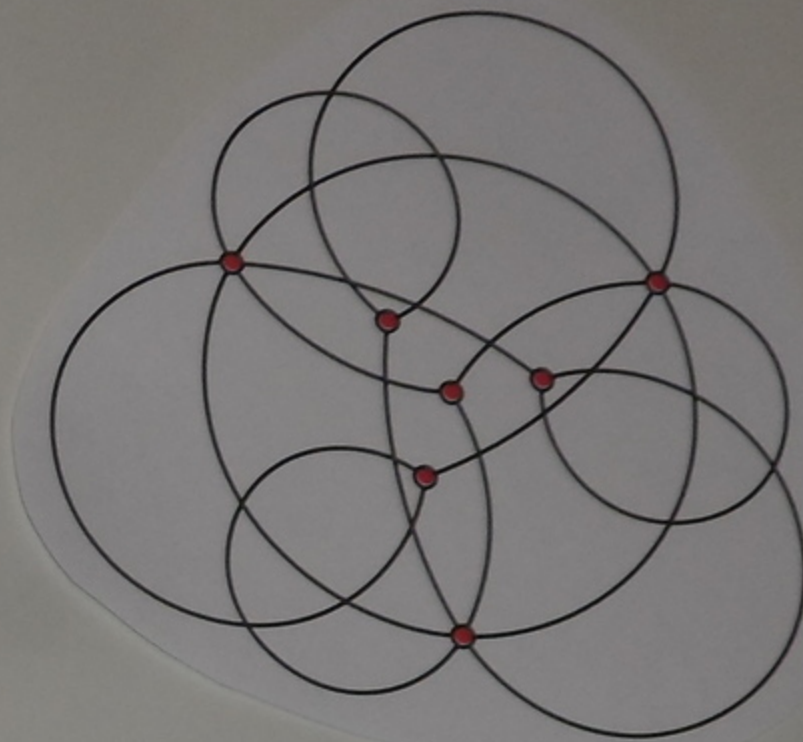
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LOMBARDI DRAWINGS

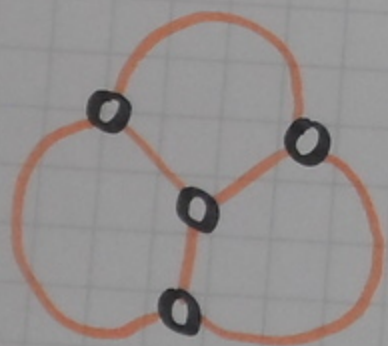
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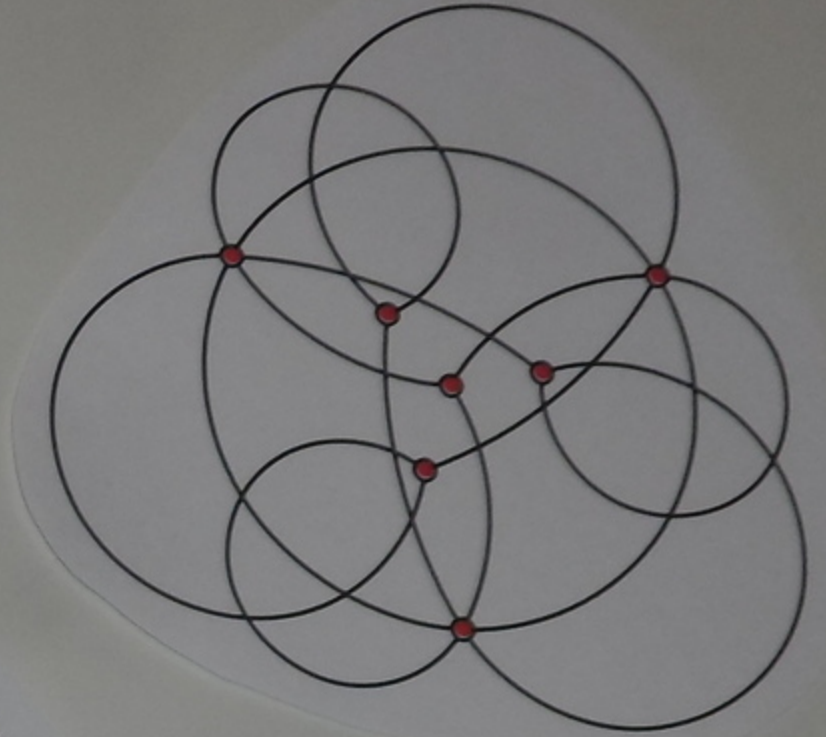
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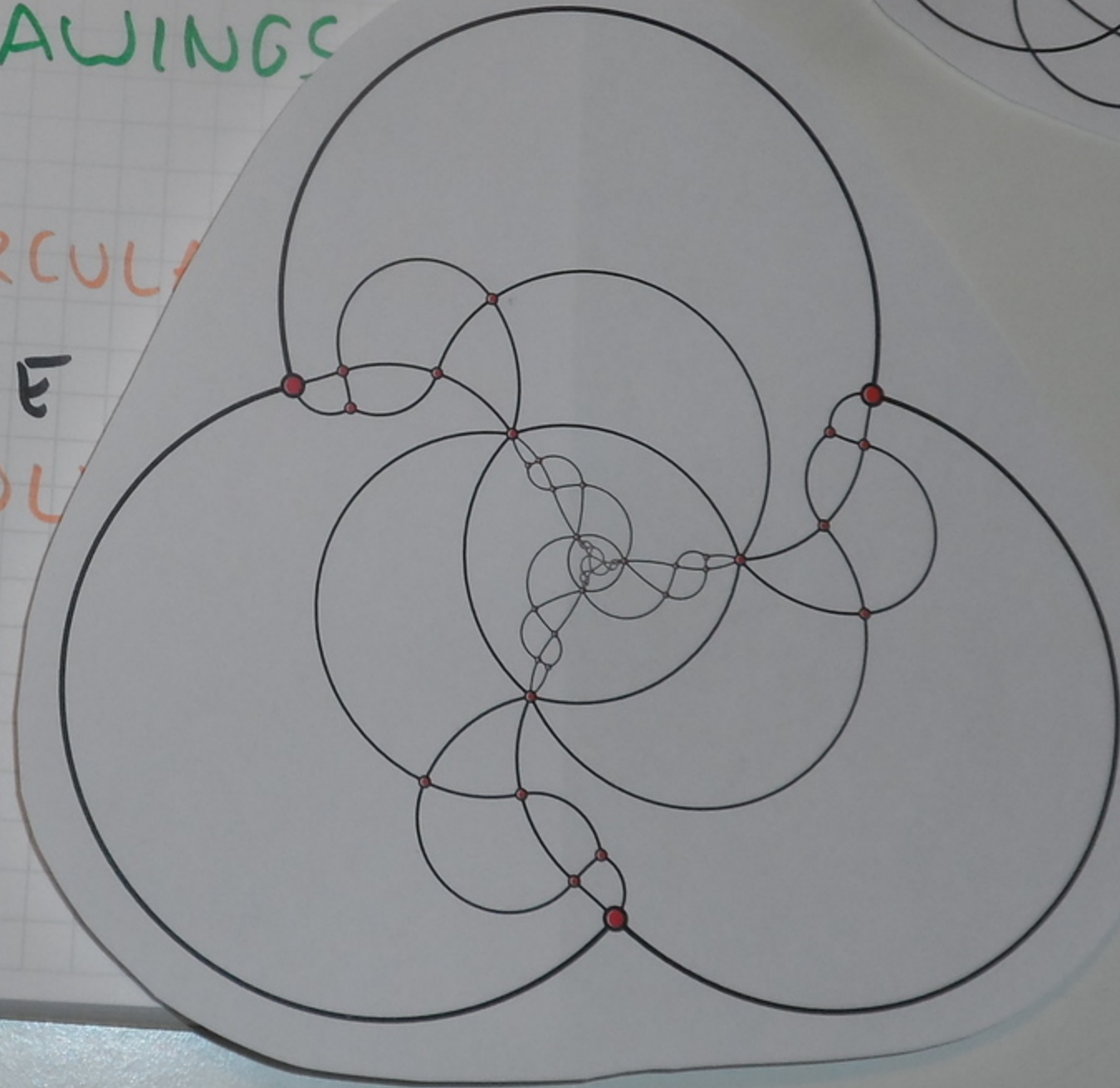
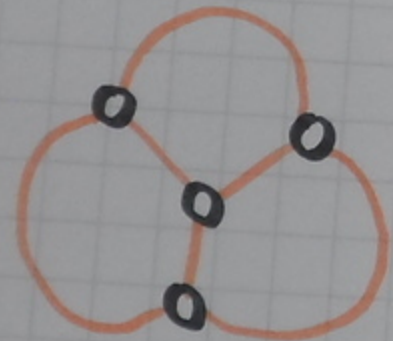
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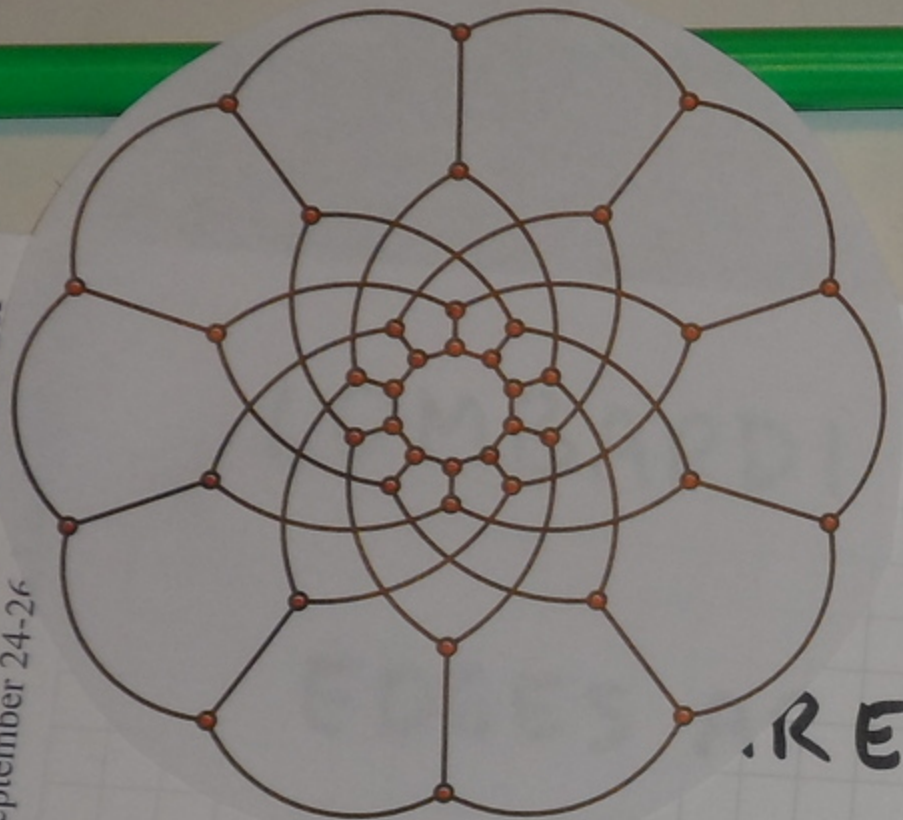
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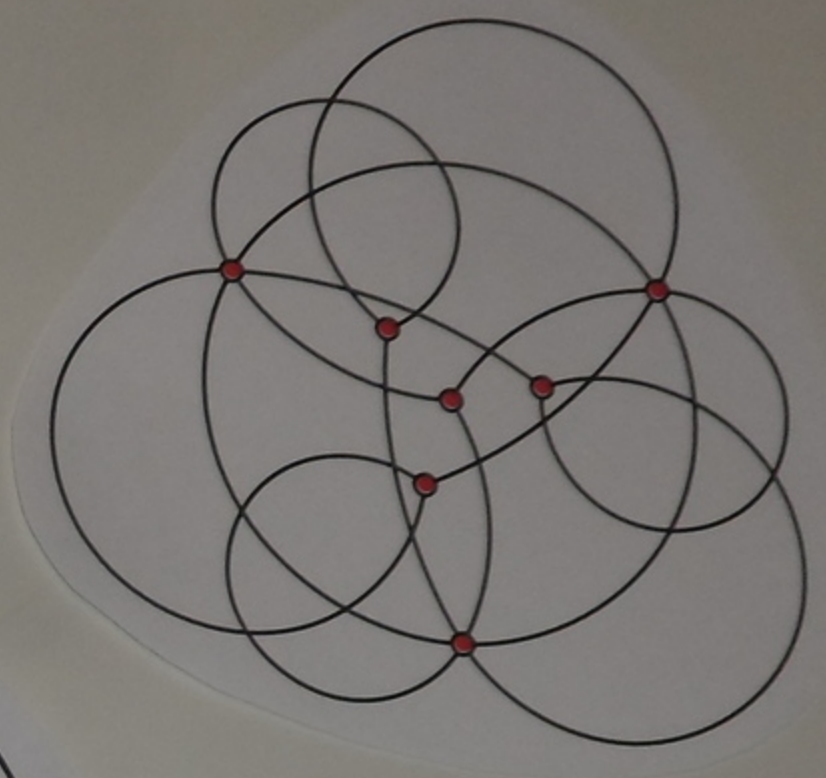
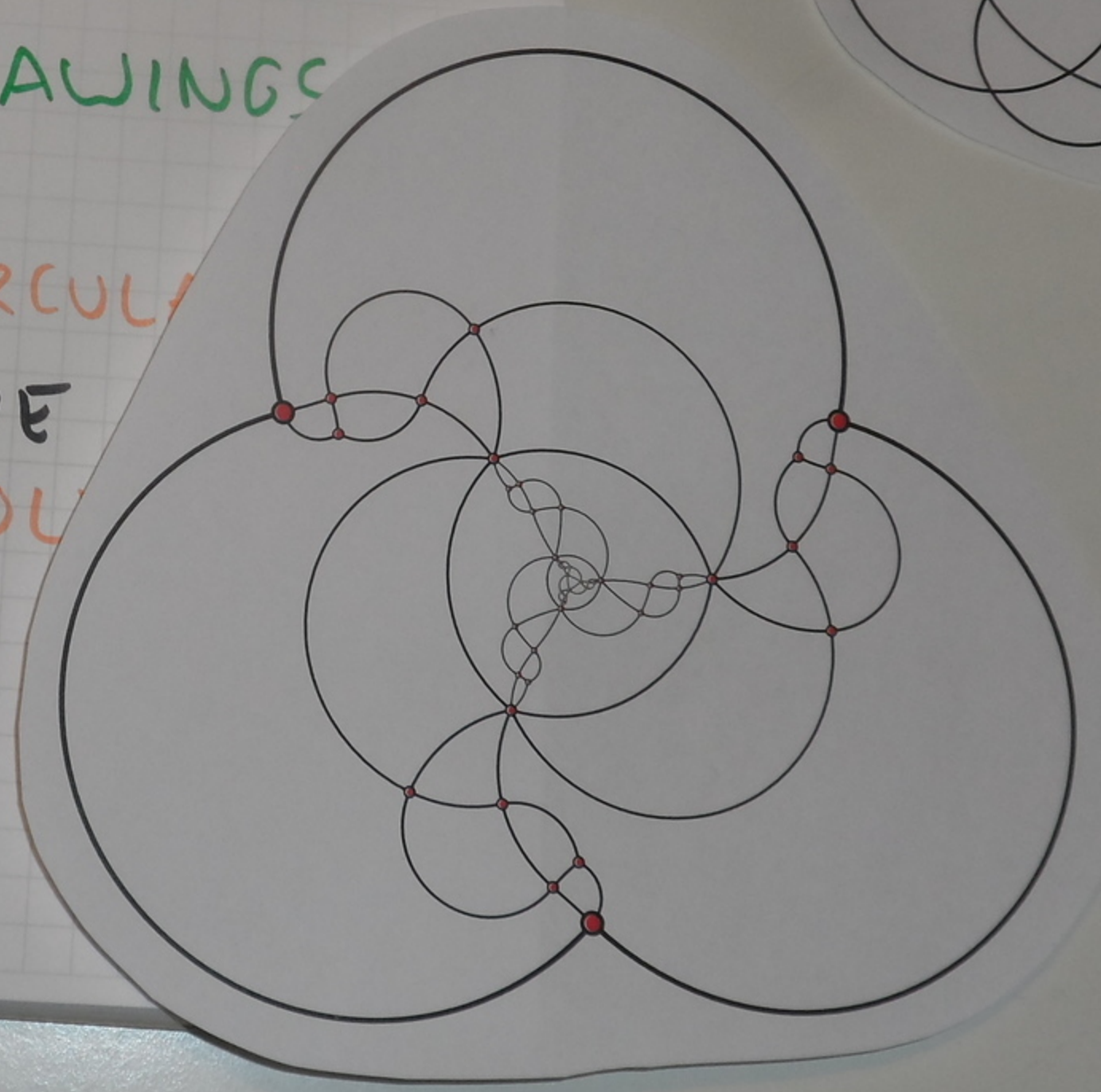
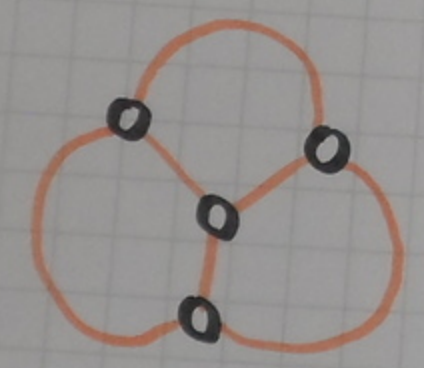
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DRAWINGS

ARE CIRCULAR
VERTICES HAVE
ANGULAR RESOLUTION



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KNOTS AS GRAPHS



KNOTS AS GRAPHS

KNOT DIAGRAMS CAN BE
INTERPRETED AS MULTIGRAPHS



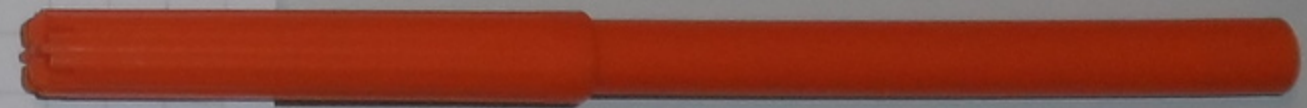
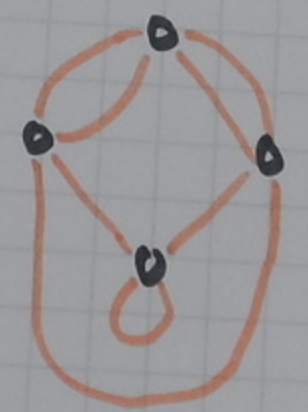
KNOTS AS GRAPHS

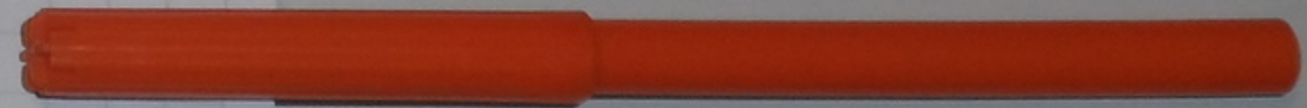
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KNOTS AS GRAPHS

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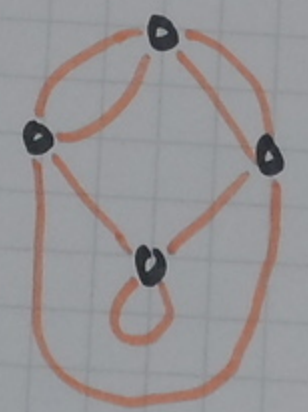


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KNOTS AS GRAPHS

KNOT DIAGRAMS CAN BE INTERPRETED AS MULTIGRAPHS

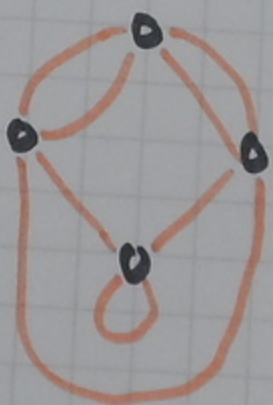
ALWAYS 4-REGULAR



KNOTS AS GRAPHS

KNOT DIAGRAMS CAN BE
INTERPRETED AS MULTIGRAPHS

ALWAYS
4-REGULAR



CAN HAVE DOUBLE
EDGES & SELF-LOOPS



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IDEA!



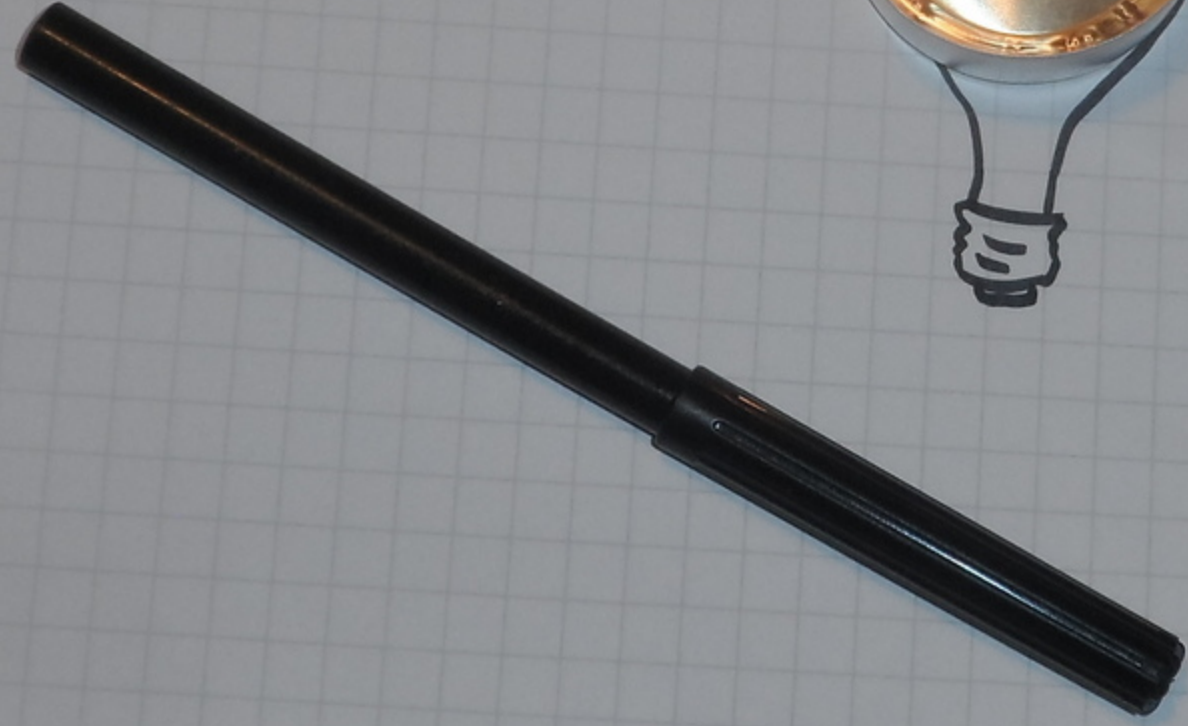
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IDEA!



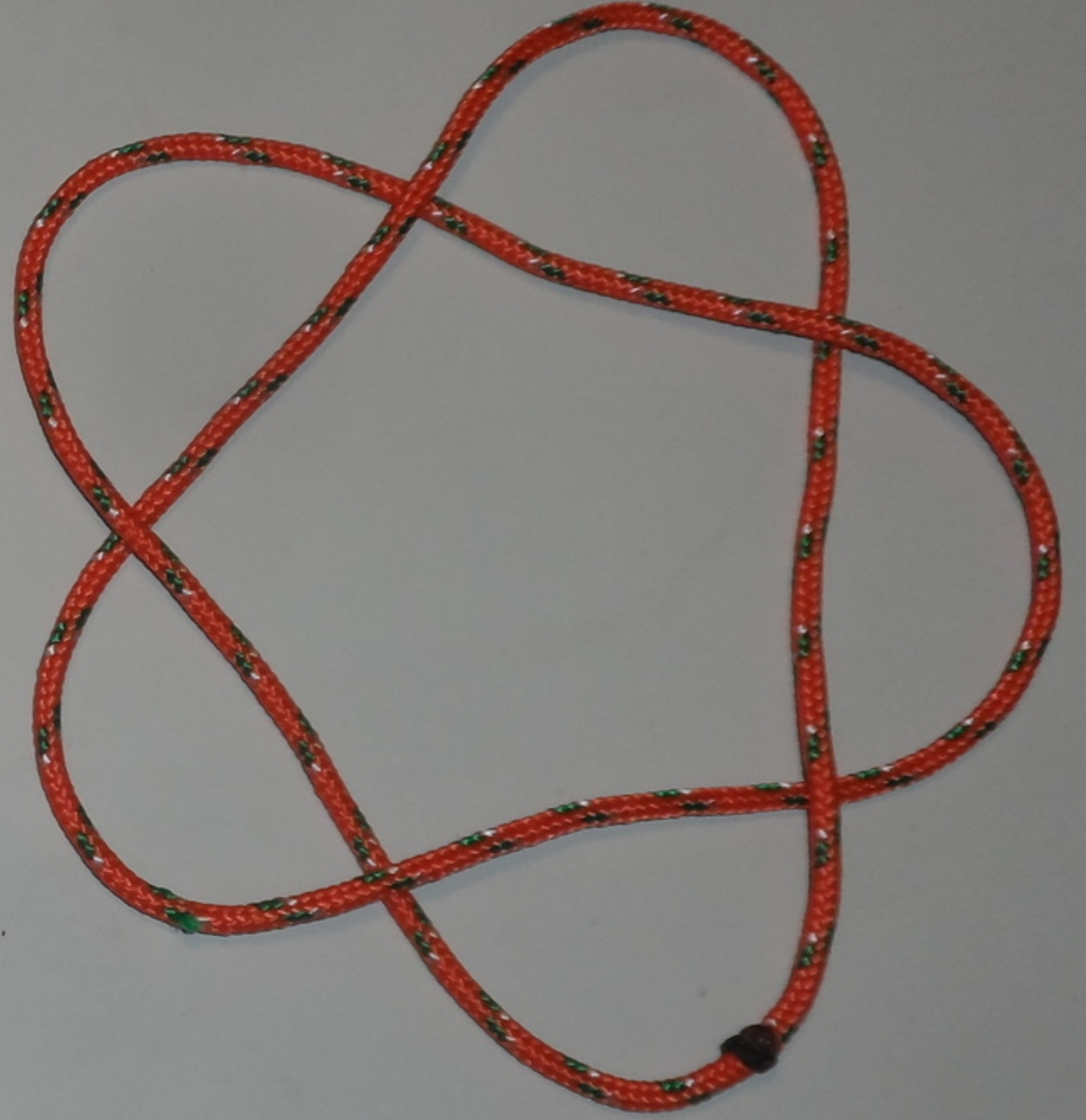
IDEA!

CAN WE USE
LOMBARDI DRAWINGS
TO DRAW KNOT DIAGRAMS?



IDEA!

CAN WE USE
LOMBARDI DRAWINGS
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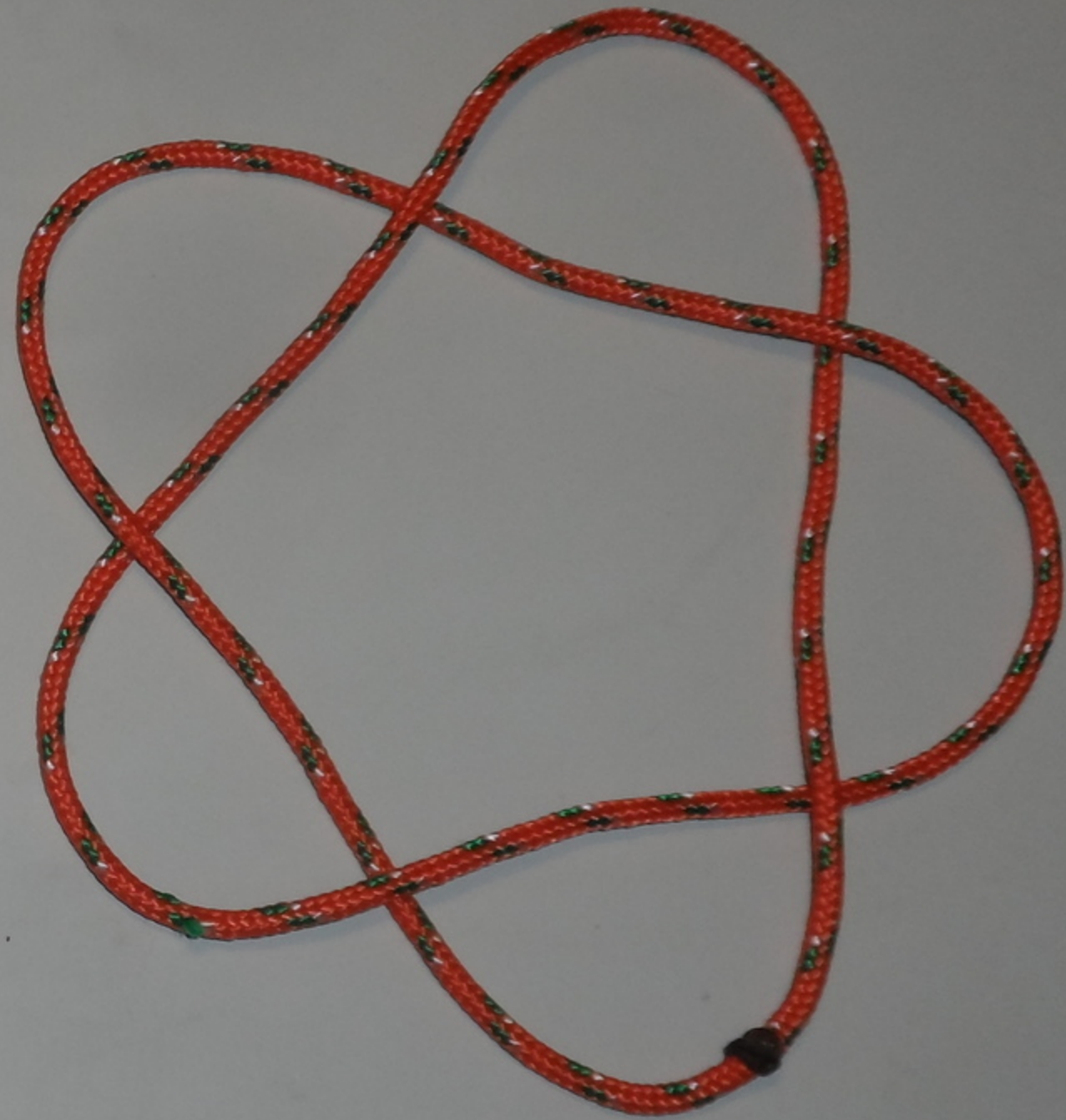


IDEA!


CAN WE USE
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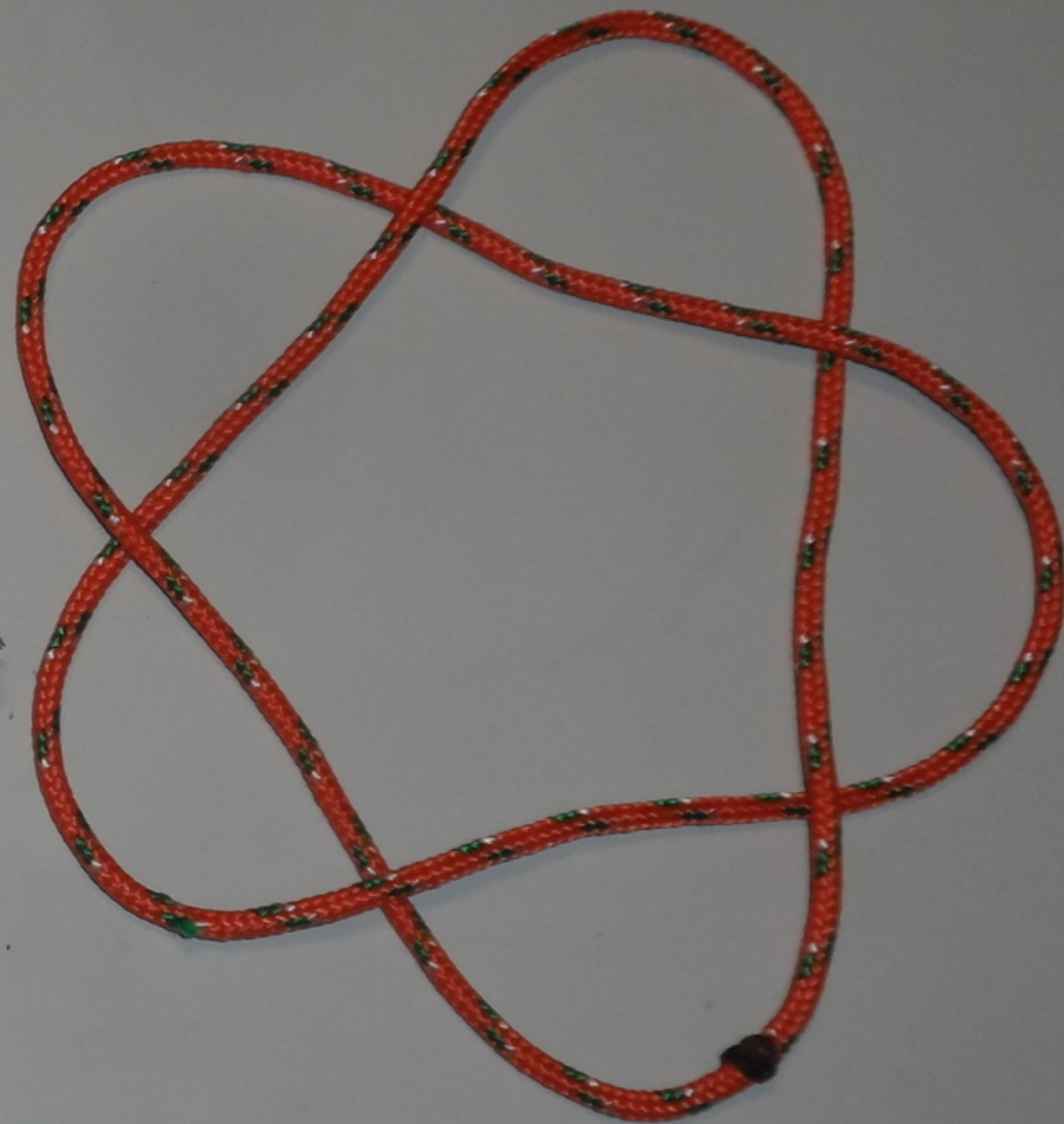
SMOOTH ARCS AND ANGLES
MAKE IT EASY TO FOLLOW
THE CURVES




IDEA!

CAN WE USE
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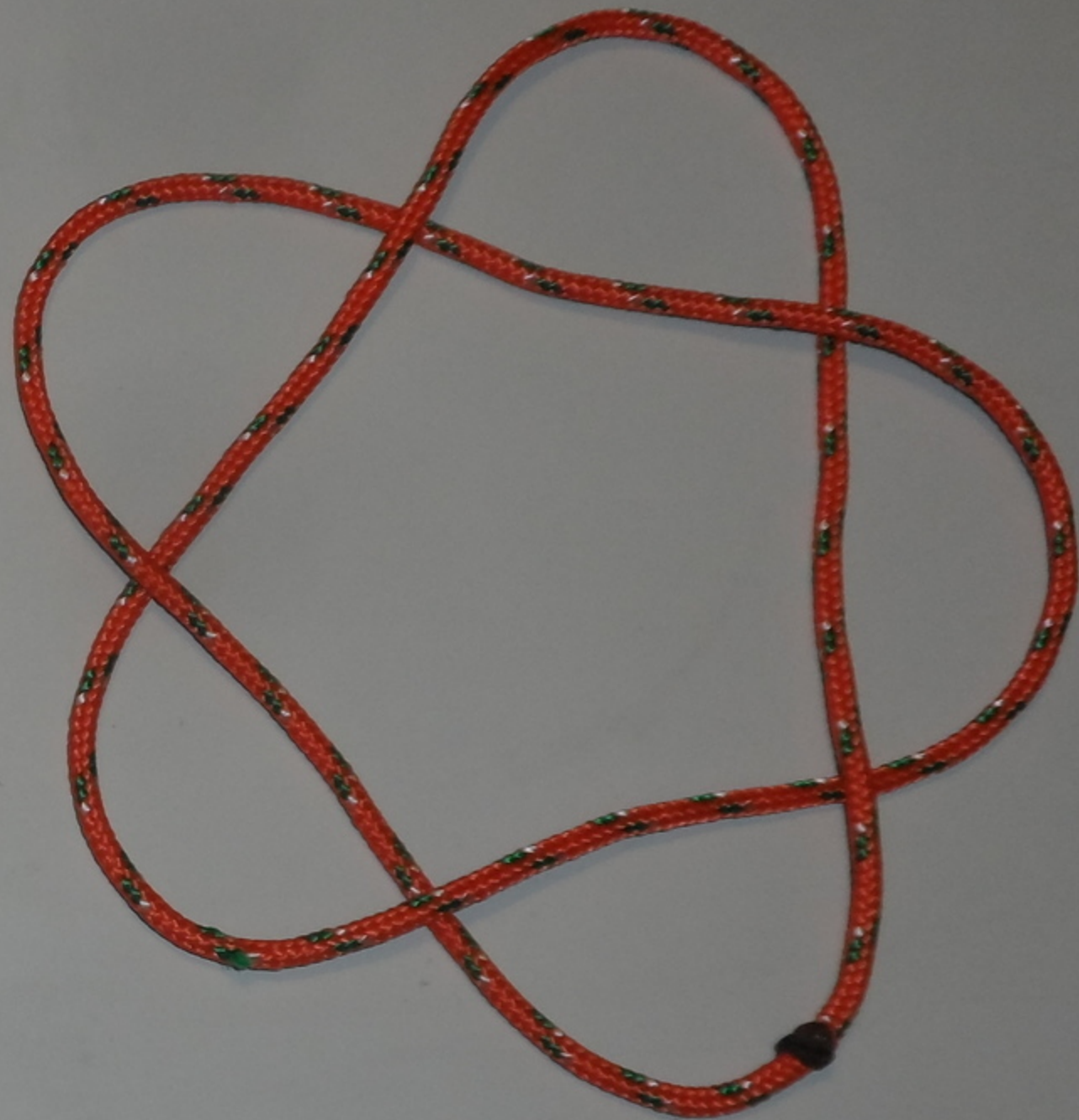
SMOOTH ARCS AND ANGLES
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IDEA!

CAN WE USE LOMBARDI DRAWINGS TO DRAW KNOT DIAGRAMS? 

SMOOTH ARCS AND ANGLES MAKE IT EASY TO FOLLOW THE CURVES



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ISSUES

NOT ALL GRAPHS ADMIT
LOMBARDI DRAWINGS...



ISSUES

NOT ALL GRAPHS ADMIT
LOMBARDI DRAWINGS...
... BUT 4-REGULAR GRAPHS DO!



ISSUES

NOT ALL GRAPHS ADMIT
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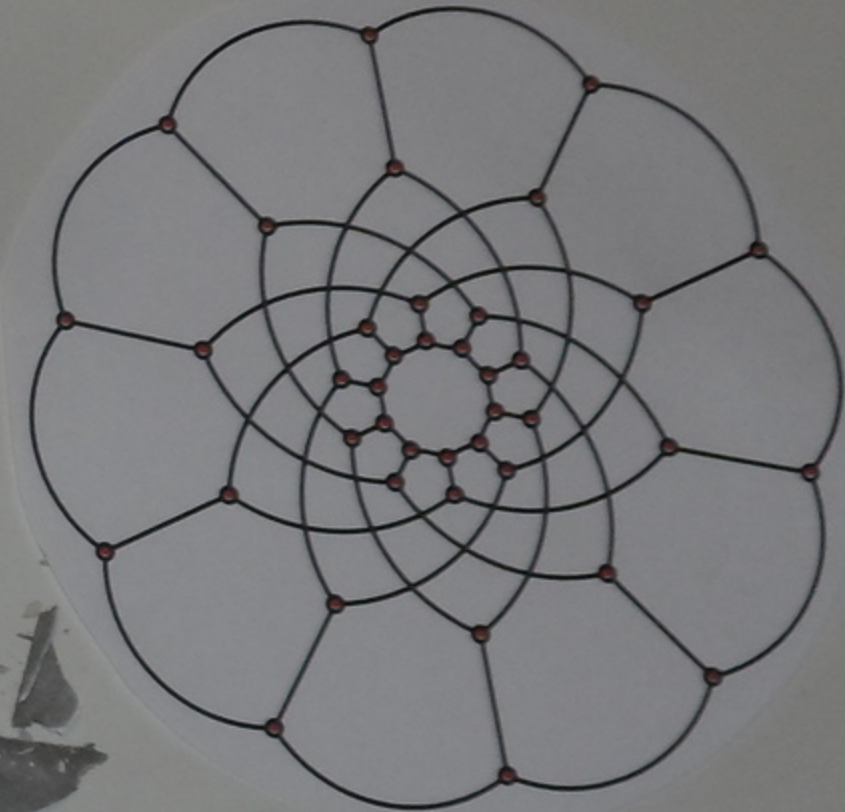
NOT ALL LOMBARDI DRAWINGS
ARE PLANAR...



ISSUES

NOT ALL GRAPHS ADMIT
LOMBARDI DRAWINGS...
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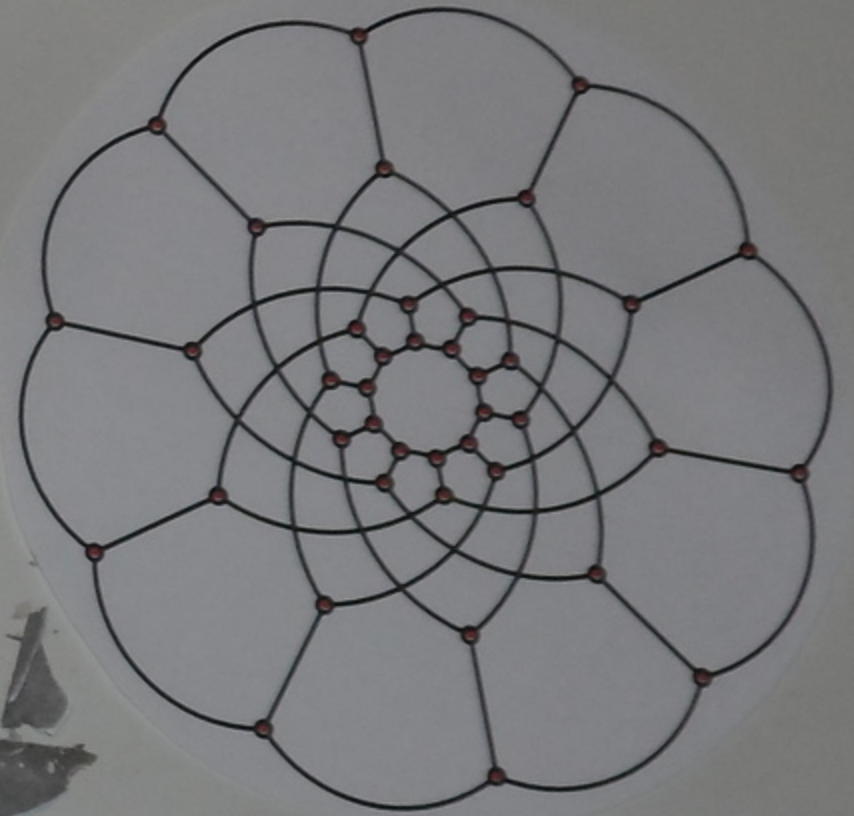


ISSUES

NOT ALL GRAPHS ADMIT
LOMBARDI DRAWINGS...

... BUT 4-REGULAR GRAPHS DO!

NOT ALL LOMBARDI DRAWINGS
ARE PLANAR... (EVEN OF PLANAR GRAPHS)

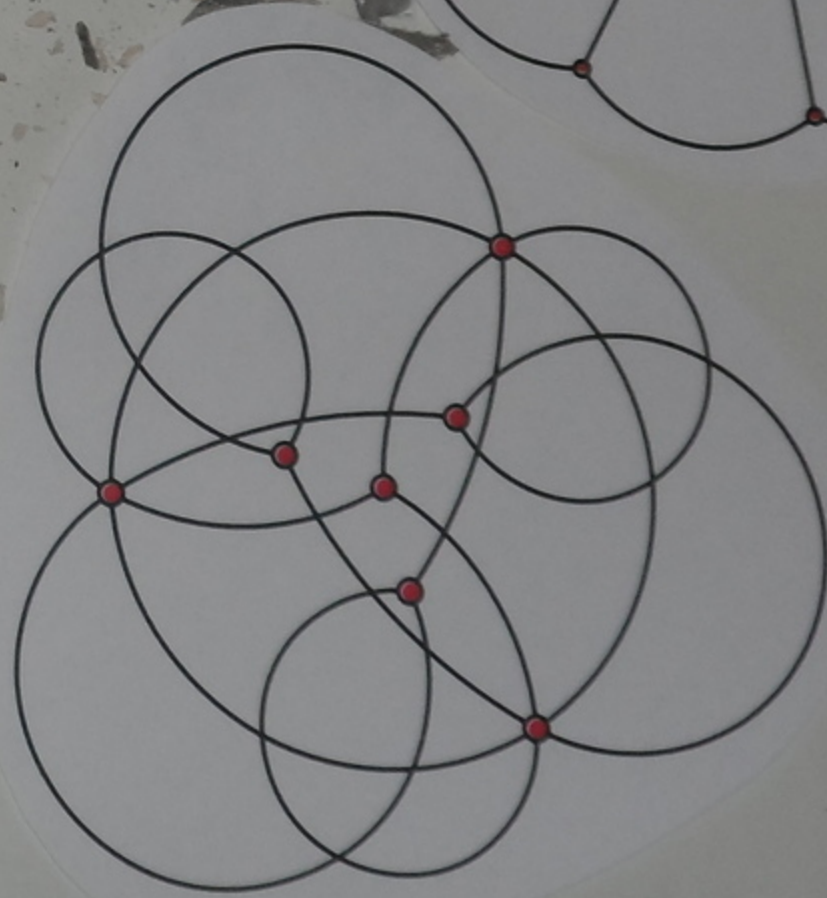
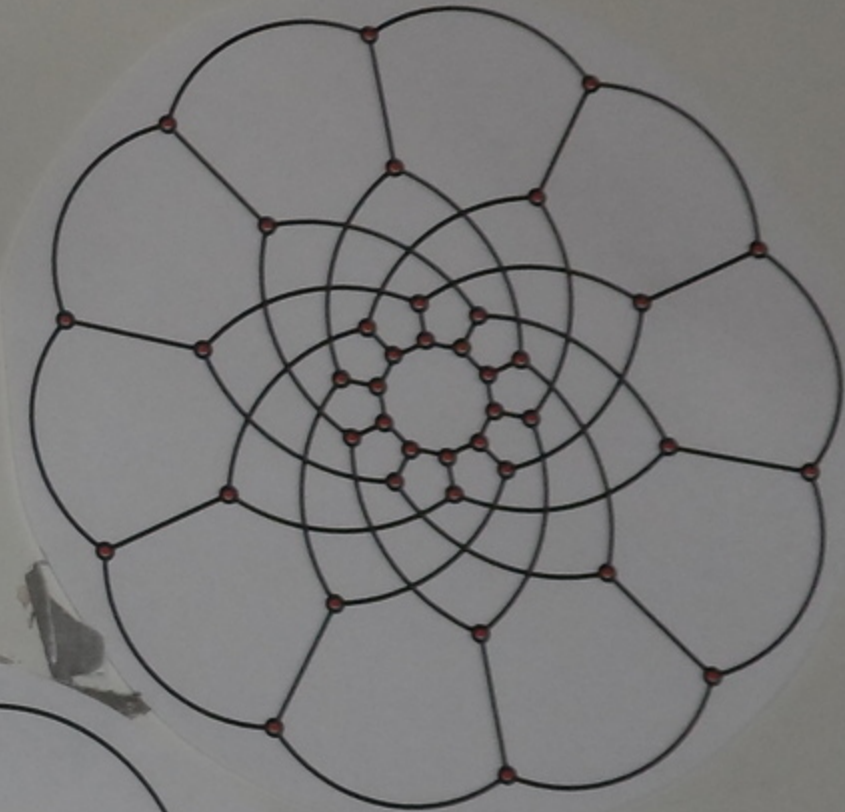


ISSUES

NOT ALL GRAPHS ADMIT LOMBARDI DRAWINGS...

... BUT 4-REGULAR GRAPHS DO!

NOT ALL LOMBARDI DRAWINGS ARE PLANAR... (EVEN OF PLANAR GRAPHS)



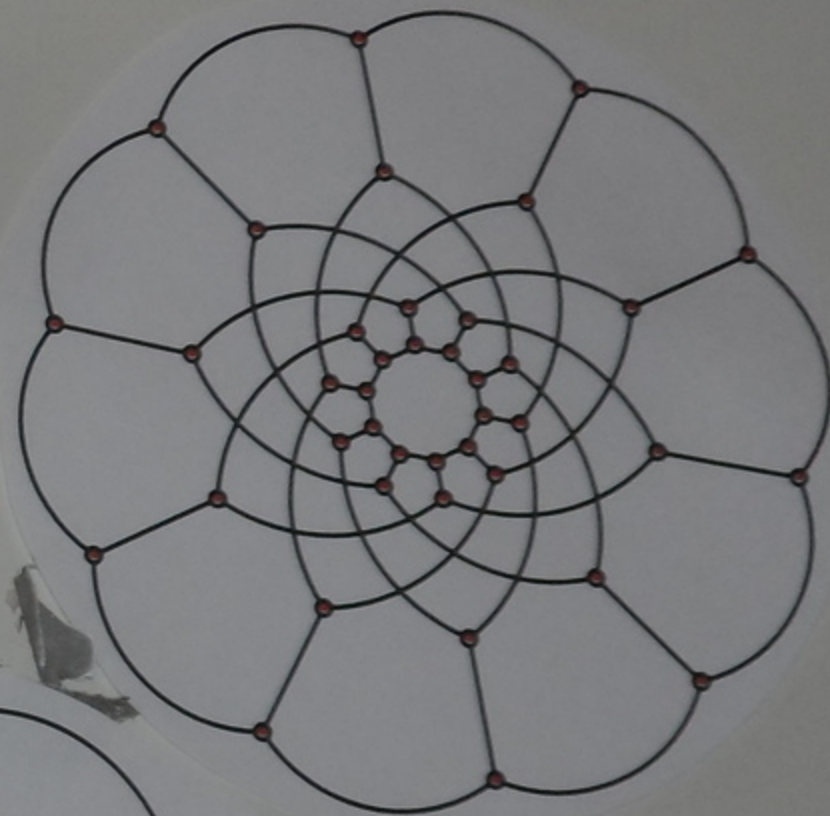
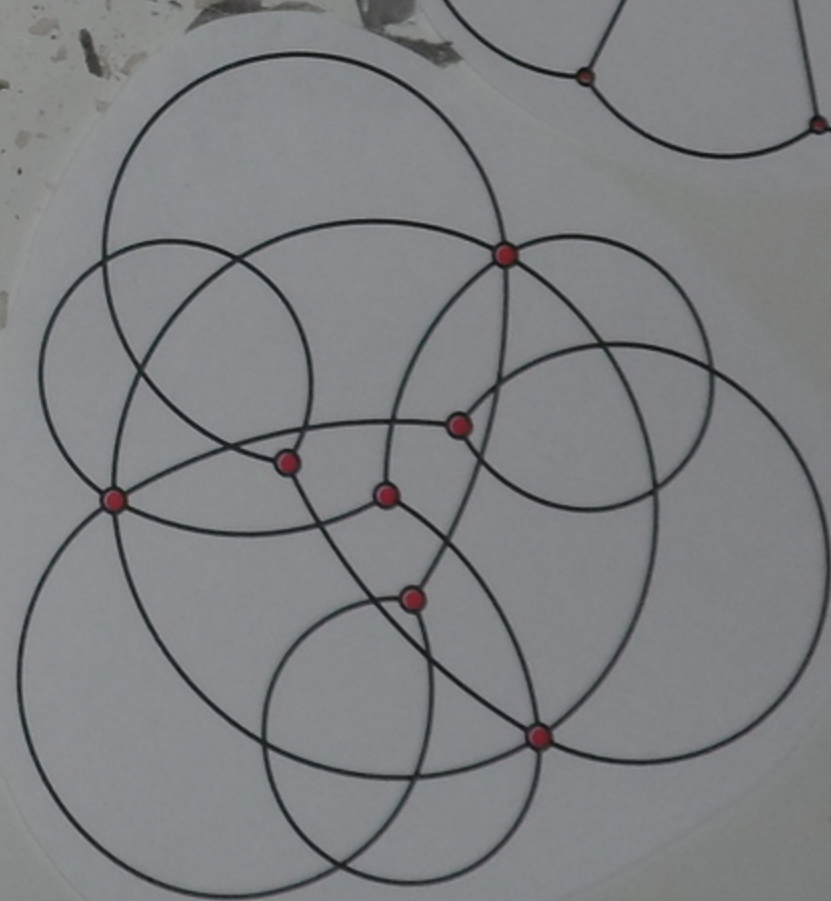
ISSUES

NOT ALL GRAPHS ADMIT
LOMBARDI DRAWINGS...

... BUT 4-REGULAR GRAPHS DO!

NOT ALL LOMBARDI DRAWINGS
ARE PLANAR... (EVEN OF PLANAR GRAPHS)

NOTHING IS KNOWN ABOUT
LOMBARDI MULTIGRAPHS



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RESULTS



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RESULTS

THERE ARE (MINIMAL) KNOT
DIAGRAMS WITHOUT PLANAR
LOMBARDI DRAWINGS



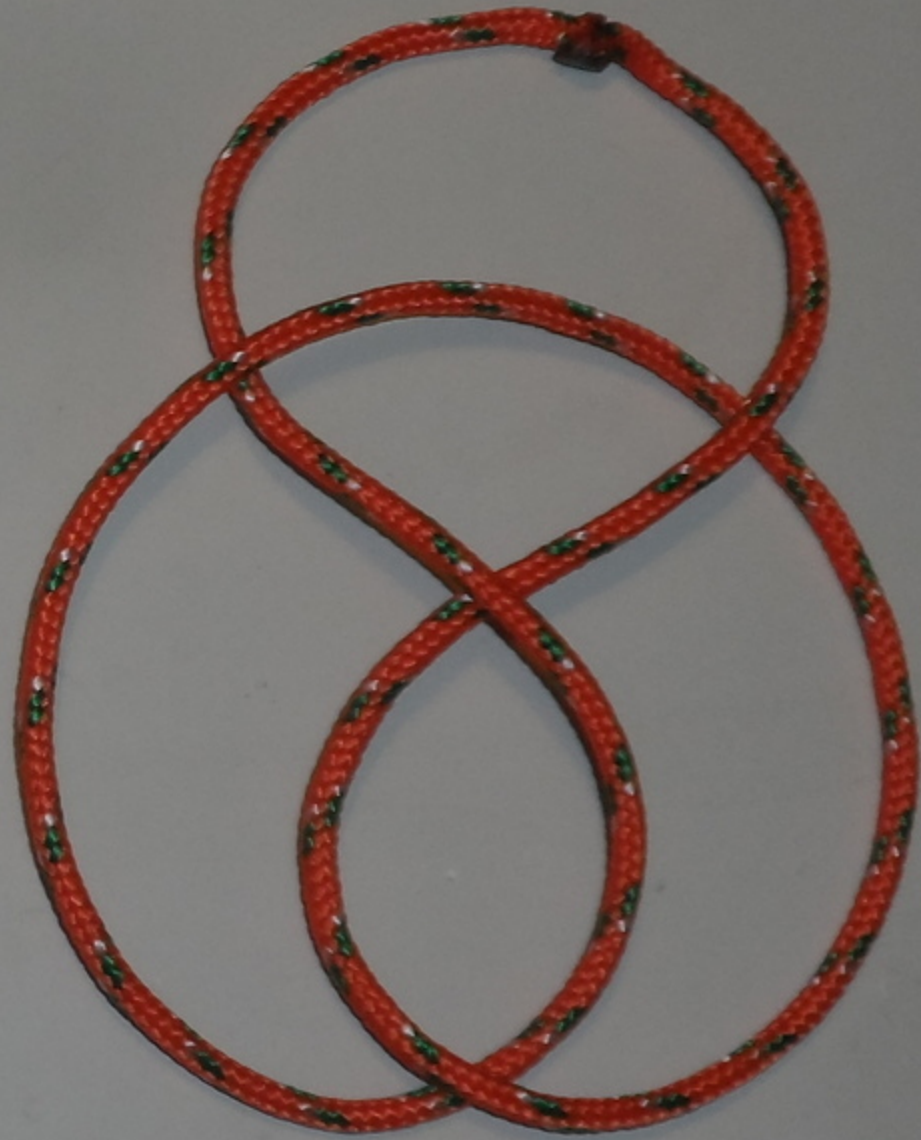
RESULTS

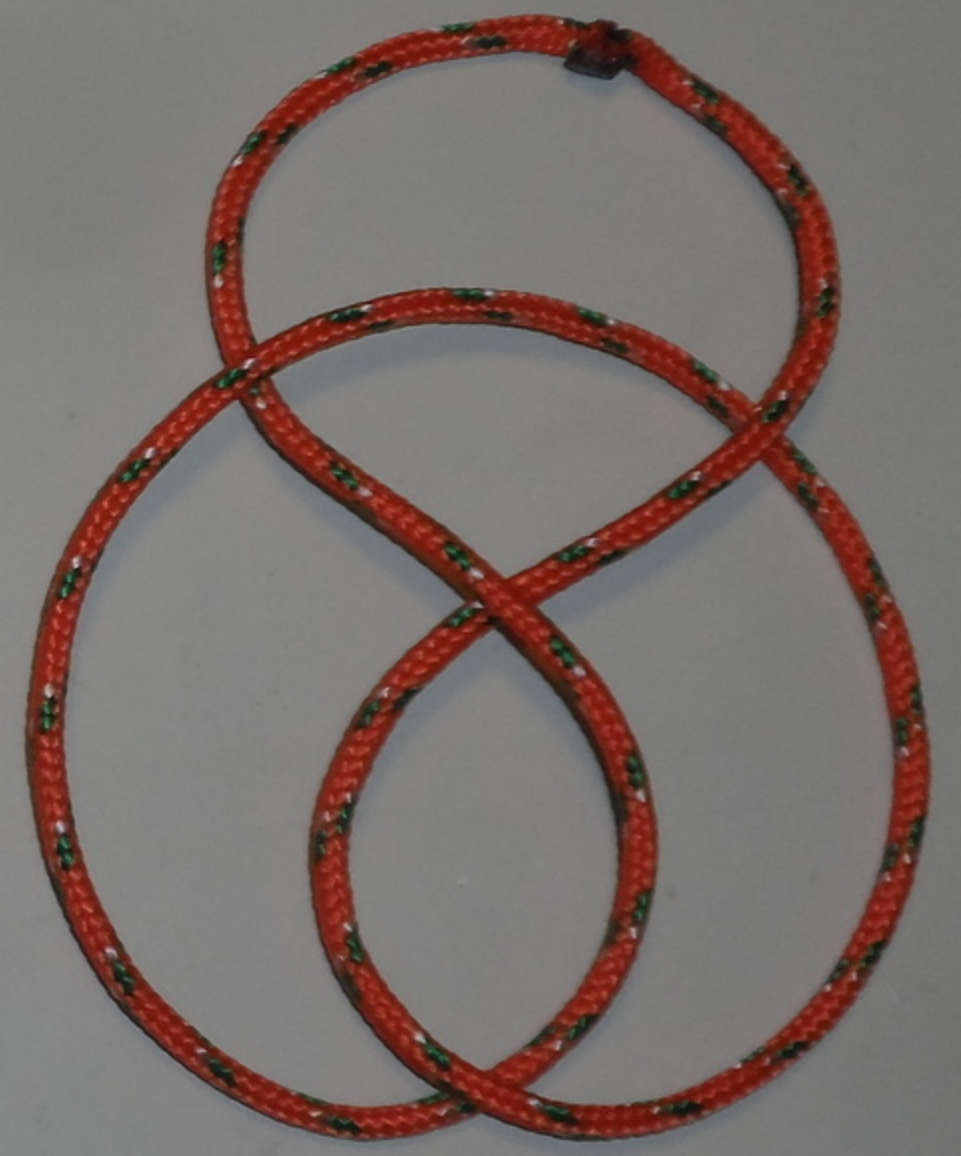
THERE ARE (MINIMAL) KNOT
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RESULTS

THERE ARE (MINIMAL) KNOT
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LOMBARDI DRAWINGS





RESULTS

THERE ARE (MINIMAL) KNOT
DIAGRAMS WITHOUT PLANAR
LOMBARDI DRAWINGS

IF G IS THE MEDIAL GRAPH OF A
PRIMAL-DUAL PAIR ONE OF WHICH
IS SIMPLE, THEN G DOES ADMIT
A PLANE LOMBARDI DRAWING

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EPSILON-LOMBARDINESS



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EPSILON-LOMBARDINESS

AN ϵ -LOMBARDI DRAWING HAS



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EPSILON-LOMBARDINESS

AN ϵ -LOMBARDI DRAWING HAS
STILL CIRCULAR EDGES



EPSILON-LOMBARDINESS

AN ϵ -LOMBARDI DRAWING HAS
STILL CIRCULAR EDGES

OPPOSITE EDGES AT VERTEX
HAVE EXACTLY 180° ANGLES

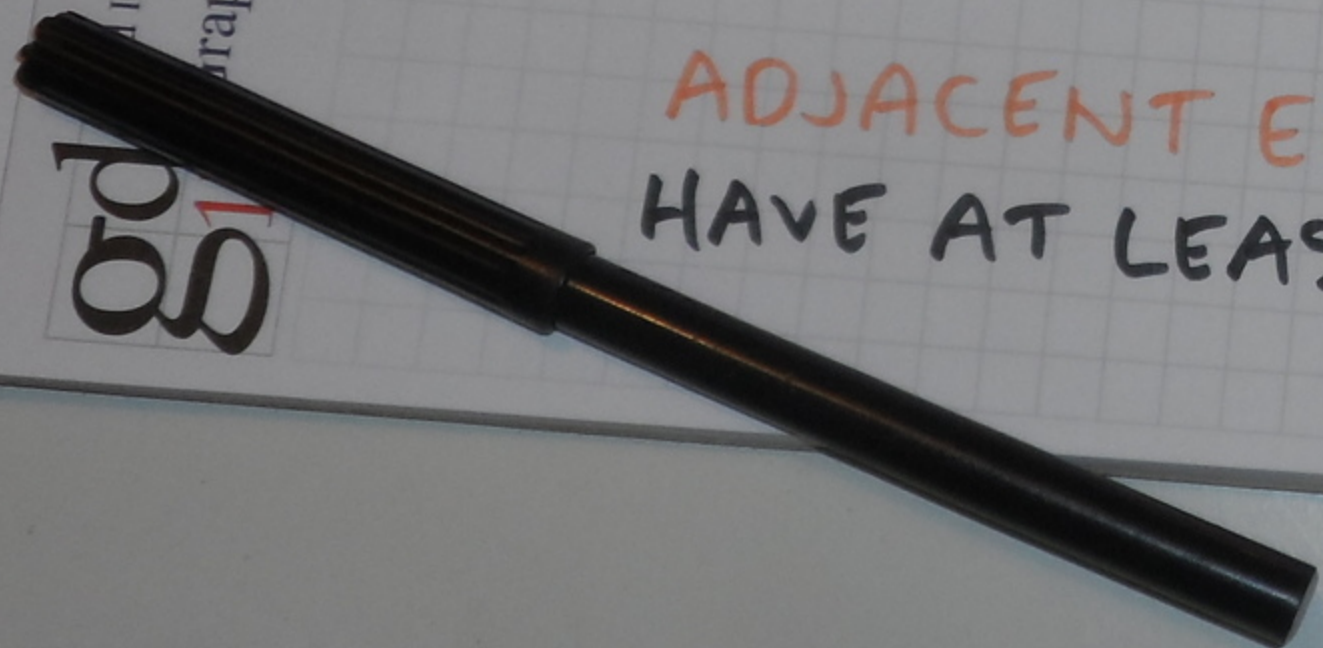
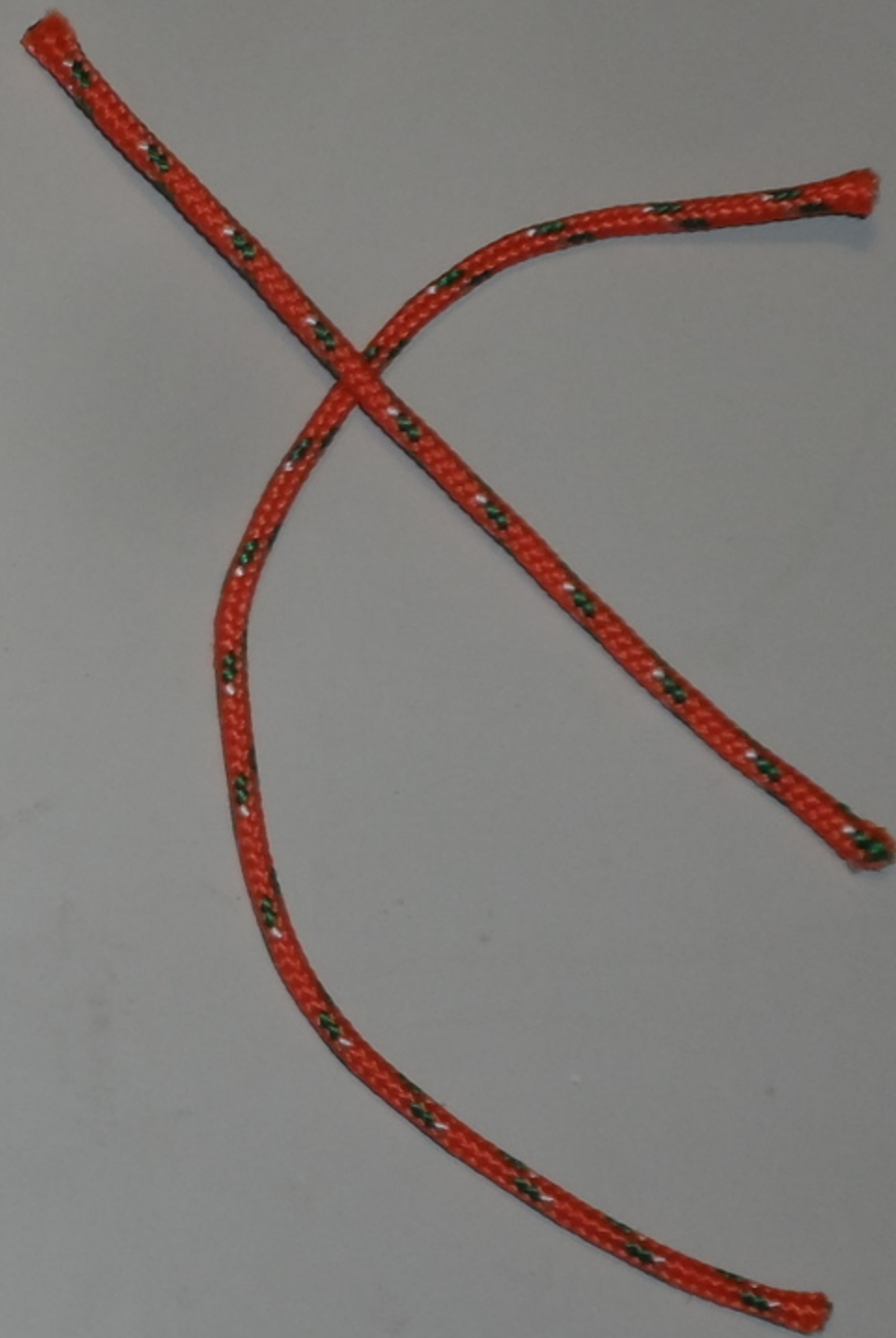


EPSILON-LOMBARDINESS

AN ϵ -LOMBARDI DRAWING HAS
STILL CIRCULAR EDGES

OPPOSITE EDGES AT VERTEX
HAVE EXACTLY 180° ANGLES

ADJACENT EDGES AT VERTEX
HAVE AT LEAST $90 - \epsilon^\circ$ ANGLES



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EPSILON-LOMBARDINESS

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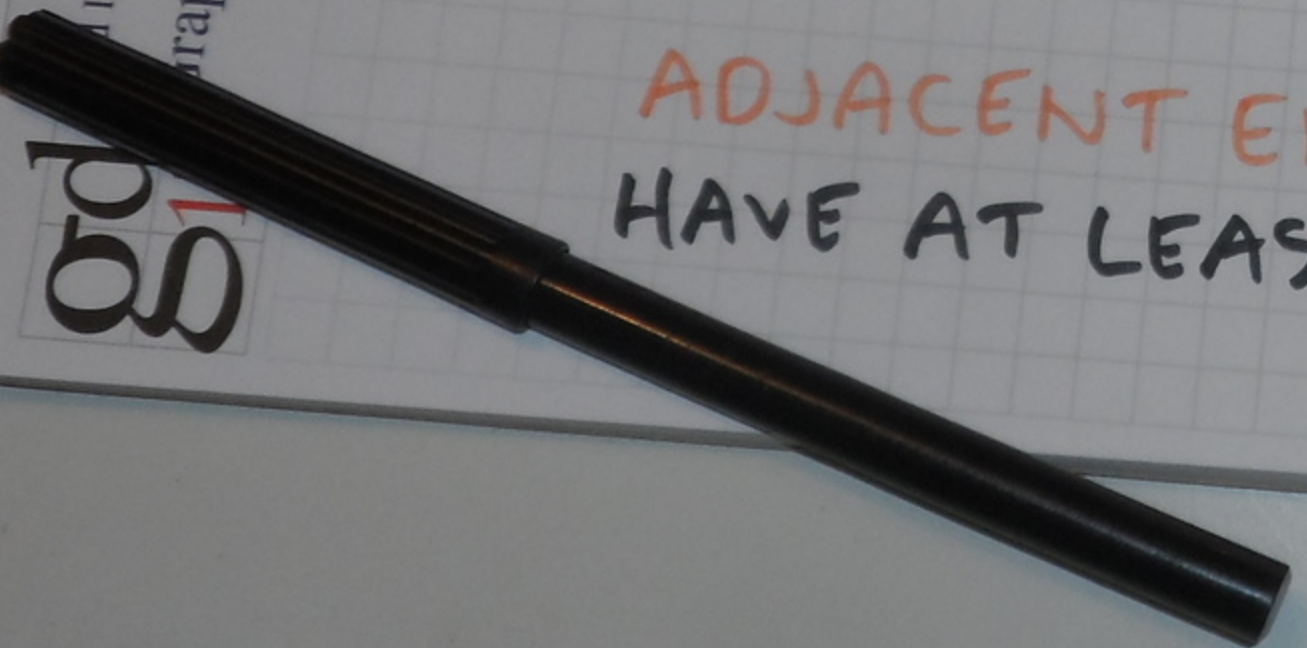


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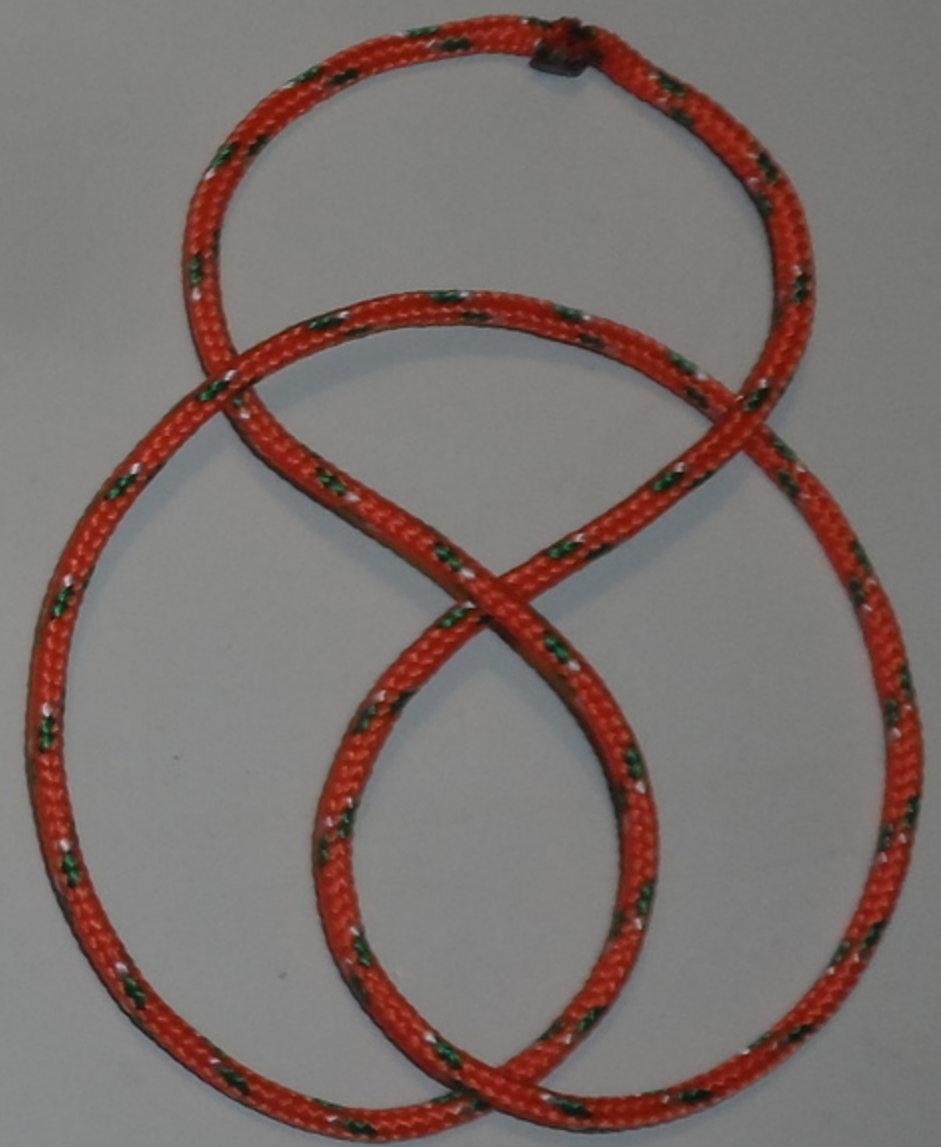


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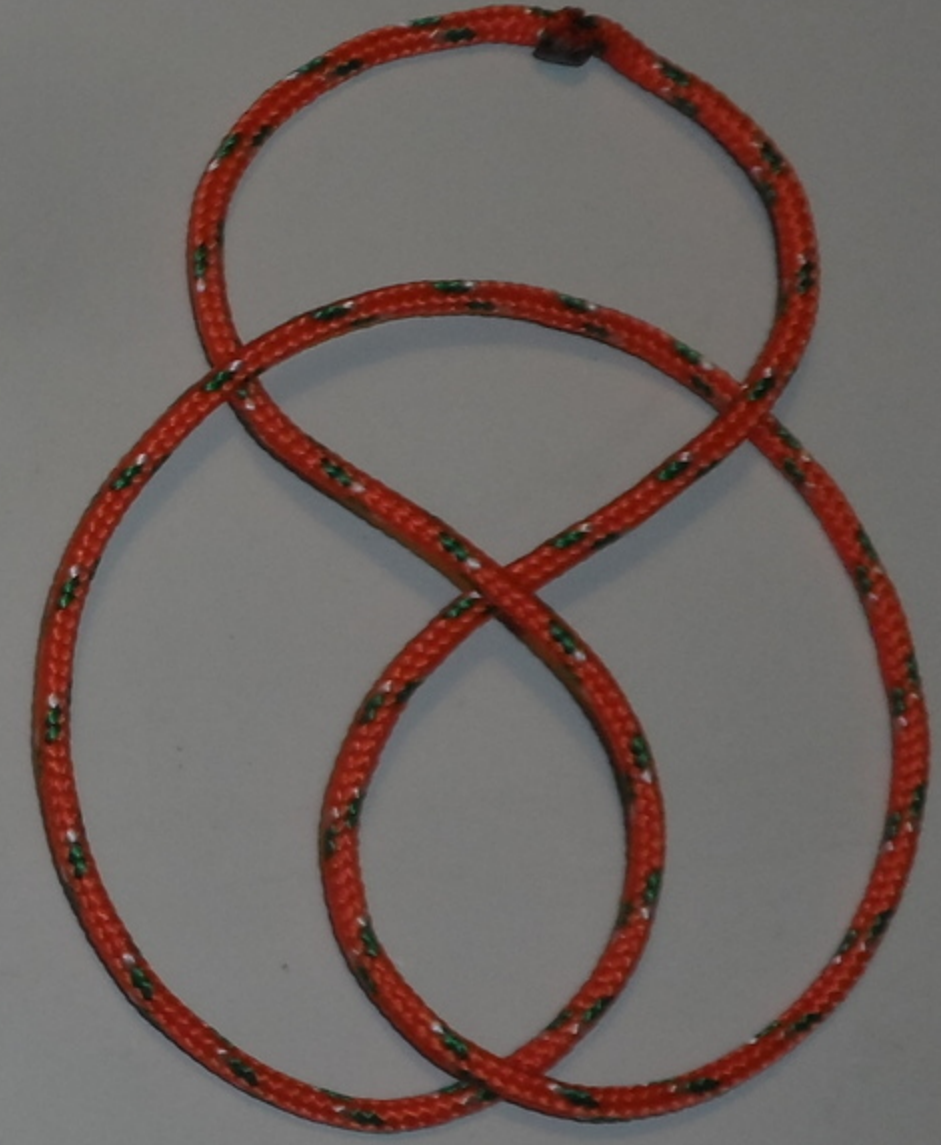
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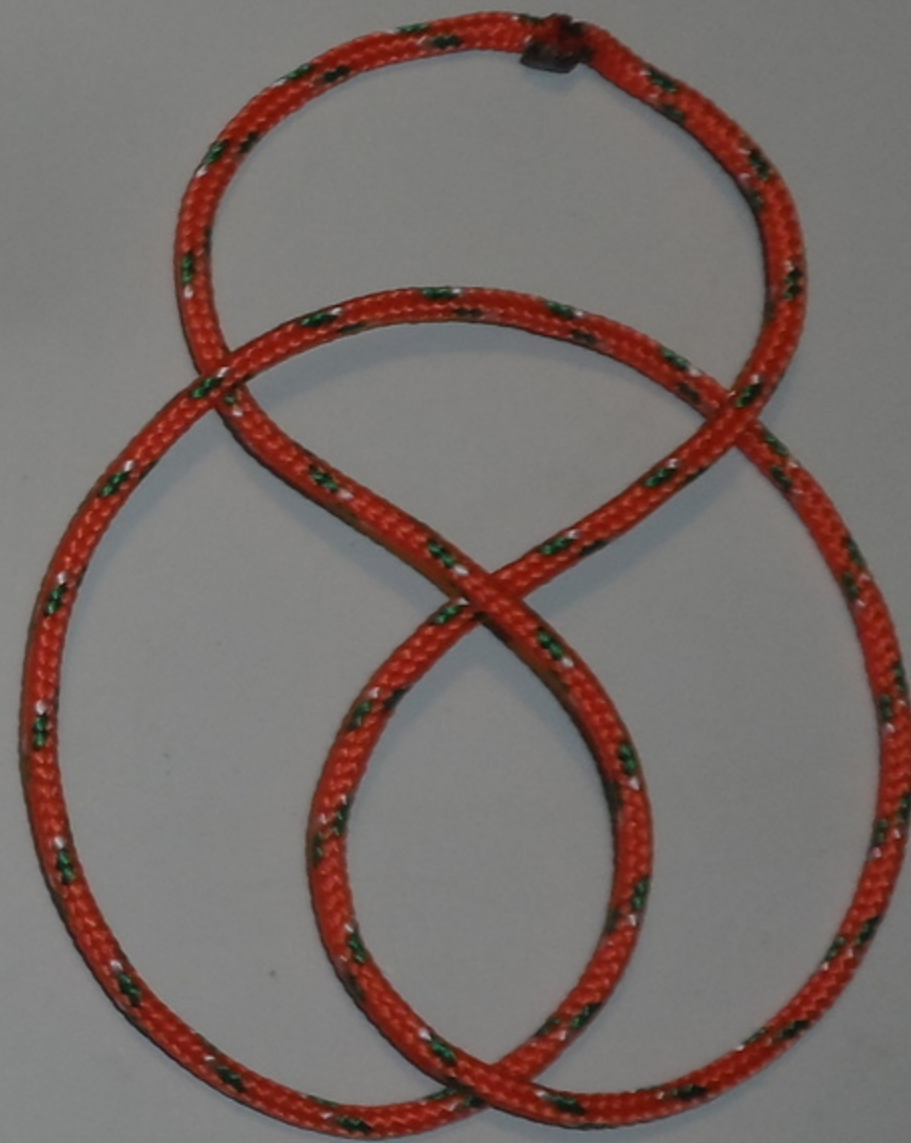
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RESULTS (CONTINUED)



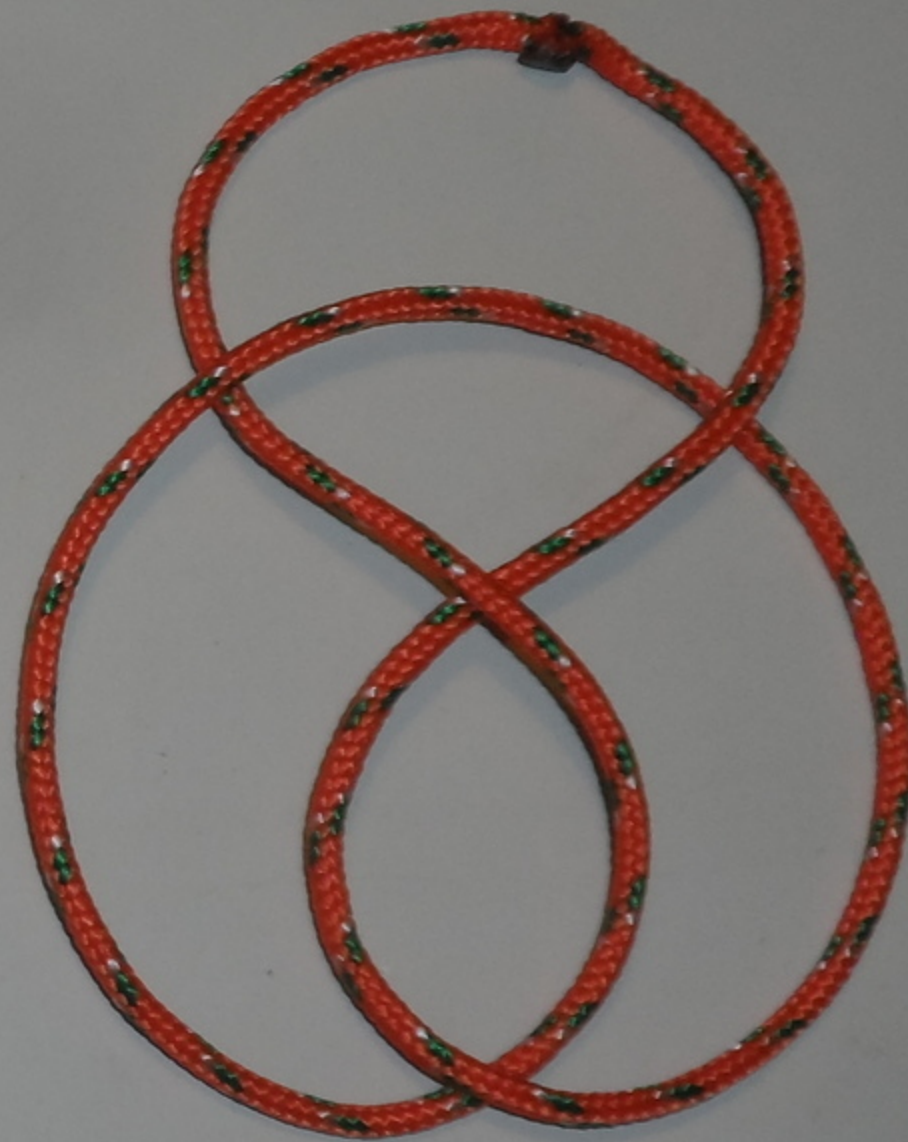
RESULTS (CONTINUED)

EVERY 4-REGULAR MULTI-
GRAPH WITHOUT SELF-LOOPS
ADMITS A PLANAR ϵ -LOMBARDI
DRAWING



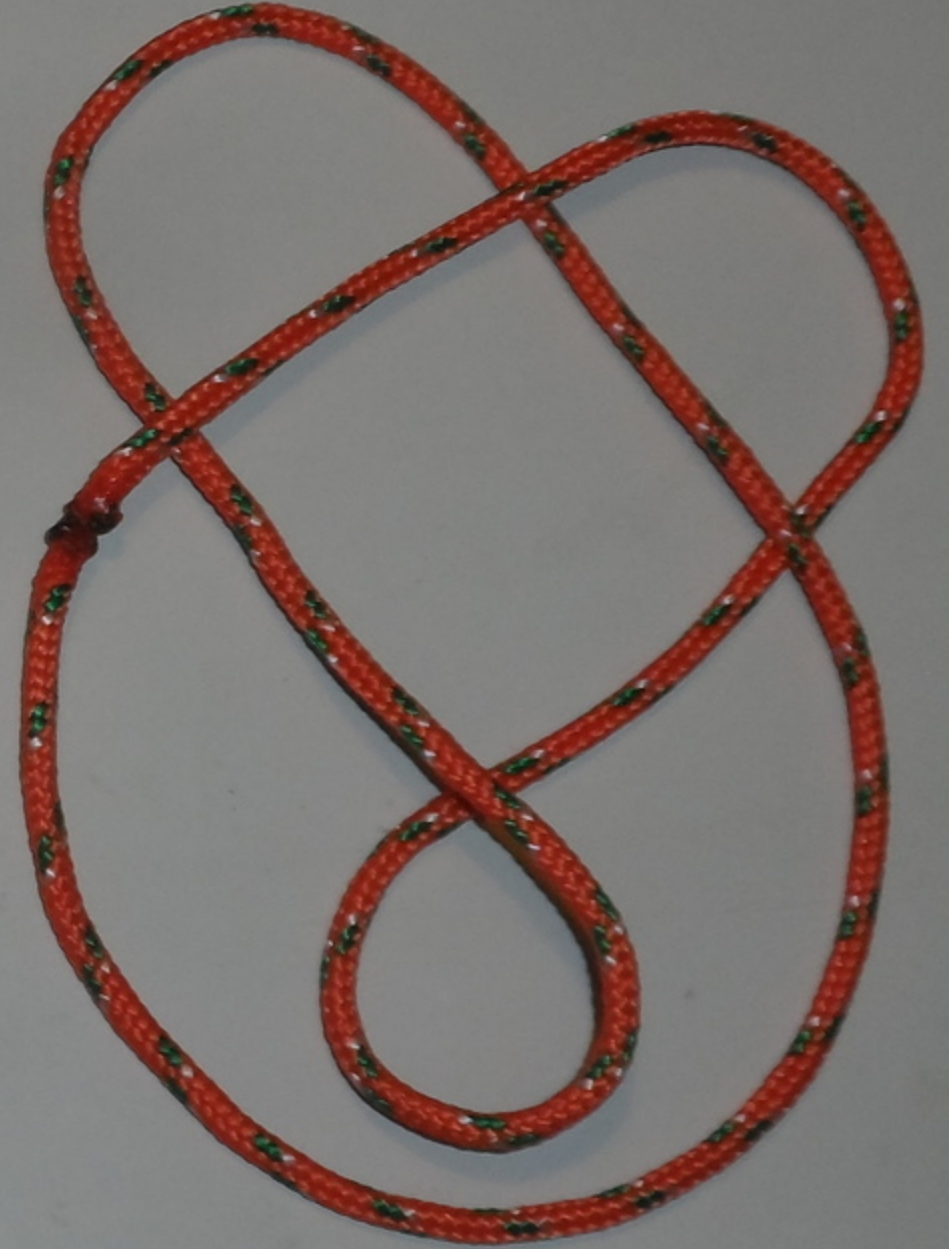
RESULTS (CONTINUED)

EVERY 4-REGULAR MULTI-
GRAPH WITHOUT SELF-LOOPS
ADMITS A PLANAR E-LOMBARDI
DRAWING $(\forall \epsilon)$



RESULTS (CONTINUED)

EVERY 4-REGULAR MULTI-
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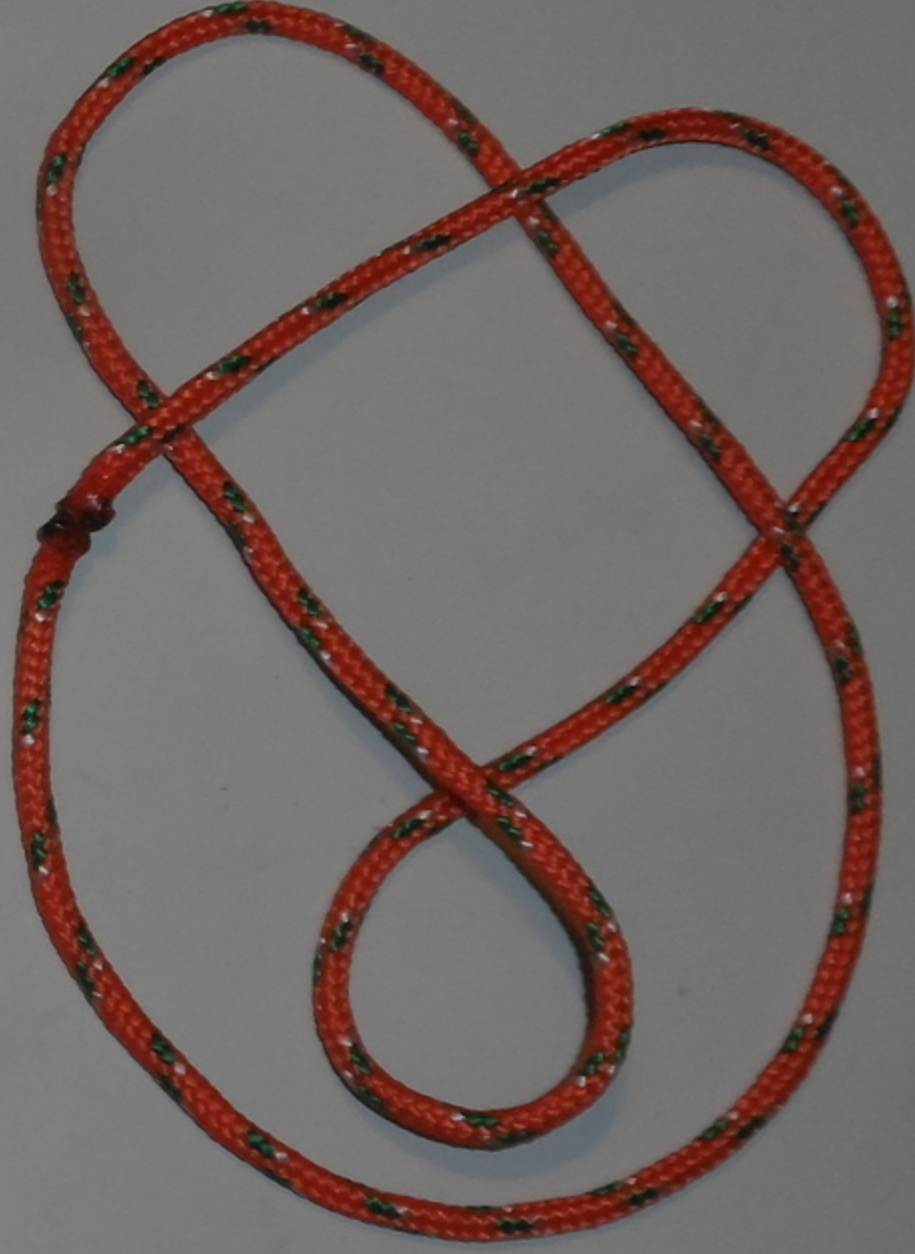


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FUTURE WORK



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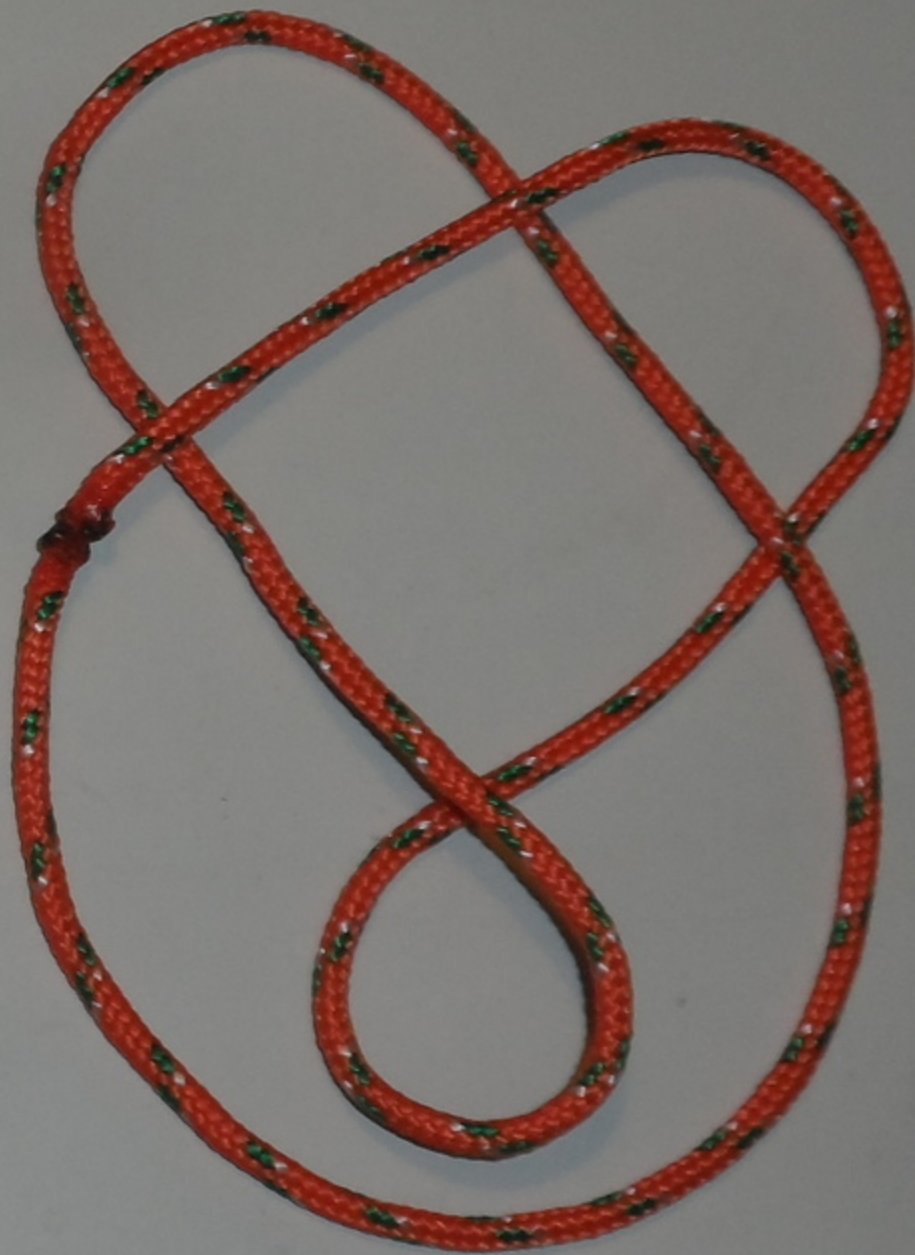
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FUTURE WORK

HOW ABOUT ACTUALLY
MORPHING BETWEEN
DRAWINGS?



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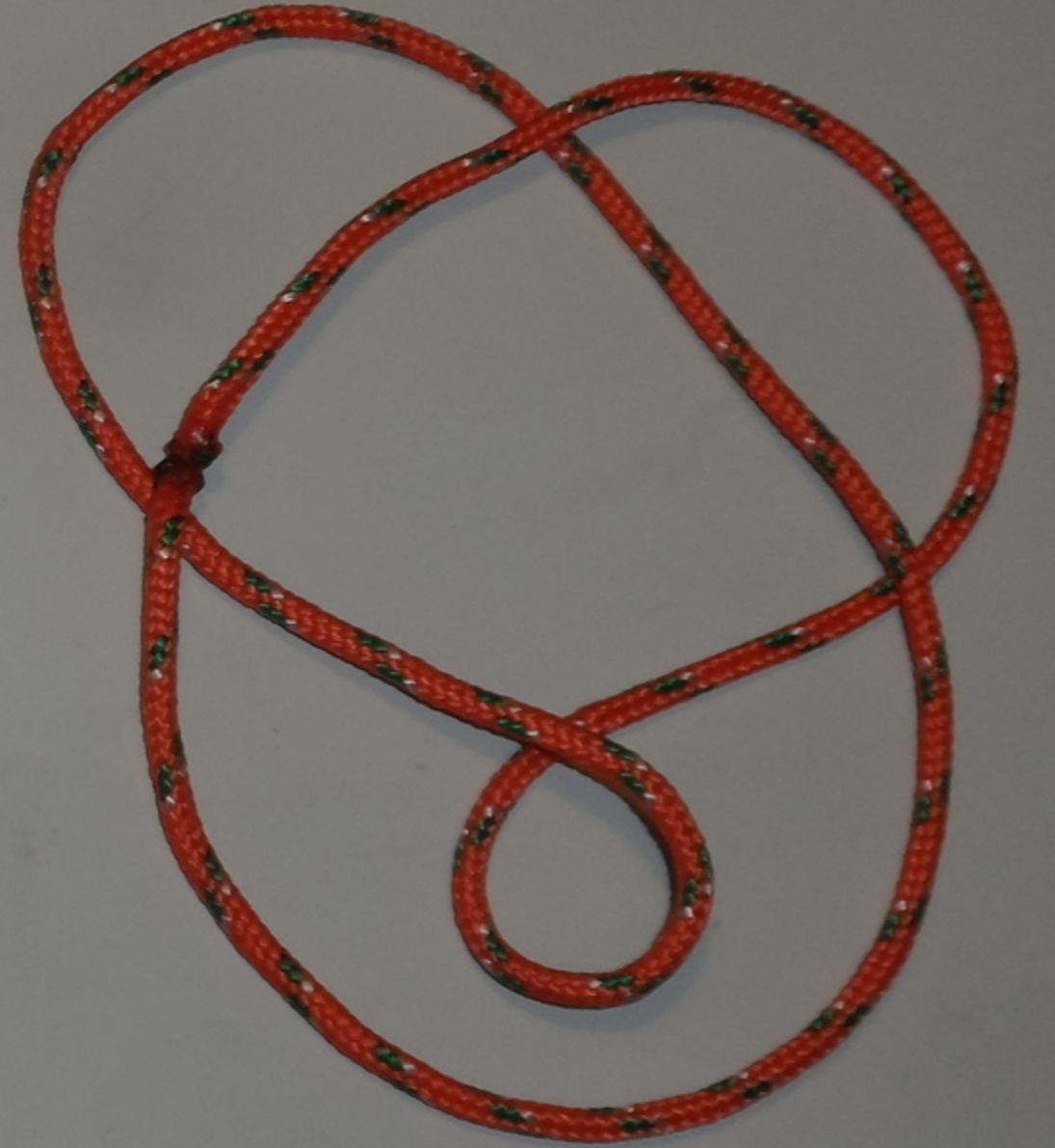
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FUTURE WORK

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FUTURE WORK

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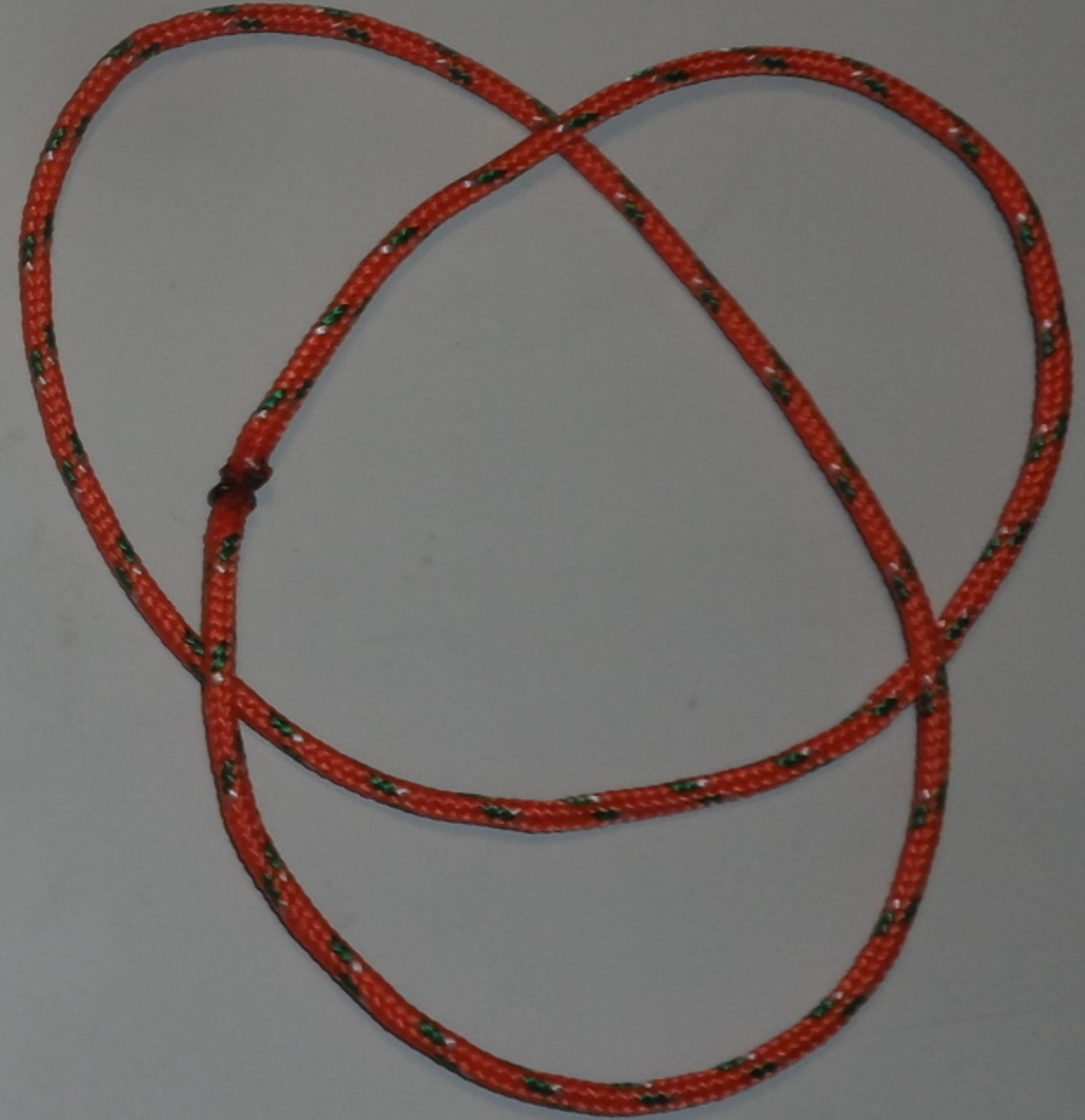
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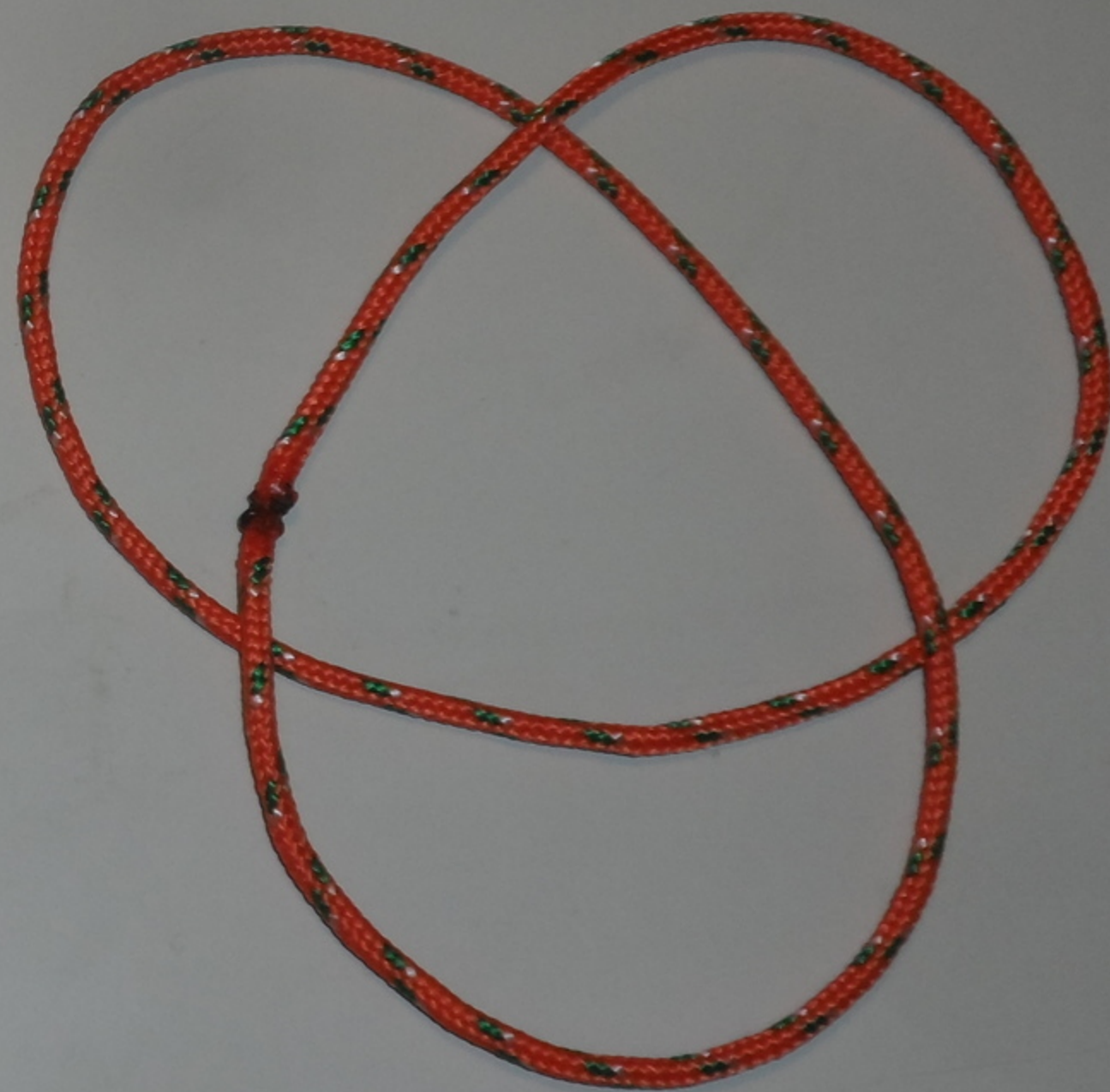
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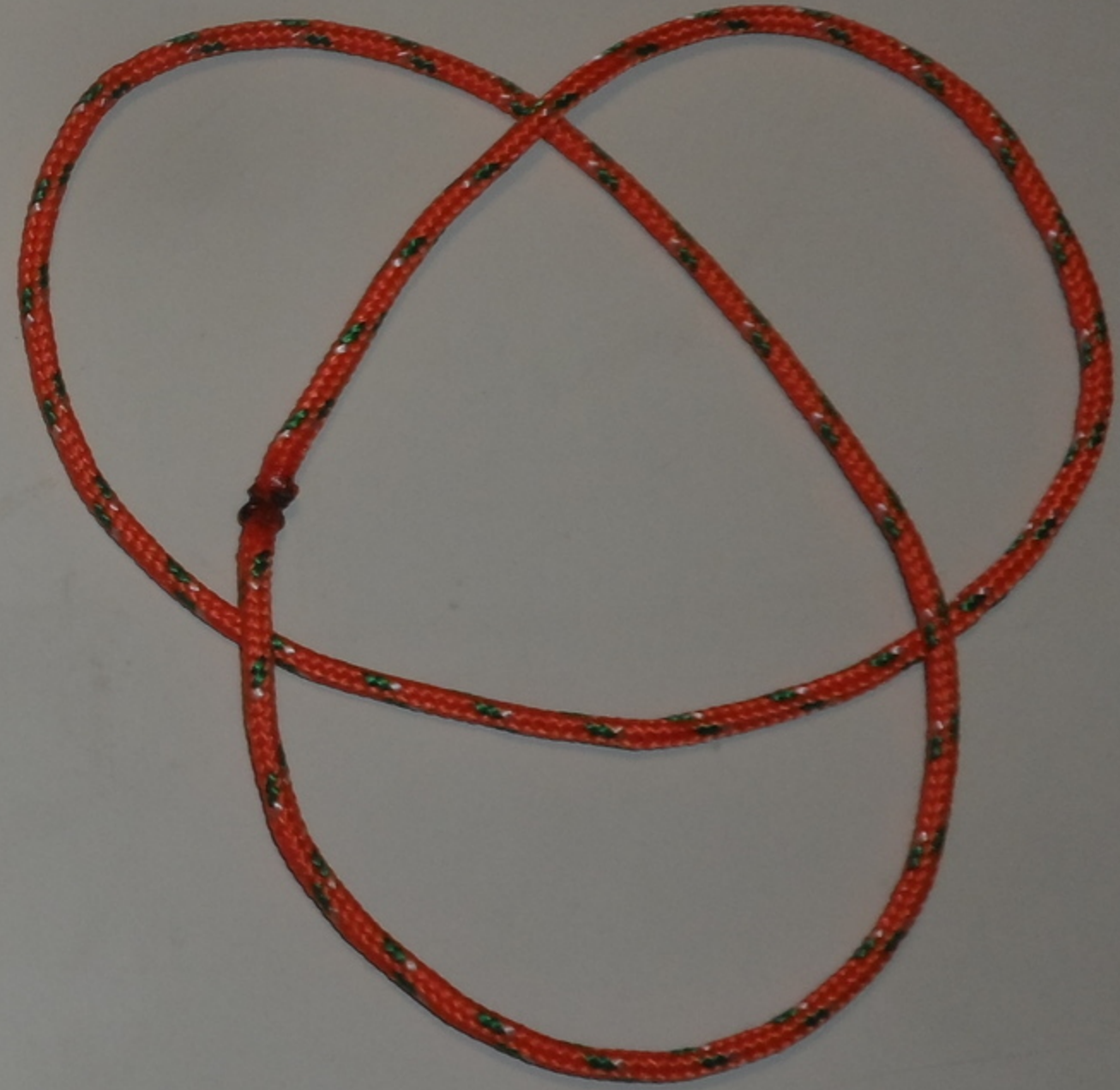
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THANK YOU!

QUESTIONS?



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THANK YOU!

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