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Instant Centers of Velocity in a Kinematically Intelligent Blackboard Environment

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INSTANT CENTERS OF VELOCITY IN A KINEMATICALLY INTELLIGENT BLACKBOARD ENVIRONMENT

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ABSTRACT

This project was part of a continuing expansion of a graphical software environment called "Skimp", originally developed by Dr. J. K. Nisbett.[1] The final version of this software package will allow the kinematic concepts of an introductory machine dynamics class to be taught exclusively on a blackboard sized projected computer screen. This software package will be used as a teaching aid in the classroom as well as a tutorial for students outside the classroom.

The scope of this project was limited to the concept of instant centers of velocity. This portion is a subroutine accessible during the regular execution of the program. The subroutine has three modes of operation which include automatic, automatic with construction lines, and tutorial.

INTRODUCTION

Background

The graphical software environment called "SKIMP" was originally developed by Dr. J.K. Nisbett as part of his Master's thesis at the University of Texas at Arlington. The scope of Dr. Nisbett's original program was limited to the construction and animation of various planar linkages. This original work allowed the construction of planar linkages, not limited to the standard four bar linkages, using both revolute and prismatic joints. Though initially limited to pre-processing for analysis through the computer aided sketching of mechanisms, Dr. Nisbett recognized the potential of an expanded version of this software as both a teaching aid and tutorial.

Theory

The instantaneous center of velocity is defined as the instantaneous location of a pair of coincident points of two different rigid bodies for which the absolute velocities of the two points are equal.[2] By the definition, the pin joints P_{12}, P_{23}, P_{34}, and P_{14}, are instant centers between the links they connect (see figure 1). Body 2 and Body 3 are two rigid bodies which have a pair of coincident points. The pin joint is a point on both bodies. These points are coincident and the absolute velocity for the points on both bodies are equal. A similar argument can be made for all remaining pin joints.

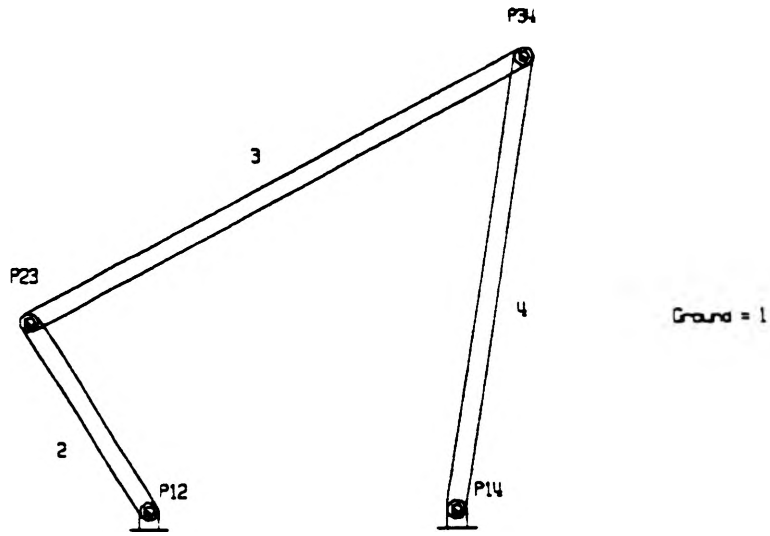

Figure 1. Standard Four Bar Linkage

For the case of straight line sliding motion between two links, the instant center of velocity will be on a line normal to the motion at a distance of infinity (see Figure 2).

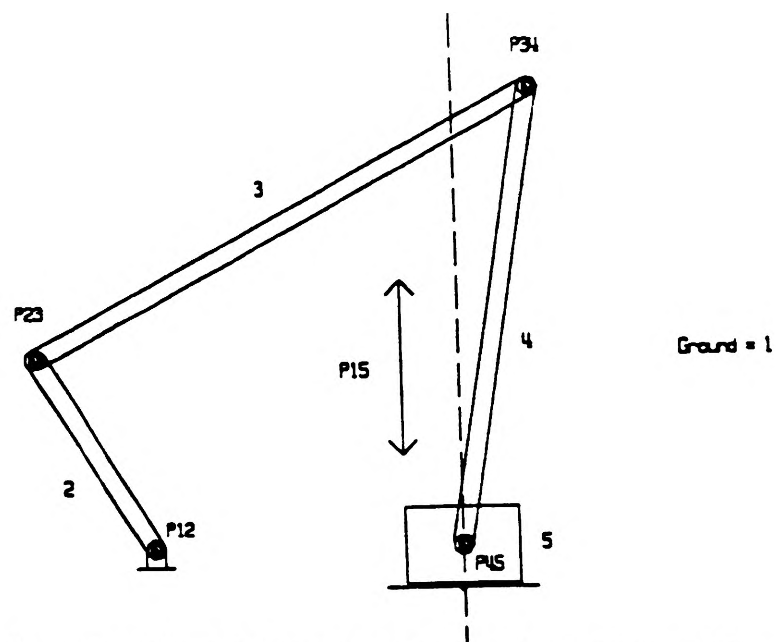

Figure 2. Slider Crank Linkage: Instant Center at Infinity

This is a known instant center of velocity which is equivalent to a pin joint connecting the two bodies at infinity.

For each linkage there are N number of instant centers as defined by Equation (1) where n is equal to the number of links in the mechanism.[2]

$$N = \frac{n(n-1)}{2} \quad (1)$$

Instant centers of velocity that are not found by obvious application of the definition are located by applying the Aronhold-Kennedy Theorem of three centers. This theorem states that the three instant centers shared by three rigid bodies in relative motion to one another (connected or not) all lie on the same straight line.[2] Body 2 (see Figure 1) is part of two sets of three rigid bodies for which this theorem can be applied. Body 2 has relative motion with bodies 3 and 4, as well as bodies 1 (ground) and 4. Applying the theorem to the first set of rigid bodies, bodies 2,3 and 4, leads to the conclusion that the instant center of velocity between bodies 2 and 4 lies somewhere on the line that passes through instant centers P_{23} and P_{34} (see Figure 3).

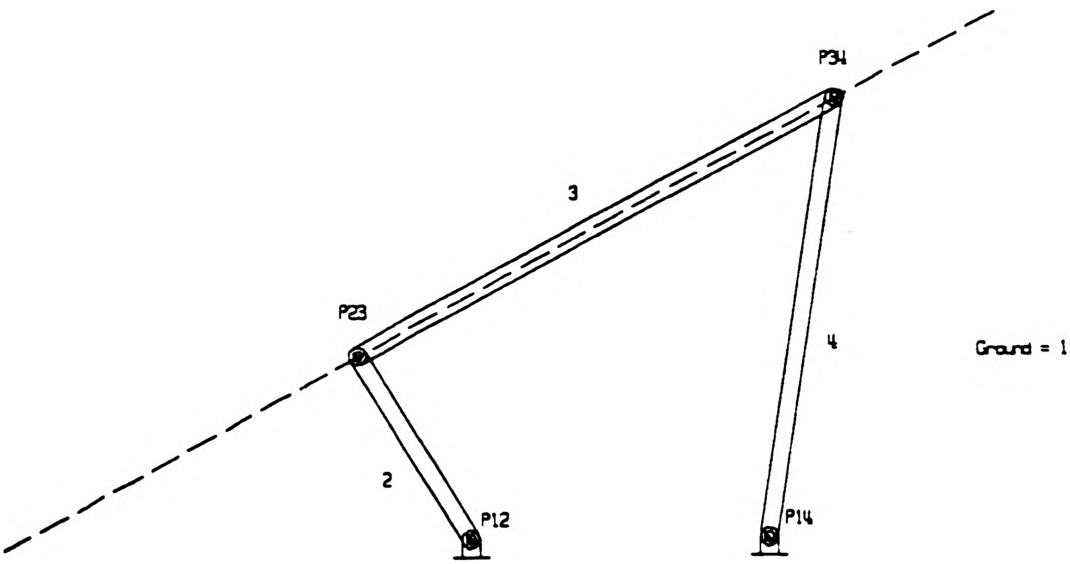

Figure 3. First Application of Aronhold-Kennedy Theorem

The exact location of the instant center of velocity between bodies 2 and 4 can now be determined by applying the theorem to the second set of rigid bodies, bodies 1,2 and 4. The instant center P_{24} lies on a line that passes through instant centers P_{12} and P_{14}. These points are two of the three instant centers shared by the three bodies in relative motion, bodies 1,2 and 4 (see Figure 4). The instant center P_{24} is then located at the intersection of the two lines formed by the application of the Aronhold - Kennedy Theorem of three centers. It is instructive to note that each time the theorem was applied, it was done through existing instant

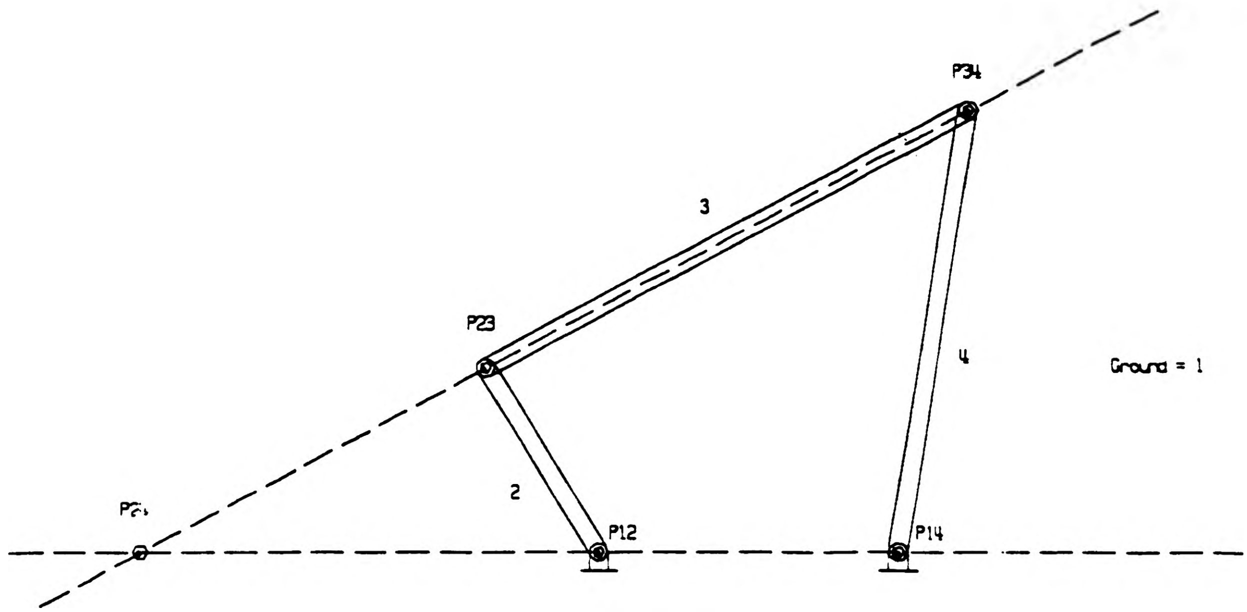

Figure 4. Second Application of Aronhold-Kennedy Theorm

centers which contained the subscript 2 and the subscript 4, together with a subscript which was common to both instant centers. By repeated application of this theorem all N number of instant centers of velocity can be found.

The best method for keeping track of which instant centers have been found is to space the link numbers around the perimeter of a circle and connect the link numbers corresponding to the subscripts of known instant centers (see Figure 5).

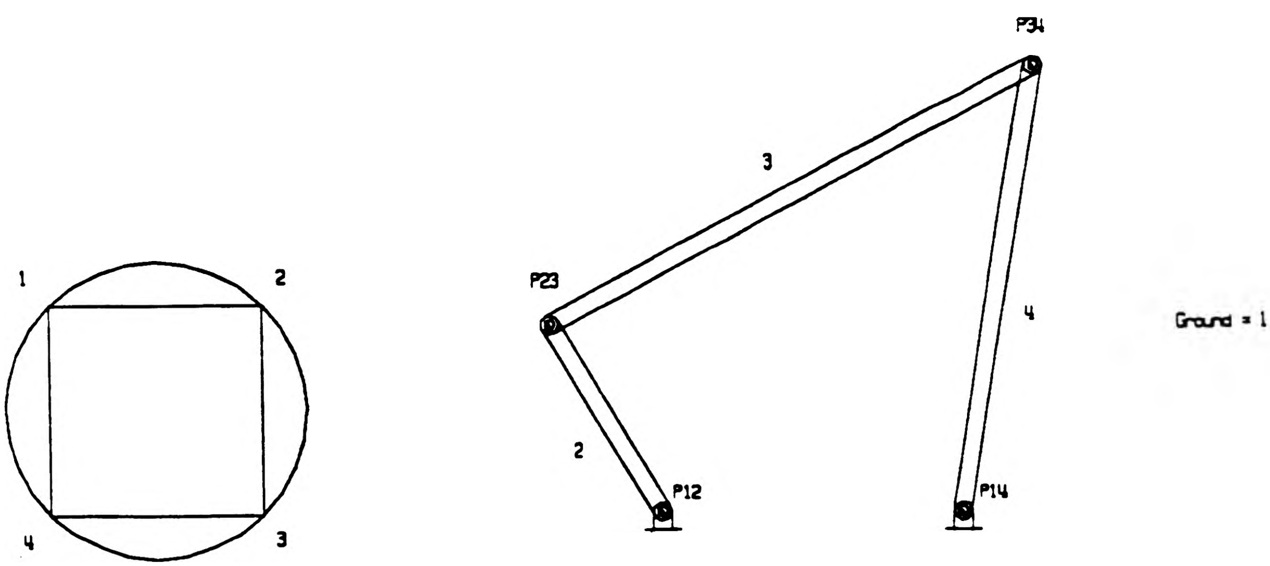

Figure 5. Instant Center Circle

As each unknown instant center location is attempted to be found using the Aronhold-Kennedy Theorem, a dotted line connecting the link numbers corresponding to the subscript of the instant center in question is drawn. The endpoints of any two lines that form a triangle with the dotted line define the subscripts of known instant centers. It is through these instant centers that the construction lines are formed using the Aronhold-Kennedy Theorem to define the location of the unknown instant center (see Figure 6).

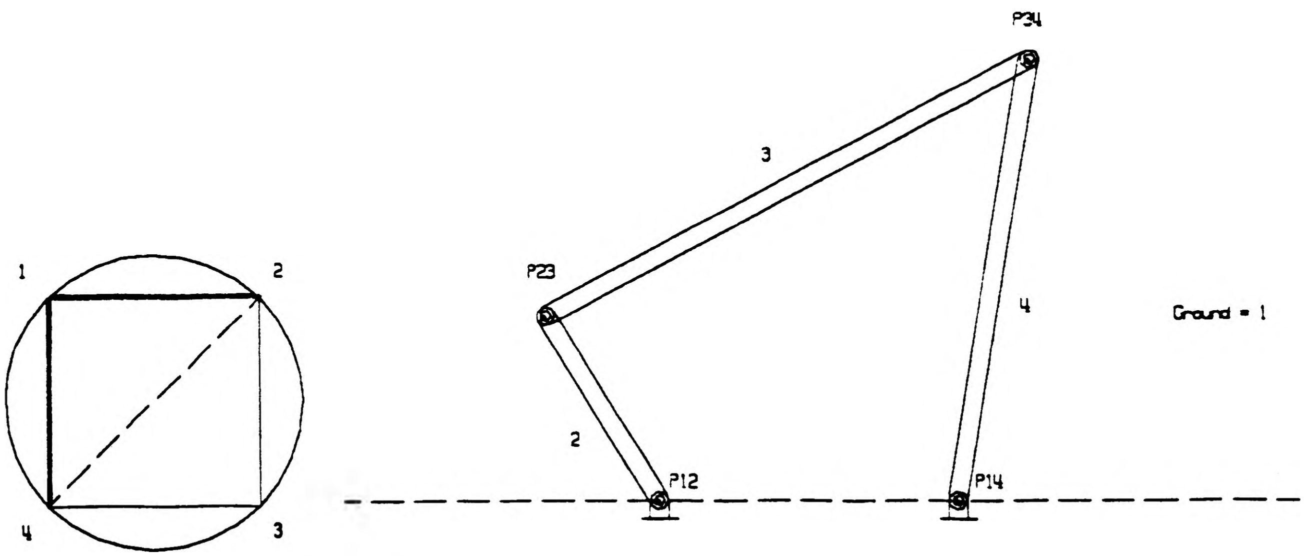

Figure 6. Instant Center circle and Aronhold-Kennedy Theorem

PROGRAM METHODOLOGY

Background

To begin the project it was necessary to convert the existing graphical subroutines of the program "SKIMP" to equivalent subroutines using GRFLIB [3] and SPECTRE.[4] This collection of graphical subroutines are in wide use and existing documentation was available. The instant centers of velocity subroutine begins by making use of three existing subroutines called jtype1, jtype2 and findunkn. These subroutines were written by J. Hair, D. Millar and S. Koehr [5] as a part of a senior level design class. The subroutine jtype1 determines the location of instant centers for grounded joints. The subroutine jtype2 determines the location of instant centers for pinned joints. The subroutine findunkn determines the location of unknown centers of velocity using the Aronhold-Kennedy Theorem of three centers. All three subroutines store the global x and y coordinate of the instant centers in a 3 by N array. The first component of each element is a flag to determine whether the location of that particular instant center is known.

Automatic With Construction Lines

This portion of the subroutine allows the step by step graphical determination of all instant centers of velocity of a mechanism. It begins after the main program "SKIMP" has sketched the mechanism. The subroutine is activated through the pull down menu labeled "Instant Centers". In this pull down menu are sub-menus whose titles are the three modes of operation: automatic, automatic with construction lines (automatic w/lines), and tutorial. (see Figure 7).

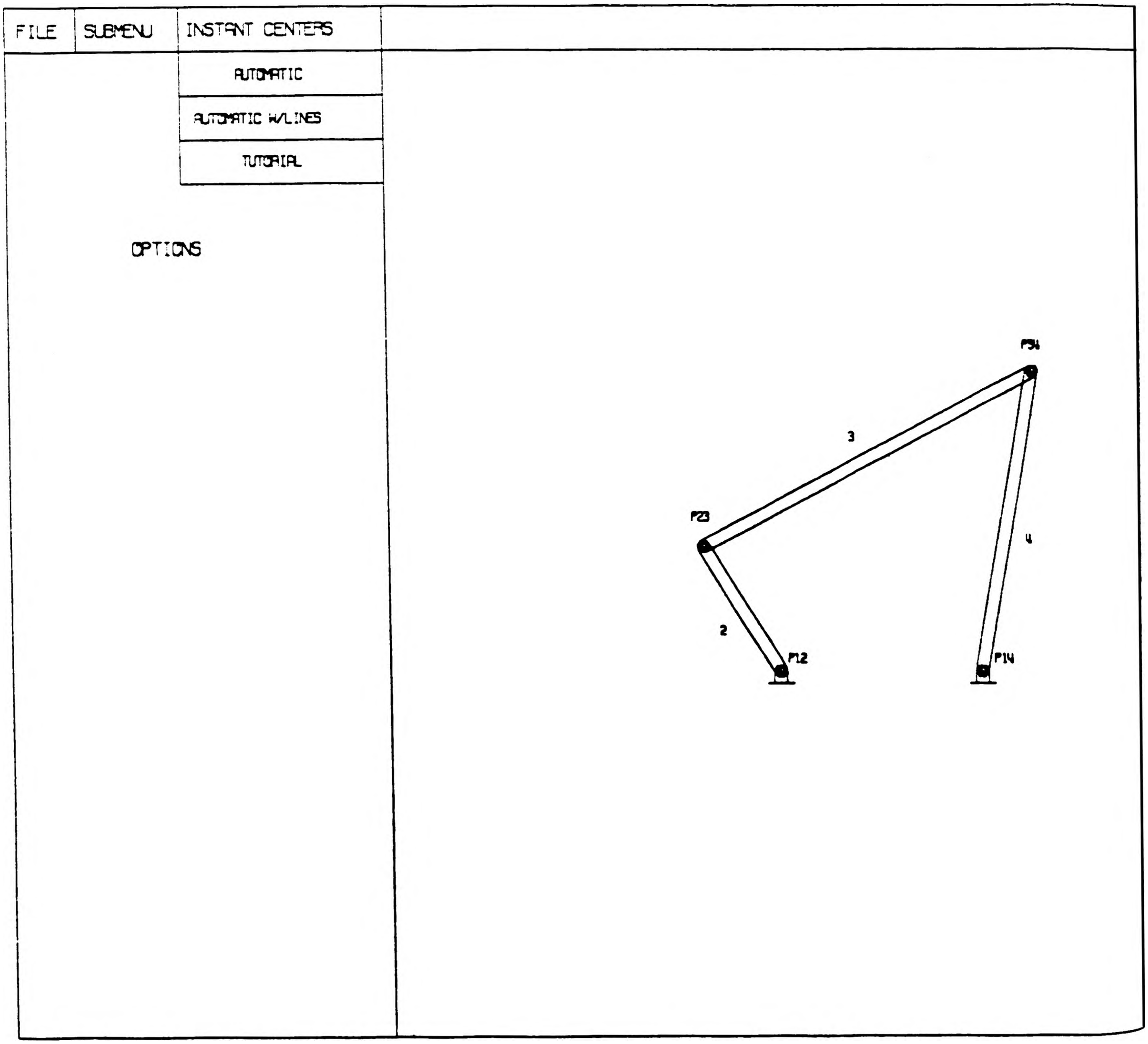

Figure 7. Skimp Environment: Instant Center Pull Down Menu

When the cursor is held on the label automatic w/lines and released the instant center circle will appear in the left window, with a line connecting all known instant centers. A pop-up menu will also appear which lists the N number of instant centers. Next to each instant center is a toggle switch for both the construction lines and the instant center (see Figure 8).

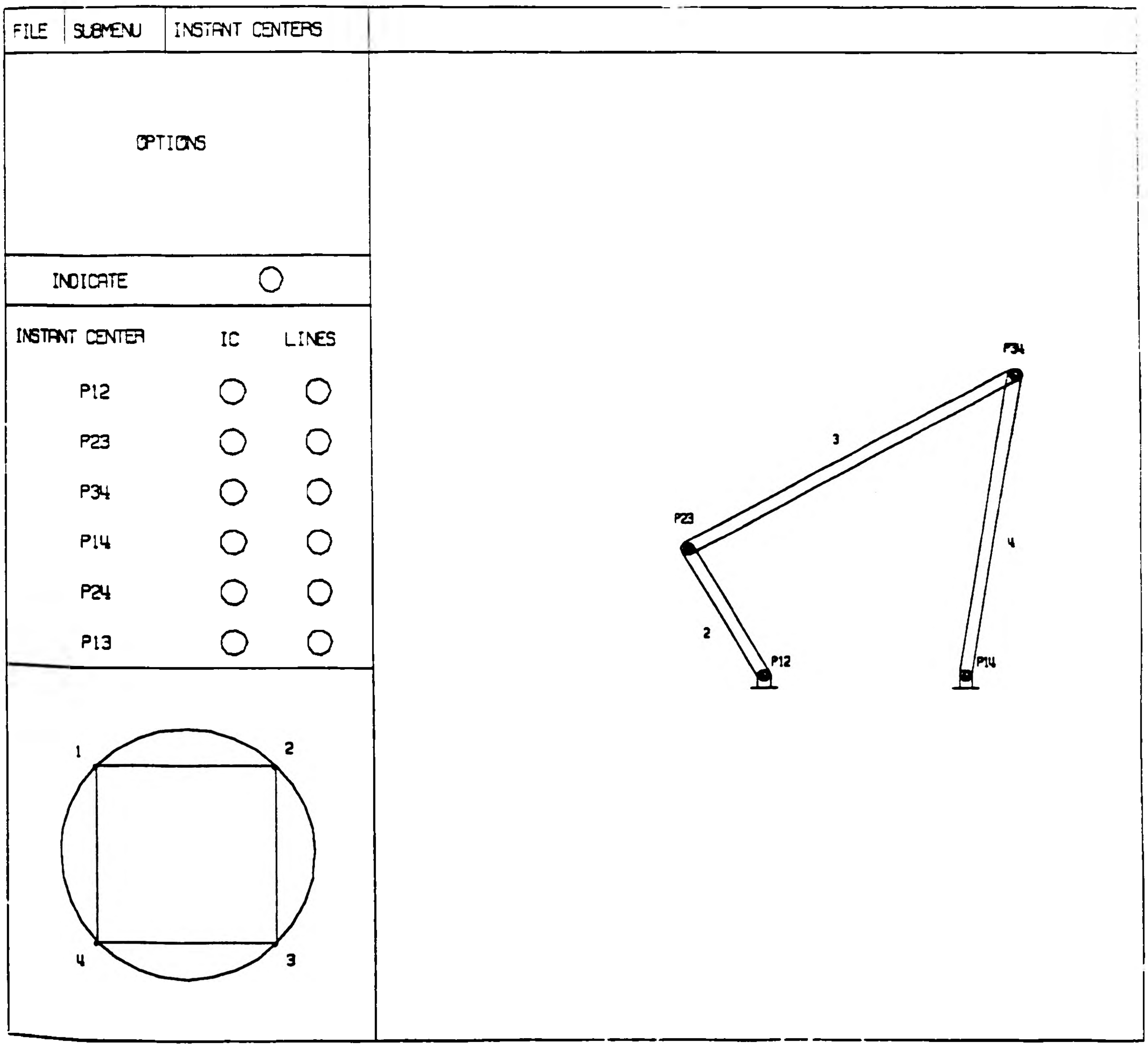

Figure 8. Skimp Environment: Automatic W/Lines

After each instant center is found the construction lines can be turned off so the screen is not cluttered when the remaining instant centers are found. As shown in the figure there is also a switch labeled "indicate". When this switch is activated, it allows the user to indicate with the cursor which particular line or instant center is to be turned off.

The subroutine findunkn has been altered to find one unknown instant center at a time and to have a keystroke pause between each application of the Aronhold-Kennedy Theorem. When the construction line is drawn through two known instant centers, the line, as well as the two legs of the triangle on the instant center circle which define the known instant centers blink on and off. This is to insure the student understands the connection between the instant center circle and the application of the Aronhold-Kennedy Theorem.

The exact location of the instant center is calculated by determining the slope and intercept of each construction line and setting the equations of the lines equal to each other and solving for their common point. A subroutine called trim is then called which calculates the length between the new instant center and the instant centers through which each construction line passes. The shortest length is the portion of the construction line which will remain on the screen. The construction line is then drawn in the background color and the shortest length is then redrawn (see Figure 9). This is repeated with a keystroke pause between each step until all instant centers of velocity are found.

Automatic

This subroutine is also available through the pull down menu. It calculates the location of all instant centers of velocity, then displays them (see Figure 10). A pop-up menu with a list of the N number of instant centers appears in the left window. A single toggle switch is next to each label allowing each to be turned on or off depending on their present state. There are also switches labeled: all on, all off, and indicate.

Tutorial

The tutorial subroutine operates in much the same way as the subroutine automatic w/lines. The most notable exception is that the choice of which known instant centers are used in applying the Aronhold-Kennedy Theorem is determined by the user and not the computer. Upon activating the subroutine, again via the pull down menu, the same pop-up menus appear in the left window as did in the subroutine automatic w/lines. An added pop-up menu will appear in the left window with the N number of instant centers as labels, as well as a single switch labeled "help". There will be two switches for each label under the headings "find" and "using". The student will be able to choose the unknown instant center to be located, then choose two instant centers under the heading "using" which will be used for the first application of the Aronhold-Kennedy Theorem. The student will then be prompted whether this construction line should then be drawn. Upon answering yes, an additional prompt asking for the second two instant centers through which the mixed construction line will be drawn. The student will once again be prompted as to whether this construction line will be

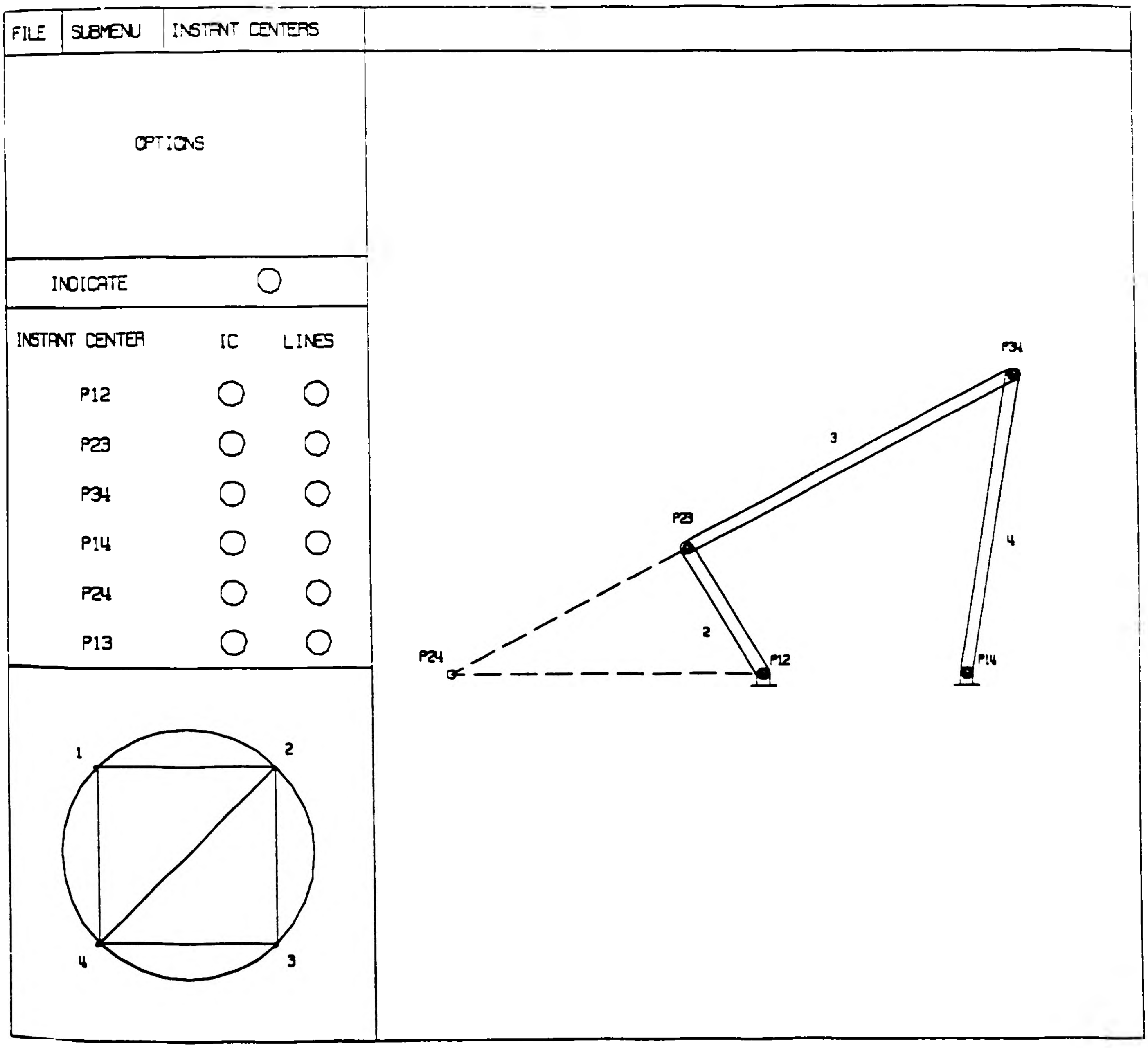

Figure 9. Skimp Environment: Finding Unknown Instant Center

drawn. The instant center circle will highlight the legs of the triangle which denote the known instant centers through which the respective construction lines have been drawn. This subroutine will allow the student to make errors and when the "help" switch is activated, the computer will delete each step with a keystroke pause between each deletion, back to the point at which the mistake was made.

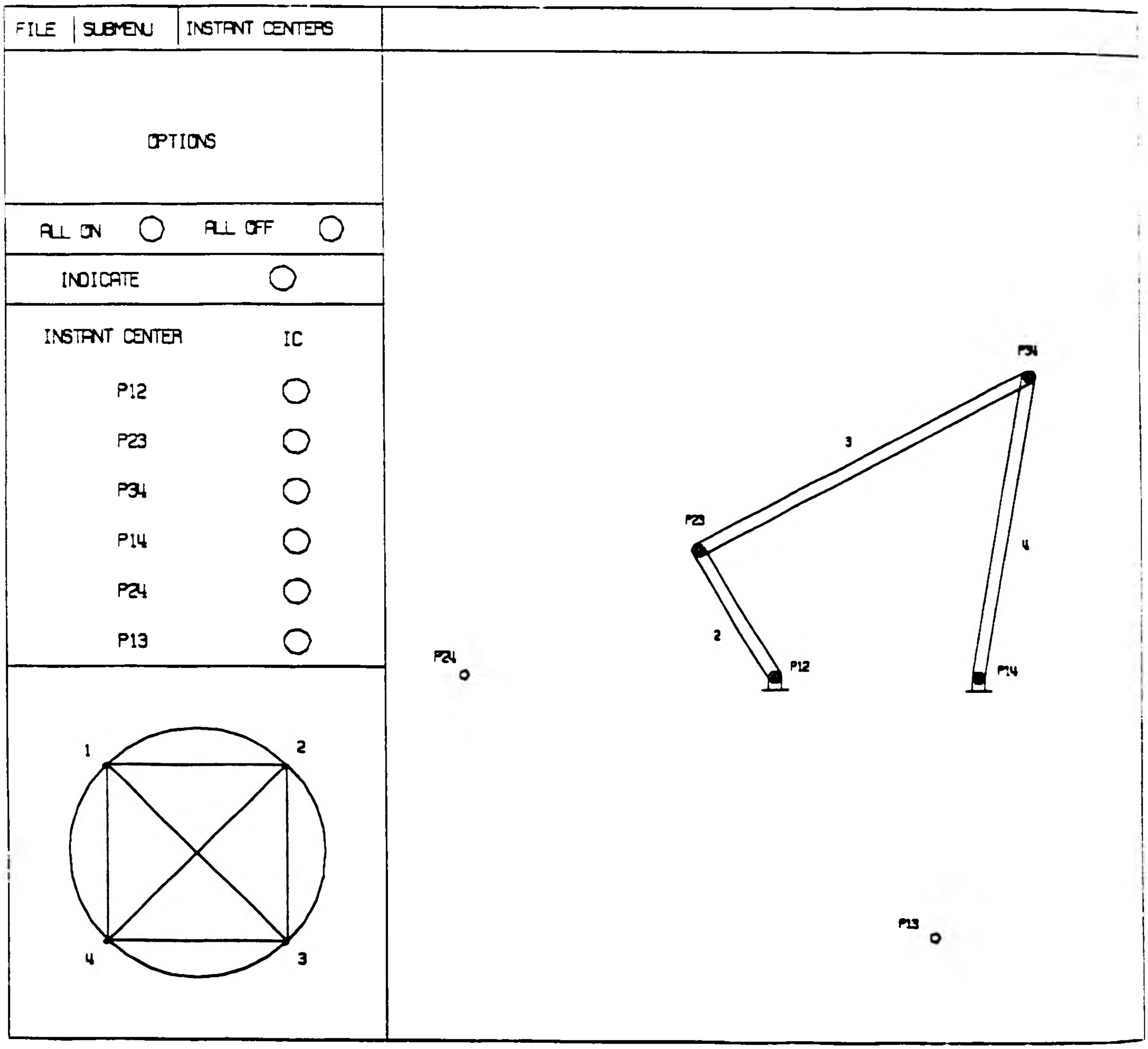

Figure 10. Skimp Environment: Automatic

CONCLUSIONS

The purpose of this project was to create a subroutine for the graphical software environment called "Skimp". This subroutine is a prototype for one module of the Kinematically Intelligent Blackboard project of Dr. J.K. Nisbett. The subroutine was responsible for teaching the concept of Instant Centers of Velocity on a blackboard sized projected computer screen. It incorporated the Aronhold-Kennedy Theorem of Three Centers which graphically determines the location of unknown instant centers by intersecting construction lines drawn through known instant centers. The subroutine has three modes of operation which include Automatic, Automatic W/Lines, and Tutorial.

One of the largest problems faced by students is not with the understanding of basic concepts such as instant centers of velocity, but the time constraint which does not allow these concepts to be applied in varying problem configurations. The greatest advantage to using the instant centers of velocity subroutine is that the classroom will not be hindered by the time constraint normally associated with traditional teaching methods.

The student will find the program valuable as a tutorial, a method for verifying solutions, and a record of lectures. The tutorial portion of the program will serve the students as their own personal tutor, available whenever the student has questions.

This subroutine is also useful in teaching concepts of machine dynamics related to instant centers of velocity. Concepts such as velocity ratios and velocity polygons can be more fully understood by using the instant centers of velocity subroutine.

Though this program has only been used in the classroom for demonstration purposes it is hoped that using the program to teach concepts of machine dynamics will benefit both instructor and student. The next step in the development is the continued expansion of the prototype and classroom testing.

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