

candidate node. A graphical map can be generated to visualize focal points detected on the geometric surface.

20 Claims, 8 Drawing Sheets

(56)

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- CPC *A61B 5/046* (2013.01); *A61B 5/0452* (2013.01); *A61B 5/0464* (2013.01); *A61B 5/486* (2013.01); *A61B 5/7264* (2013.01); *A61N 1/36* (2013.01); *A61B 5/0422* (2013.01);

A61B 5/04085 (2013.01); *A61B 18/1492* (2013.01); *A61B 2576/023* (2013.01)

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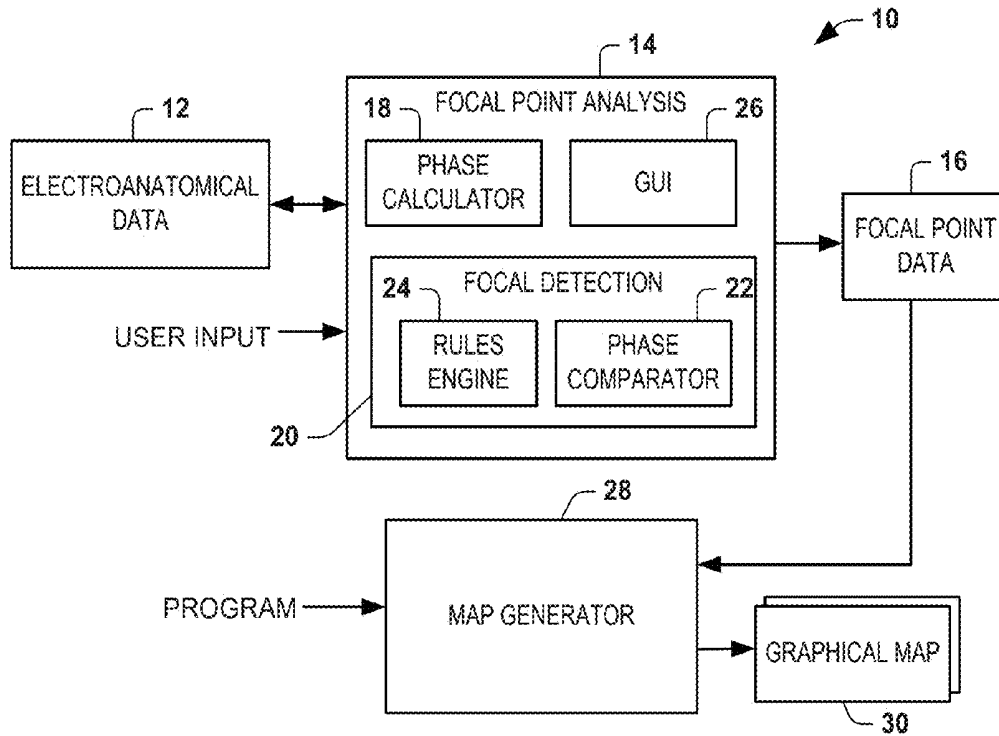


FIG. 1

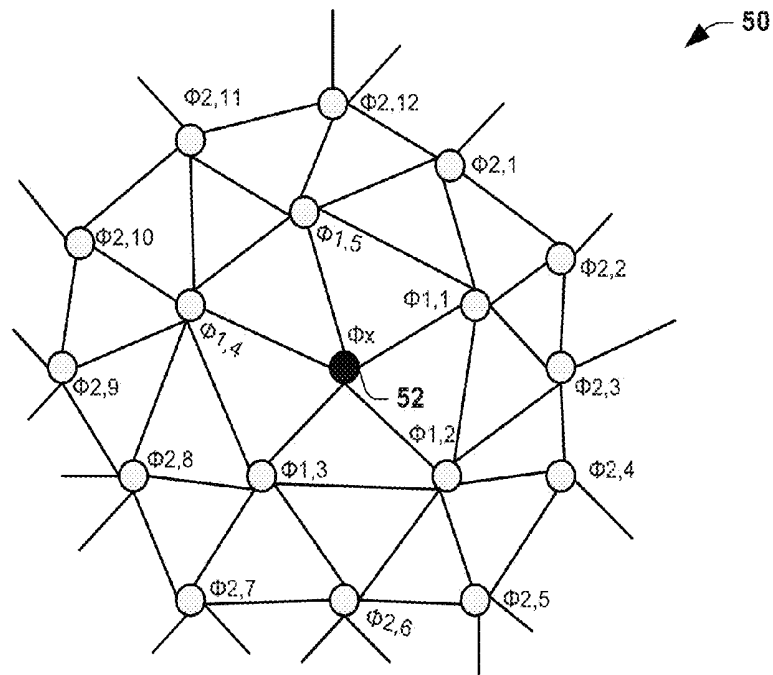


FIG. 2

70

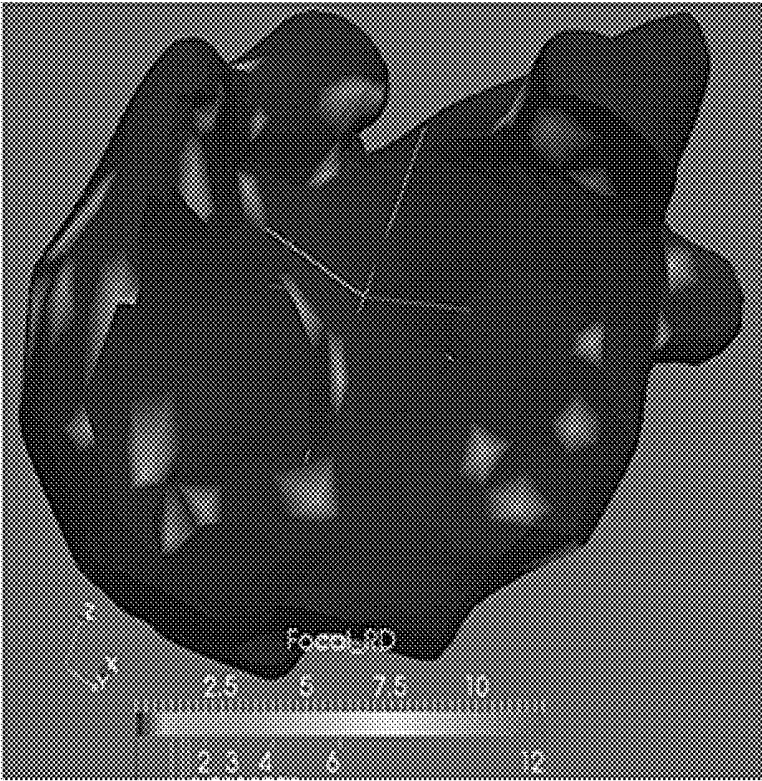


FIG. 3

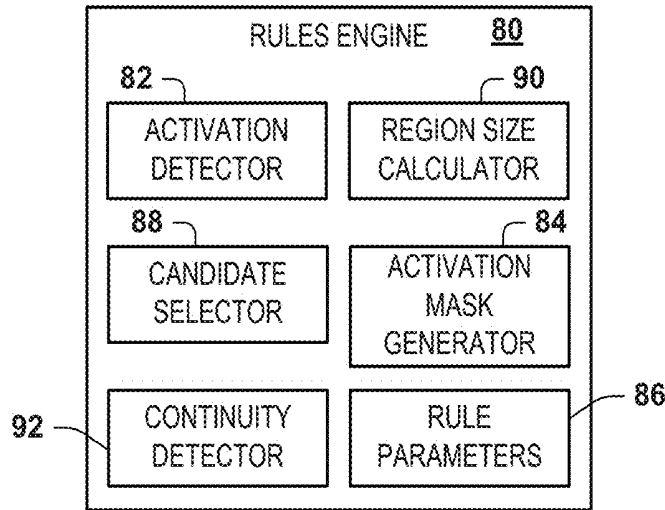


FIG. 4

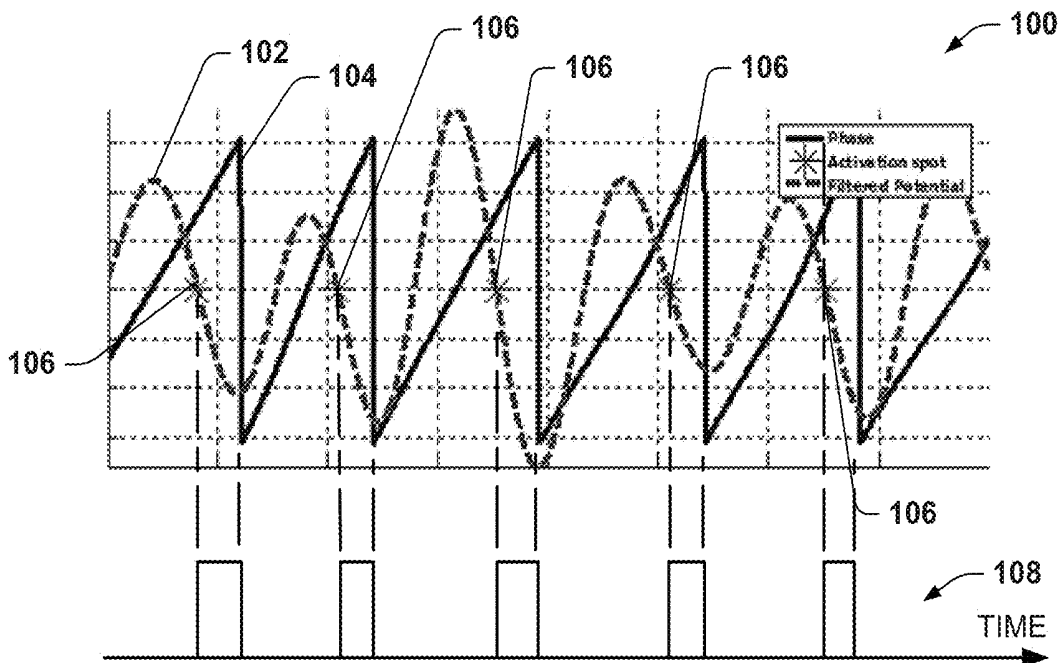


FIG. 5

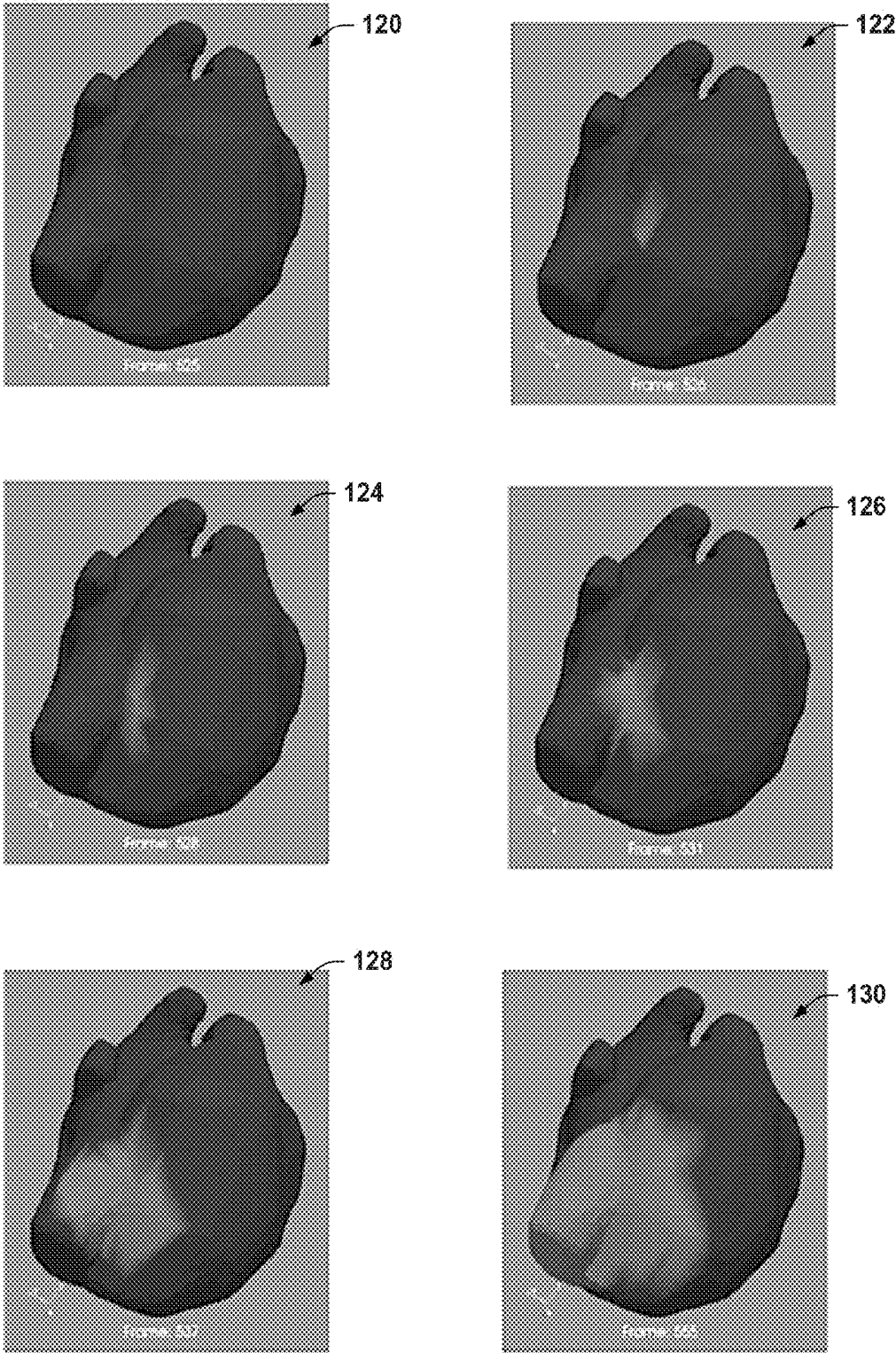


FIG. 6

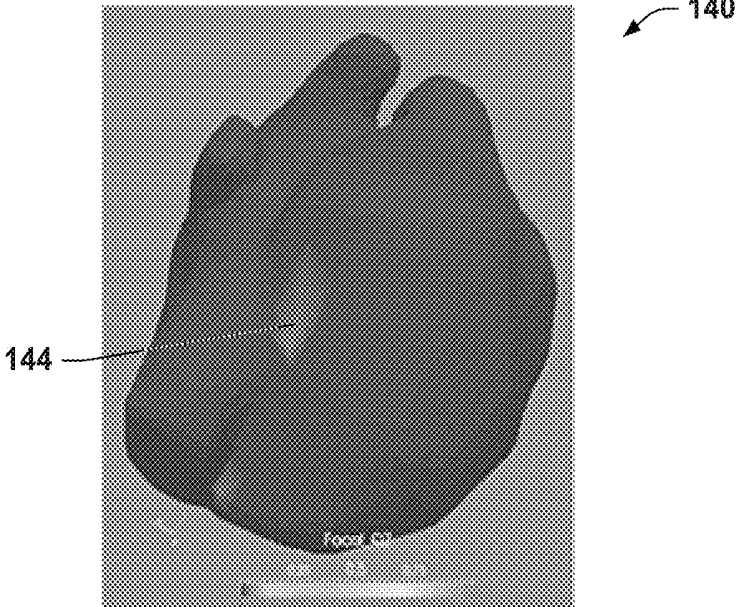


FIG. 7

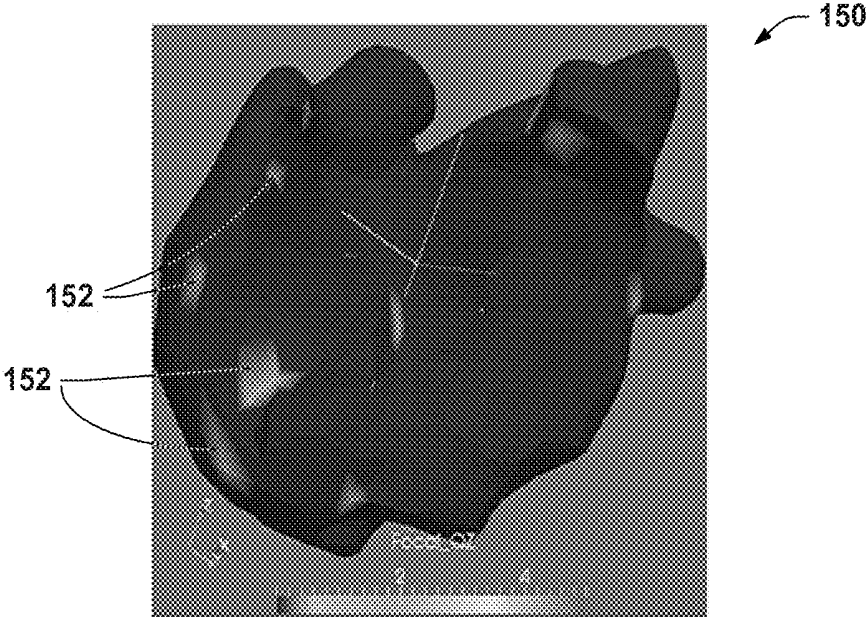


FIG. 8

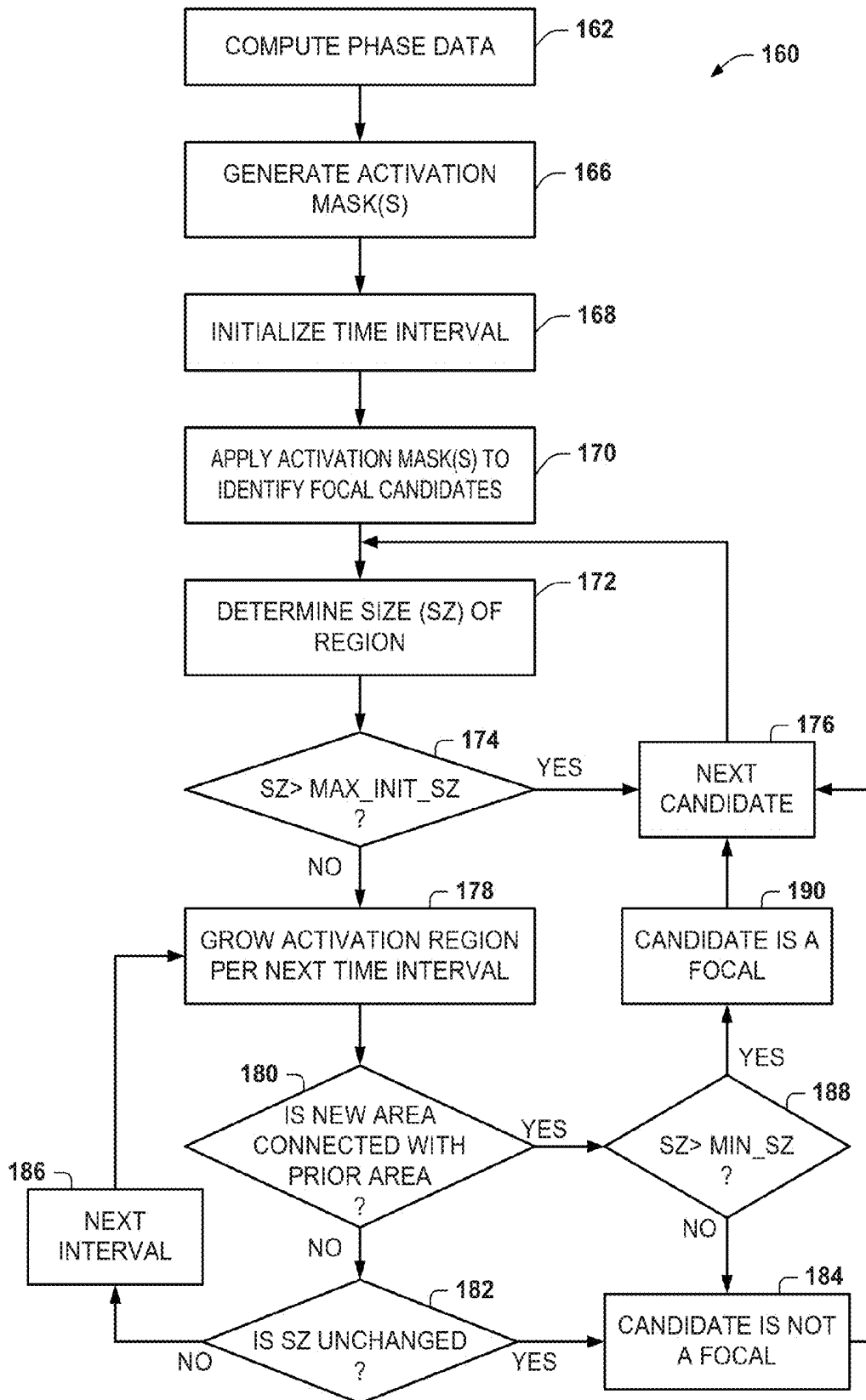


FIG. 9

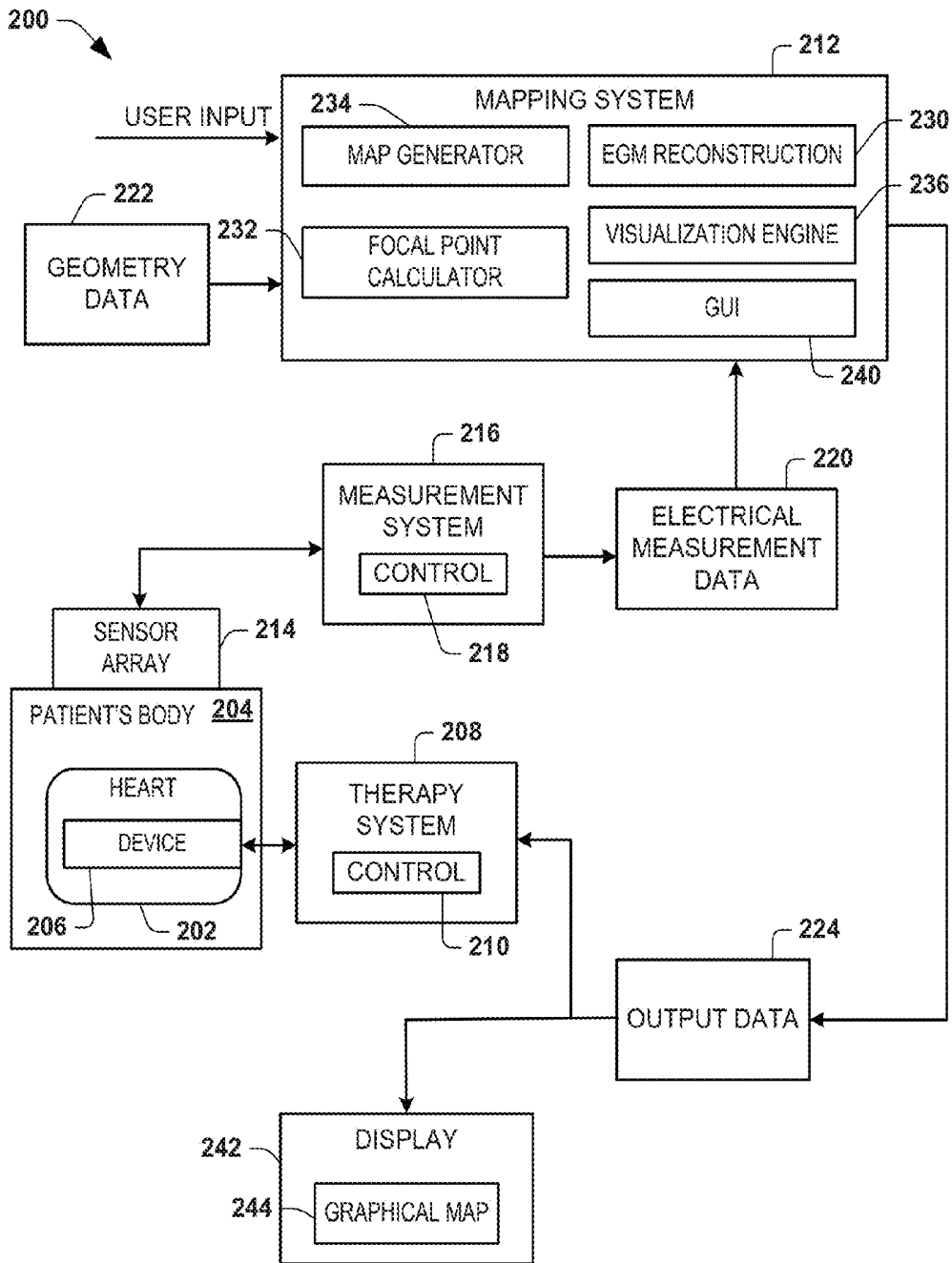


FIG. 10

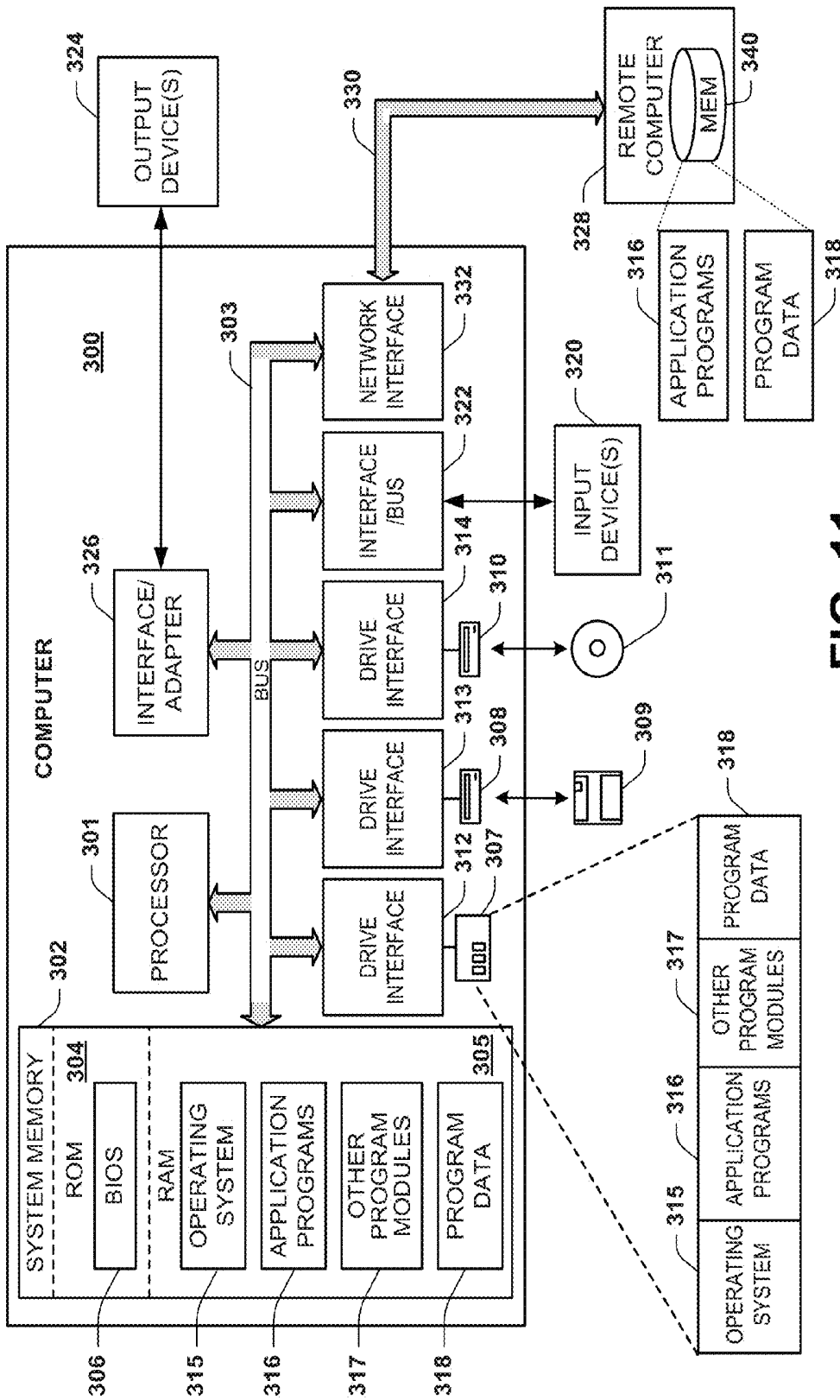


FIG. 11

FOCAL POINT IDENTIFICATION AND MAPPING

RELATED APPLICATION

This application is a continuation of U.S. application Ser. No. 14/156,903 filed Jan. 16, 2014, which claims the benefit of U.S. Provisional Patent Application No. 61/753,753 filed Jan. 17, 2013 and entitled FOCAL POINT IDENTIFICATION AND MAPPING, the entire contents of which is incorporated herein by reference.

TECHNICAL FIELD

This disclosure relates to focal point identification and mapping.

BACKGROUND

Electrocardiographic mapping (ECM) is a technology that is used to determine and display heart electrical information from sensed electrical signals. Mapping of cardiac electrical activity can be important in the diagnosis of cardiac arrhythmia such as fibrillation, including atrial and ventricular fibrillation, as well as tachycardia, including atria tachycardia and ventricular tachycardia. In many arrhythmias, the origin of the aberrant beat is from a small region of abnormal or triggered activity that propagates from this point and results in abnormal activation of the heart. Detecting and visualizing this mechanism of arrhythmias can be relevant to the clinical diagnosis of arrhythmias.

SUMMARY

This disclosure relates to focal point identification and mapping.

An example can include a non-transitory computer-readable medium having instructions executable by a processor for performing a method. The method can include computing phase for signals of each of a plurality of nodes on a geometric surface region associated with tissue of a patient, a subset of the nodes surrounding a given node of the plurality of nodes defining neighboring nodes of the given node. The method can also include analyzing the computed phase of the given node relative to the phase of each of a set of neighboring nodes of the given node over an activation time period associated with the given node. The method can also include determining if the given node is a focal point based on the analyzing. The computing, analyzing and determining can be repeated for each node of at least a substantial portion of the plurality of nodes to provide focal point data specifying a spatial location corresponding to each detected focal point for the geometric surface region.

Another example can be directed to a system that includes memory to store data and machine readable instructions a processor to access the memory and execute the machine readable instructions. The machine readable instructions can include a phase calculator programmed to compute phase for electrical signals at a plurality of nodes distributed across a geometric surface corresponding to patient tissue. The instructions can also include a focal detector programmed to determine whether or not a given candidate node of the plurality of nodes is a focal point based on the analyzing the computed phase of the given candidate node relative to the phase of each node in a set of nodes neighboring the given node for an activation time interval associated with the given candidate node, focal point data being stored in the memory

based on the determination by the focal detector. The instructions can also include a map generator programmed to generate a graphical map representing focal points detected on the geometric surface based on the focal point data.

As another example a method can include storing, in memory, electrical data representing electrical signals for a geometric surface corresponding to patient tissue. A processor can compute phase for the electrical signals at a plurality of nodes distributed across the geometric surface based on the electrical data. A processor can further determine whether or not a given candidate node of the plurality of nodes is a focal point based on the analyzing the computed phase of the given candidate node relative to the phase of each node in a set of nodes neighboring the given node for an activation time interval associated with the given candidate node. Focal point data can be stored in the memory based on the determination. A graphical map can be provided to a display to visualize focal points detected on the geometric surface based on the focal point data.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts an example of a system to identify and map one or more focal points.

FIG. 2 depicts an example of a layered neighbor diagram that can be implemented for analyzing a selected vertex as a focal point.

FIG. 3 depicts an example of a graphical map that can be generated to visually identify one or more focal points.

FIG. 4 depicts an example of a rules engine that can be implemented to control focal detection.

FIG. 5 depicts plots of signals that can be utilized to determine activation times.

FIG. 6 depicts graphical maps demonstrating a growing focal region over time.

FIG. 7 depicts an example of a graphical map demonstrating a detected focal point.

FIG. 8 depicts an example of a graphical map demonstrating focal points over multiple intervals.

FIG. 9 is a flow diagram demonstrating a method for identifying focal points.

FIG. 10 depicts an example of a system that can be implemented for diagnosis and therapy delivery.

FIG. 11 depicts an example computing environment.

DETAILED DESCRIPTION

This disclosure relates to identifying one or more origins of focal electrical activity, such as arrhythmia. In several examples disclosed herein, the approach is described in relation to identifying a focal point (also referred to as an activation trigger or focal trigger) for atrial fibrillation; however, the approach can be applied to identify focal points of other types of cardiac activity including arrhythmias such as atrial tachycardia, ventricular fibrillation, ventricular tachycardia or the like. As disclosed herein, a focal point can thus refer to any point a location where an activation initiates and spreads out from such initial location to its surrounding tissue.

By way of example, systems and methods can identify focal points for a given geometric surface based on analysis spatial and temporal information related to activation and phase of signals for nodes across a geometrical surface. The analysis can include a comparison of a phase of node on the given geometric surface relative to the phase of nodes residing in a neighborhood (e.g., one or more layers of

nodes) around the given node. The comparison can be made between the given node and its neighboring nodes over a time period sufficient to encompass a trigger event—corresponding to a focal point. For instance, neighbors of a focal point node have a later activation time, but are synchronized in phase with the focal point node. Scores can be assigned to each node based on comparisons. A corresponding focal point map can be generated based on the scores accumulated for each node.

As another example, the systems and methods can identify focal points for a given geometric surface by analyzing a set of one or more focal candidate nodes according to a spread of activation from an initial focal candidate node relative to surrounding nodes in a neighborhood (e.g., one or more layers) around the initial candidate node. Such systems and methods can apply rules to evaluate the spread of activation spatially and temporally to determine whether or not to classify the initial focal candidate node as a focal point.

The resulting focal point data can also be utilized to generate a graphical visualization to present spatially and temporally consistent information in the one or more maps (e.g., presented according to a color scale or grayscale. The spatial location of each identified focal point can be used as a clinical target for performing a therapy, such as disclosed herein (see, e.g., FIG. 11).

The systems and methods disclosed herein can be used as part of a diagnostic and/or treatment workflow to facilitate the identification and locating of fibrillation mechanisms based on electrical activity acquired for the patient. In some examples, the patient electrical activity can include non-invasive body surface measurements of body surface electrical activity. Additionally or alternatively, the patient electrical activity can include invasive measurements of heart electrical activity, including epicardial measurements and/or endocardial measurements.

FIG. 1 depicts an example of a system 10 to identify focal points on a geometric surface based on analysis of electroanatomic data (e.g., data describing electrical information in relation to anatomical structures) 12. The electroanatomic data 12 can be provided to characterize electrical activity for a geometric surface, such as tissue, of the patient (e.g., human or other animal). The electroanatomic data can be determined from non-invasively acquired electrophysiological signals, invasively acquired electrophysiological signals or a combination of non-invasive and invasive electrophysiological signals.

As disclosed herein, the electroanatomic data 12 can represent electrical activity for an anatomic structure of the patient, such as can include the heart, brain or other anatomic structures. For the example where the anatomic structure is the patient's heart, the electroanatomic data 12 can represent electrical information for a geometric surface corresponding to the heart, such as an epicardial surface, an endocardial surface or another cardiac envelope. The geometric surface can be patient specific (e.g., based on imaging data for the patient) or it can correspond to a generic model or it can be a hybrid model that is generated based on patient-specific data (e.g., imaging data, patient measurements and/or the like) and a generic anatomic model for the surface. Thus, the geometric surface need not correspond to an actual surface of the tissue but instead can represent a spatial construct associated with the electroanatomic data 12.

The system 10 can include a focal analysis module 14 that is programmed to generate focal point data 16 identifying one or more (or in some cases zero) focal points based on the

electroanatomic data 12. The focal analysis module 14 can provide the focal point data 16 for at least a portion (e.g., a region of interest) and suitably the entire geometric surface. As disclosed herein, a focal point can correspond to a single node or a group of one or more contiguous nodes on the geometric surface.

The focal point analysis module 14 can include a phase calculator 18 to compute phase values for each of a plurality of nodes on a geometric surface (e.g., a spatial region of the heart) for a time interval or a plurality of time intervals. The approach used to compute the phases can vary depending on the type of electroanatomic data. The phase calculator 18 can be programmed to selectively implement a phase computation technique that can be selected from a predetermined list or be a user-specified calculation, such as in response to a user input. As one example, the phase calculator 18 can be programmed to compute phase according to the approach disclosed in PCT Application No. PCT/US13/60851 filed Sep. 20, 2013, and entitled PHYSIOLOGICAL MAPPING FOR ARRHYTHMIA, which is incorporated herein by reference.

Phase could alternatively be computed by other approaches. The phase calculator 18 thus can compute the phase for each of the nodes on a geometric surface for a period of time (e.g., one or more time intervals). This time period can be set based on a user input or be a predetermined default amount of time.

The focal analysis module 14 includes a focal detection function 20 programmed to classify a given candidate node as a focal point or not a focal point based on the phase computed (e.g., by the phase calculator 18) for the given candidate node and each of its neighboring nodes in a corresponding interval. In the example of FIG. 1, the focal detection function 20 employs a phase comparator 22 and rules engine 24 to determine whether or not each candidate node is a focal point. The focal detection function 20 can make the determination for each candidate node and a set of its neighboring nodes, which can include a layered set of one or more neighbors. The definition of the number of layers can be stored as part of the rules engine 24, which can be fixed or programmable in response to a user input.

As an example, FIG. 2 depicts a layered diagram 50 demonstrating an example of a neighborhood for a given candidate node 52. A subset of the nodes surrounding a given node 52 thus can define the given node's neighboring nodes. The neighboring nodes of the given node can include an arrangement of nodes having a plurality of layers that provide a multi-layer neighborhood of the nodes for the given node (e.g., the vertex) 52. Each respective layer around the given node can be defined based on spatial connectivity and/or spatial distance with respect to the given node. For example, a first layer of neighboring nodes can surround (e.g., circumscribe) just the given node 52. The nodes in the first layer can correspond to vertices with phases $\varphi_{1,1}$, $\varphi_{1,2}$, $\varphi_{1,3}$, $\varphi_{1,4}$, and $\varphi_{1,5}$ (e.g., computed by the phase calculator 18). A next layer of the neighborhood 50 can include another subset of nodes that surround the first layer and the given node. The nodes in such second layer are represented as vertices with respective phases $\varphi_{2,1}$, $\varphi_{2,2}$, $\varphi_{2,3}$, $\varphi_{2,4}$, $\varphi_{2,5}$, $\varphi_{2,6}$, $\varphi_{2,7}$, $\varphi_{2,8}$, $\varphi_{2,9}$, $\varphi_{2,10}$, $\varphi_{2,11}$ and $\varphi_{2,12}$. There can be any number of layers, which further can be programmable in response to a user input (e.g., via a GUI 24), as disclosed herein.

Referring back to FIG. 1, the phase comparator 22 can compare the phase of the given node to the phase of each of the nodes in one or more layers as a function of time. The phase comparator 22 can assign a prescribed score to one of

the given node and its neighboring node based on each comparison. The resulting score from the set of comparisons can be stored in memory for each node on geometric surface. As mentioned, the rules engine **24** can control the size (e.g., number of layers) of the neighborhood for each candidate node, which can be the same or vary across the geometric surface.

The rules engine **24** can also control the scoring that is implemented by the focal detection function **20**, including by the phase comparator **22**. For instance, a binary score can be used or a weighted score can be implemented depending on spatial and/or temporal characteristics between the nodes or phase values that are compared. In some examples, the score for each comparison can be a fixed value, such as binary value depending on the results of the phase comparison (e.g., 1 if candidate has a greater phase than its neighbor, otherwise 0). In other examples, the rules can be set to vary the computed score. For instance, the score can vary as a function of the distance between the given node and each respective node to which the comparison is being made. As another example, the score can vary depending on which layer the node resides to which the comparison is being made. The score can be accumulated based on all comparisons made for each candidate node. For example, the score assigned based on a first layer comparison can be greater than a comparison for a higher layer. The comparing and scoring can be repeated for at least a substantial portion of the nodes on the geometric surface (and suitably all nodes on the geometric surface) such that each of the nodes is assigned a score that provides an indication of a location of a least one focal point for the geometric surface.

By way of further example, from a mathematical definition, at a given time t , the phase comparator **22** can determine that a focal point occurs at the location x if

$$\varphi_x(t) > \varphi_{i,l}(t), \forall l = 1 \dots n, i \in N_l(x), \quad (1)$$

where: $\varphi_x(t)$ is the phase value at vertex x at time t ,
 $\varphi_{i,l}(t)$ is the phase value at the i th vertex in the l th layer of neighborhood,
 n is an adjustable parameter to control number of layers, and
 $N_l(x)$ is a set containing all vertices in the l th layer of neighborhood of vertex x , as demonstrated in the layered neighbor diagram of FIG. 2.

To make this process robust against noise, several layers (e.g., $n=2$ to $n=4$ or more) can be utilized. A focal trigger typically will last at least a few milliseconds. Accordingly, the inequality above shall hold for a few consecutive samples across a time interval.

$$\varphi_x(t) > \varphi_{i,l}(t), \forall l = 1 \dots n, i \in N_l(x), t = 1 \dots m \quad (1)$$

where m is an adjustable parameter to control the minimum duration of this event to classify a vertex to be a focal (e.g., $m=5$ ms).

The rules engine **24** thus can be configured to control m and n when implemented by the phase comparator **22** of the focal detection **20**. As mentioned, the parameter m and n (as well as other rules) can be set in response to a user input.

The phase comparison based on (2) can be performed at the time of activation for node X and a post activation time period. The time period for which the comparison is evaluated following activation at X can be a fixed default time period or it may be user programmable. In some examples, a variable evaluation time period can be set to vary based on the number of layers being evaluated in the neighborhood of node X (e.g., a greater number of layers can employ a larger time period to accommodate for spread). As an example, the activation time for each node, including the given node X , can be determined based on a time derivative of the elec-

trogram signal at X , such as may be the time of minimum slope for the electrogram at X or maximum absolute slope; although other activation time detection algorithms may be used.

To represent the focal detection result numerically, for each node detected as a focal point per (2) above, the phase comparator **22** can score a given node with 1, for multiple instances occurring at the same or different nodes, such that the focal point analysis module **14** can accumulate scores for each node. As a mathematical example, the focal point analysis module **14** can employ the phase comparator **22** to determine a score $F_x(t)$ for vertex x at a given sample time t , which can be represented as follows:

$$F_x(t) = \begin{cases} 1, & \text{if } \phi_x(k) > \phi_{i,l}(k), \forall l = 1 \dots n, i \in N_l(x), k = t + 1, \dots, t + m \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

The focal point analysis module **14** can further calculate an aggregate score over time, such as can be represented as follows:

$$CF_x = \sum_t F_x(t) \quad (4)$$

As a further example, the rules engine **24** can establish a variable scoring to be applied for each comparison. Thus, instead of scoring each comparison between a vertex node and a neighboring node to be 1 or 0, as mentioned above, comparisons between a vertex node and neighbors can vary as a function of distance between nodes being compared. For example, the score assigned to the node having the greater phase for each focal point comparison (e.g., by phase comparator **22**) can be weighted with decreasing scores if the neighbor node is further from the vertex node. In some examples, the weighted score can be set for each layer or the score can be computed as a function of a distance computed between the respective nodes.

By way of an example, if a vertex at a given sampling time is detected as a trigger, i.e., $F_x(t)=1$, then the rules engine **24** can be programmed to score all its n layers of neighbors as:

$$F_{i,l}(t) = \begin{cases} \frac{n+1-l}{n+1}, & \text{if } i \in N_l(x), F_x(t) = 1 \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

The above rule implemented by the focal detection function **20** operates to weight scores spatially (e.g., inversely proportional to distance from the candidate node). For instance, the rules implemented by equation (5) will provide a first neighborhood with score

$$\frac{n}{n+1},$$

and provide the n th neighborhood with score

$$\frac{1}{n+1}.$$

For an example where $n=4$, the scores are 0.8, 0.2 for 1st and 4th layer neighbors, respectively. The rules provided by this

approach allow the focal point with score 1.0 standing out among its neighboring nodes. The accumulated scores for each respective node can be stored (e.g., in memory) as the focal point data 16.

The system 10 can include a map generator 28 programmed to generate one or more graphical maps 30 to represent one or more focal points for the geometric surface based on the focal point data 16. For example, the map generator 28 can be programmed to generate a graphical map in which the accumulated focal point scores for each of the nodes on the geometric surface are mapped to a corresponding scale visualized on three-dimensional surface (e.g., a cardiac surface). For instance, the graphical map 30 can be visualized on the geometric surface according to a given scale (e.g., color scale or grayscale) to depict the range of focal point scores. The scale can be set by the map generator 28 to accommodate the range of accumulated scores that have been assigned to the nodes on the geometric surface. The resulting map thus can be used to identify focal points on the geometric surface. As a further example, the map generator 34 can be programmed to present a plurality of the graphical maps 30 for different time intervals and/or different geometric surfaces.

FIG. 3 depicts an example of focal map 70 that can be generated based on focal point data computed based on the systems and methods disclosed herein. In the example of FIG. 3, detected focal points are demonstrated as being distributed across the atria. In some cases, detecting focals based solely upon a neighborhood-based phase comparison, such as demonstrated in the example of FIG. 3, may yield false positive and/or false negative detections. Accordingly, the rules engine 24 can be programmed to apply additional rules (e.g., logic and/or controls) to help improve sensitivity and/or specificity.

An example of a rules engine 80 that can implement additional rules to improve sensitivity and/or specificity for the focal point detection is demonstrated in FIG. 4. The rules engine 80 can correspond to and be implemented as the rules engine 24 of FIG. 1, and reference can be made back to FIG. 1 for additional context.

The rules engine 80 can be programmed to include analytics, logic and parameter data for implementing a variety of rules to provide enhanced specificity and/or sensitivity for use in detecting one or more focal points from electrical activity (e.g., based on measured electrical potentials) distributed across a geometric surface for patient anatomy (e.g., the heart or other tissue). In conjunction with the focal detection function 20 of FIG. 1 disclosed above, the rules engine 80 can mitigate false positive detection as well as false negative detections. The rules engine 80 can thus be implemented as machine readable instructions that can be stored in one or more non-transitory media and be executed by a processing resource (e.g., one or more processor cores) of one or more computers. An example of a method that can correspond to the machine readable instructions implemented as the rules engine 80 is demonstrated in FIG. 9.

In the example of FIG. 4, the rules engine 80 includes an activation detector 82 that is programmed to detect activation for each node on the geometric surface. For example, the activation detector 82 can be programmed to detect activation as beginning at a chosen phase value (θ_1) and mark the node as being ON or activated until the phase changes to another chosen phase value (θ_2 , where $\theta_1 \neq \theta_2$). As an example, θ_2 can be selected automatically as a time when activation for the node has been determined to end. In other examples, θ_2 can be selected to provide a predetermined activation time (e.g., $\theta_2 - \theta_1 =$ a fixed time interval).

The values of θ_1 and θ_2 can be programmed in response to a user input and can vary depending on how the phase calculator translates the electrical cycle for a given node into phase.

FIG. 5 depicts an example of signal diagram 100 that includes a filtered electrical potential 102 for a given node and a corresponding phase 104 the given node. For example, the phase 104 can be calculated (e.g., by phase calculator 18 of FIG. 1) to represent the phase of the electrical signal for the given node. In the example of FIG. 5, activation begins at an activation spot 106, corresponding to when the phase has a value of θ_1 , and continues to when the computed phase value of the signal 104 changes to π . Thus the activation time for each cycle of the given node's phase 104 extends from the activation spot 106 to a time when the phase changes at θ_2 . The activation time for the signal can vary over time for each respective node, as illustrated by the activation coding demonstrated at 108. In other examples, the activation time interval can be a fixed time. For instance, the activation time interval for a given node can extend from a beginning time, such as when the phase has a value of θ_1 to an end time following a fixed time window (e.g., about 50 ms). The activation detector 82 thus can generate activation coding 108 to encode the activation for each respective node over the surface of interest.

By way of further example, the activation coding 108 can be utilized to mark each respective node as activated (e.g., ON) between the starting and ending time indices and mark each node as deactivated (e.g., OFF) otherwise. This provides the example activation coding 108 for each node, such as shown in FIG. 5. Since each respective node across the surface can be coded as being ON or OFF over a time interval, a contiguous set of nodes that are concurrently ON for the geometric (e.g., cardiac) surface will form a region of activation, such as the changing growing region demonstrated in FIG. 6. The focal detection function can employ the rules engine 80 to determine whether or not each respective node is a focal point, as disclosed herein.

The rules engine 80 can also include rule parameters 86 that can be utilized by the components of the rules engine 80 (and focal detection function 22 of FIG. 1) to implement the logic and analytics disclosed herein. For instance, the rule parameters 86 can specify values to set one or more thresholds and other parameters that can control the focal detection process. The rule parameters can be stored in memory, and may be fixed values or may be programmable in response to a user input.

An activation mask generator 84 can be programmed to generate one or more activation masks. For example, the activation mask generator 84 can generate an activation coding mask, such as corresponding to the activation coding 108 of FIG. 5, to mark the beginning and end of each activation for a given node. In other examples, a fixed time from each initial activation on-time can be used to configure the mask. The corresponding activation mask can be generated for each respective candidate node on the geometric surface. Additionally, the activation mask generator 84 can provide a magnitude activation mask, such as by setting a minimum magnitude threshold (e.g., in a range from about 0.01 mV to about 0.1 mV) for the electrical signals for each node.

The rules engine 80 can include a candidate selector 88 that is programmed to apply each mask that was generated by the activation mask generator 84 to identify a set of focal candidates across the geometric surface of interest. The set of focal candidates can be a proper subset of the total set of nodes across the geometric surface. For example, the can-

didate selector can employ combinational logic (e.g., a logical AND function) to phase and potential signals for each node for identifying focal candidate nodes. As described herein, in some examples, the geometric surface of interest can include a particular region of interest or it can include an entire surface of the heart.

The identified focal candidates thus can be stored in memory as a set of prospective candidates meeting the initial criteria established by the masks. In some examples, this may include the direct phase comparisons disclosed with respect to FIG. 1. Each of the focal candidates thus can be evaluated by the rules engine 80 in conjunction with the focal detection function (focal detection 20 of FIG. 1) to determine whether or not each of the respective candidate node is a focal point.

As a further example, the rules engine 80 can include a region size calculator 90 can be programmed to determine the size of a region that has been activated (e.g., one or more nodes distributed across the surface) at a given time interval for a given candidate. The activation for each such node can be determined by the activation detector 82, as mentioned above. For example, at or near (e.g., within one or two intervals from) an initial activation time for a given node (e.g., corresponding to the time of activation at activation spot 106 of FIG. 5), the rules engine 80 can ascertain whether the initial size of the activated region exceeds a maximum initial size threshold (e.g., set by rule parameters 86). The maximum initial size can be used to determine whether the candidate may be a focal point or not. For example, if the maximum initial size is exceeded, it can be ascertained that the respective candidate is not a focal point. The rules engine 80 further can add one or more subsequent time frames in the sample to continue adding one or more nodes that may be activated at a time following the initial activation of the given candidate node that is being evaluated by the rules engine 80. The region size calculator 90 can in turn determine if the additional activations for one or more other nodes has affected the size of the activated region. This can be utilized to determine whether the size of the activation region has grown or otherwise changed size over a predetermined period of time, such as a plurality of intervals. The absence of changes in size over such time period can help classify the candidate as not being a focal trigger.

The rules engine 80 can also include a continuity detector 92 that is programmed to ascertain whether the set of nodes forming the activated region are a contiguous set of nodes in a given neighborhood. The continuity detector 92 can evaluate a spatial and/or temporal continuity to determine if the current activation region is connected with the earlier activation for the given candidate node. If the following activation region is not connected with the earlier activation, the focal detection function can determine that the candidate node is not a focal point, such as if its size does not change (or shrinks) over time.

The rules engine 80 can also employ the regions size calculator 90 to determine if at or near the end of the activation time, the activated region is larger than a threshold minimum final size, such as can be set by the rules parameter 86. The minimum final size can be a fixed value or be user programmable (e.g., in response to a user input). The focal detection function thus can employ the rules engine 80 to determine whether or not each of the nodes is a focal point. The results, including the final results as well as at intermediate stages, can be stored in memory as focal data and used to generate one or more graphical maps, such as disclosed herein.

FIG. 6 depicts an example of multiple time frames demonstrating how activation from one spot can trigger activation in surrounding nodes that grows over time from the initial trigger across the geometric surface of a patient's heart. The example of FIG. 6 demonstrates six different time frames demonstrated at 120, 122, 124, 126, 128 and 130 (e.g., ranging over about 30 ms). Each of the respective time frames correspond to different instances in time during activation of a given candidate focal node. As demonstrated in the focal point maps 120, 122, 124, 126, 128 and 130, it is demonstrated that activation initiates at a given spot or region such as corresponding to one or more nodes on the surface in map 120 then forms a small island, as demonstrated at 122 through 124, and continues to spread and grow as demonstrated at 126 through 130. As demonstrated in FIG. 6, the spreading of activation from a focal point can be anisotropic.

FIG. 7 depicts an example of an electrophysiological map 140 demonstrating a focal trigger 144 (e.g., one or more nodes) that can be generated by a map generator (e.g., map generator 28 of FIG. 1). The focal trigger in the example of FIG. 7 can be detected (e.g. by focal detection function 20 of FIG. 1) based on applying rules during the growth of the focal region demonstrated in the example of FIG. 6 over a given interval.

FIG. 8 depicts of an electrophysiological map 150 that can be generated by a map generator (e.g., map generator 28 of FIG. 1). The electrophysiological map 150 includes a plurality of focal points 152 detected for on a plurality of different intervals. For instance the focal points can be detected based on application of the rules engine by the focal detection function as disclosed herein.

In view of the foregoing structural and functional features described above, methods that can be implemented will be better appreciated with reference to FIG. 9. While, for purposes of simplicity of explanation, the method of FIG. 9 is shown and described as executing serially, it is to be understood and appreciated that the present invention is not limited by the illustrated order, as some aspects could, in accordance with the present invention, occur in different orders and/or concurrently with other aspects from that shown and described herein. Moreover, not all illustrated features may be required to implement a method. The methods or portions thereof can be implemented as instructions stored in one or more non-transitory storage media as well as be executed by a processor of a computer device, for example.

FIG. 9 depicts a flow diagram demonstrating an example method for identifying one or more focal points. The method 160 can be implemented by the focal detection function and rules engine disclosed herein (e.g., focal detection function 20 and rules engine 24 of FIG. 1 or rules engine 80 of FIG. 4). At 162, phase data is computed based on a sampling interval over a period of time, which may be selected by a user in response to a user input or be automatically detected.

At 166, one or more activation masks can be generated (e.g., by mask generator 84 of FIG. 4) based on the phase information computed at 162. For instance, one activation mask can encode activation temporal, such as the beginning and end time of activation for each respective node such as beginning at a time when the phase has a value of θ_1 and an ending time. The ending time can be determined when the phase has a value of θ_2 or it can establish a fixed time period for the activation time from the detected beginning. Time indices can be set to correspond to each of the starting and end times for each activation time period. Another mask can be generated to set a minimum threshold magnitude for the

sensed electrical signal at each node (e.g., a filtered or processed electrical potential). The generated masks and associated thresholds can be stored as parameters (e.g., rule parameters **86** of FIG. **4**) in corresponding memory. The time interval for analyzing the phase values and activation can be set and initialized at **168**. This time interval can range anywhere from a selected portion of a sampling interval for which the phase data is computed at **162** up to an entire length of one or more sampling intervals.

At **170**, the activation masks that are applied to the phase data to identify a set of focal candidates for further evaluation (e.g., corresponding to candidate selector **88** of FIG. **4**). Each of the nodes corresponding to the focal candidates thus can be stored in memory for use in performing the remaining portion of the method **160** with respect to each respective candidate. At **172** a size of the region can be determined (e.g., by region size calculator **90** of FIG. **4**) for an initial activation time period (e.g., a second interval of activation for the candidate node). At **174**, a determination can be made as to whether the determined size is greater than a maximum initial size. If the size of the initial region is determined to exceed the maximum initial size, the method proceeds to **176** in which a next candidate node is selected (e.g., by candidate selector **88** of FIG. **4**) for processing. This can correspond to an example where an initial region is too large such that it is too difficult to ascertain which node or set of nodes corresponds to a trigger. From **176** the method returns to **172** to process the next candidate that has been selected.

If at **174**, the size does not exceed the maximum initial size for the corresponding candidate, the method can proceed to **178**. At **178** the method grows the activation region for a next time intervals. For example, a time interval can correspond to a time when each sample of electrical information is measured, such as ranging from 0.5 to about 2 ms. At **180** a determination is made (e.g., by continuity detector **92** of FIG. **4**) whether the region that is activated for the next time interval is connected with the prior region that was activated (in the previous time interval). This determination at **180** thus can consider temporal and/or spatial connections, such as to confirm whether the newly activated area was triggered by the proceeding activation area. If the new area is not connected with the prior area, the method proceeds to **182**.

At **182**, a determination is made as to whether the determined size remains unchanged over a predetermined period of time. For example, the method can determine whether the size remains unchanged over a time interval (e.g., 4 ms). If the size remains unchanged over this time period such as expanding multiple intervals, the method proceeds to **184** to identify the candidate node as not being a focal point. From **184** the method can proceed to **176** to process the next candidate node from the set of candidates identified at **170**. If at **182** it is determined that the size has changed, the method can proceed to **186** to increment to a next time interval and the method can continue to **178** to grow the corresponding activation region for such next interval.

Returning back to **180** if it is determined that the newly activated area is connected with the prior area (e.g., temporary and/or spatially), the method can proceed to **188**. At **188**, a determination can be made as to whether a size exceeds a minimum final size if the aggregate size of the activated region does not exceed the minimum final size the method proceeds to **184** in which the candidate can be marked as not being a focal point. However, if the size

exceeds the minimum final size the method can proceed to **190** in which the candidate can be identified as a focal point.

From **190**, the method can proceed to **176** to process the next focal candidate. As mentioned, the method **160** can be repeated for each candidate focal point over the time interval initialized at **168**. For instance, the method **160** can loop from **172** to **190** for each respective candidate. Additionally, the method can further loop from **168** to **190** for each respective time frame (e.g., interval) that is being processed. In this way, the method **160** can identify different focal points over different time intervals. The identified focal points further can be aggregated and utilized to generate a corresponding focal point map (e.g., map generator **28** of FIG. **1**), such as shown in FIG. **8**.

FIG. **10** depicts an example of a system **200** that can be utilized for performing diagnostics and/or treatment of a patient. In some examples, the system **200** can generate focal point maps for the heart **202** in real time as part of a diagnostic procedure (e.g., an electrophysiology study) to help assess the electrical activity and conduction pathways of a patient's heart.

Additionally or alternatively, the system **200** can be utilized as part of a treatment procedure such as to help a physician determine parameters for delivering a therapy to the patient (e.g., delivery location, amount and type of therapy). For example, a catheter, such as a pacing catheter, having one or more therapy delivery devices **206** affixed thereto can be inserted into the body **204** as to contact the patient's heart **202**, endocardially or epicardially. Those skilled in the art will understand and appreciate various type and configurations of therapy delivery devices **206** that can be utilized, which can vary depending on the type of treatment and the procedure. For instance, the therapy device **206** can be configured to deliver electrical therapy, chemical therapy, sound wave therapy, thermal therapy or any combination thereof.

By way of example, the therapy delivery device **206** can include one or more electrodes located at a tip of an ablation catheter configured to generate heat for ablating tissue in response to electrical signals (e.g., radiofrequency energy) supplied by a therapy system **208**. In other examples, the therapy delivery device **206** can be configured to deliver cooling to perform ablation (e.g., cryogenic ablation), to deliver chemicals (e.g., drugs), ultrasound ablation, high-frequency ablation, or a combination of these or other therapy mechanisms. In still other examples, the therapy delivery device **206** can include one or more electrodes located at a tip of a pacing catheter to deliver electrical stimulation, such as for pacing the heart, in response to electrical signals (e.g., pacing pulses) supplied by a therapy system **208**. Other types of therapy can also be delivered via the therapy system **208** and the invasive therapy delivery device **206** that is positioned within the body.

The therapy system **208** can be located external to the patient's body **204** and be configured to control therapy that is being delivered by the device **206**. For instance, the therapy system **208** includes control circuitry **210** that can communicate (e.g., supply) electrical signals via a conductive link electrically connected between the device (e.g., electrodes) **206** and the therapy system **208**. The control system **210** can control parameters of the signals supplied to the device **206** (e.g., current, voltage, repetition rate, trigger delay, sensing trigger amplitude) for delivering therapy (e.g., ablation or stimulation) via the electrode(s) **204** to one or more location of the heart **202**. The control circuitry **210** can set the therapy parameters and apply stimulation based automatic, manual (e.g., user input) or a combination of

automatic and manual (e.g., semiautomatic) controls. Output data **224**, including data identifying one or more focal points, can also be provided to the therapy system **208** for implementing such controls. One or more sensors (not shown) can also communicate sensor information back to the therapy system **208**. The position of the device **206** relative to the heart **202** can be determined and tracked intraoperatively via an imaging modality (e.g., fluoroscopy, xray), a mapping system **212**, direct vision or the like. The location of the device **206** and the therapy parameters thus can be combined to provide corresponding therapy parameter data.

Before, during and/or after providing a therapy via the therapy system **208**, another system or subsystem can be utilized to acquire electrophysiology information for the patient. In the example of FIG. **10**, a sensor array **214** includes one or more electrodes that can be utilized for recording patient activity. The sensor array can be positioned non-invasively on the patient's body and/or it can be positioned invasively in the body to measure patient electrical activity.

As one example, the sensor array **214** can correspond to a high-density arrangement of body surface sensors (e.g., greater than 200 electrodes) that are distributed over a portion of the patient's torso for measuring electrical activity associated with the patient's heart (e.g., as part of an electrocardiographic mapping procedure). An example of a non-invasive sensor array that can be used is shown and described in International application No. PCT/US2009/063803, filed 10 Nov. 2009, which is incorporated herein by reference. Other arrangements of sensing electrodes can be used as the sensor array **214**. The array can be a reduced set of electrodes, which that does not cover the patient's entire torso and is designed for measuring electrical activity for a particular purpose (e.g., an array of electrodes specially designed for analyzing AF and/or VF) and/or for monitoring a predetermined spatial region of the heart.

One or more sensors may also be located on the device **206** that is inserted into the patient's body. Such electrode can be utilized in conjunction with the sensor array **214** for mapping electrical activity for an endocardial surface, such as the wall of a heart chamber, as well as for an epicardial surface. Additionally, such electrode can also be utilized to help localize the device **206** within the heart **202**, which can be registered into an image or map that is generated by the system **200**. Alternatively, such localization can be implemented in the absence of emitting a signal from an electrode within or on the heart **202**.

In each of such example approaches for acquiring patient electrical information, including invasively, non-invasively, or a combination of invasive and non-invasive sensors, the sensor array(s) **214** provide the sensed electrical information to a corresponding measurement system **216**. The measurement system **216** can include appropriate controls and signal processing circuitry **218** for providing corresponding measurement data **220** that describes electrical activity detected by the sensors in the sensor array **214**. The measurement data **220** can include analog or digital information.

The control **218** can also be configured to control the data acquisition process for measuring electrical activity and providing the measurement data **220**. The measurement data **220** can be acquired concurrently with the delivering therapy by the therapy system, such as to detect electrical activity of the heart **202** that occurs in response to applying a given therapy (e.g., according to therapy parameters). For instance, appropriate time stamps can be utilized for index-

ing the temporal relationship between the respective data **220** and therapy parameters to facilitate the evaluation and analysis thereof.

The mapping system **212** is programmed to combine the measurement data **220** corresponding to electrical activity of the heart **202** with geometry data **222** by applying appropriate processing and computations to provide corresponding output data **224**. The output data **224** can be represent or characterize one or more focal points across a geometric surface (e.g., a cardiac envelope or other surface associated with the heart **202**).

Since the measurement system **216** can measure electrical activity of a predetermined region or the entire heart concurrently (e.g., where the sensor array covers the entire thorax of the patient's body **204**) the resulting output data **224** thus can also represent concurrent data for the predetermined region or the entire heart in a temporally and spatially consistent manner. This can include concurrent measurements for the both atria and/or both ventricles. The time interval for which the output data/maps are computed can be selected based on user input. Additionally or alternatively, the selected intervals can be synchronized with the application of therapy by the therapy system **208**.

For the example where the electrical measurement data is obtained non-invasively (e.g., via body surface sensor array **214**), electrogram reconstruction **230** can be programmed to compute an inverse solution and provide corresponding reconstructed electrograms based on the process signals and the geometry data **222**. The reconstructed electrograms thus can correspond to electrocardiographic activity across a cardiac envelope, and can include static (three-dimensional at a given instant in time) and/or be dynamic (e.g., four-dimensional map that varies over time). Examples of inverse algorithms that can be utilized in the system **10** are disclosed in U.S. Pat. Nos. 7,983,743 and 6,772,004, which are incorporated herein by reference. The EGM reconstruction **230** thus can reconstruct the body surface electrical activity measured via the sensor array **214** onto a multitude of locations on a cardiac envelope (e.g., greater than 1000 locations, such as about 2000 locations or more). In other examples, the mapping system **212** can compute electrical activity over a region of the heart based on electrical activity measured invasively, such as via a basket catheter or other form of measurement probe.

As disclosed herein, the cardiac envelope can correspond to a three dimensional surface geometry corresponding to a patient's heart, which surface can be epicardial or endocardial. Alternatively or additionally, the cardiac envelope can correspond to a geometric surface that resides between the epicardial surface of a patient's heart and the surface of the patient's body where the sensor array **214** has been positioned. Additionally, the geometry data **222** that is utilized by the electrogram reconstruction **230** can correspond to actual patient anatomical geometry, a preprogrammed model or a combination thereof (e.g., a model that is modified based on patient anatomy).

As an example, the geometry data **222** may be in the form of a three-dimensional graphical representation of the patient's torso, such as image data acquired for the patient. Such image processing can include extraction and segmentation of anatomical features, including one or more organs and other structures, from a digital image set. Additionally, a location for each of the electrodes in the sensor array **214** can be included in the geometry data **222**, such as by acquiring the image while the electrodes are disposed on the patient and identifying the electrode locations in a coordinate system through appropriate extraction and segmenta-

tion. Other non-imaging based techniques can also be utilized to obtain the position of the electrodes in the sensor array, such as a digitizer.

Alternatively or additionally, the geometry data **222** can correspond to a mathematical model, such as can be a generic model or a model that has been constructed based on image data for the patient. Appropriate anatomical or other landmarks, including locations for the electrodes in the sensor array **214** can be identified in the geometry data **222** to facilitate registration of the electrical measurement data **220** and performing the inverse method thereon. The identification of such landmarks can be done manually (e.g., by a person via image editing software) or automatically (e.g., via image processing techniques).

By way of further example, the geometry data **222** can be acquired using nearly any imaging modality based on which a corresponding representation can be constructed, such as described herein. Such imaging may be performed concurrently with recording the electrical activity that is utilized to generate the patient measurement data **220** or the imaging can be performed separately (e.g., before the measurement data has been acquired).

Following (or concurrently with) determining electrical potential data (e.g., electrogram data computed from non-invasively and/or invasively acquired measurements) across the geometric surface of the heart, the electrogram data can further undergo signal processing to compute one or more cardiac maps. The mapping system **212** can include a focal point calculator **232** that can be programmed to compute focal point data for each of a plurality of points in the given spatial region based on the geometry and electrical measurement data. For example, the focal point can be programmed to compute phase for nodes distributed across a given geometric surface of the patient's heart, such as disclosed herein. The focal point calculator **232** can also compute focal point data based on comparing phase information of a given vertex node relative to the phase of each of its neighboring nodes. The comparison can be performed for the vertex node and each node in one or more layers (see, e.g., FIG. 2). A score can be assigned to one of the given node and its neighboring node based on each comparison. The score can be a fixed value or it may vary as disclosed herein. The comparing and scoring can be repeated for each of the nodes to provide corresponding focal point map data, demonstrated as output data **224**.

As a further example, the focal point calculator **232** can include a rules engine (e.g., rules engine **80**) programmed to apply one or more rules to increase the sensitivity and specificity of the focal point analysis. For instance, the rules engine can employ parameters that can be set to control the focal analysis for each candidate node over a set of one or more intervals, such as disclose with respect to the method FIG. 9. The focal point calculator **232** thus can provide a set of one or more focal points as part of output data **224** for each of the time intervals that are analyzed based on the electrical measurement data sensed for the patient.

The output data **224** can be employed by a display **242** to render a graphical map representation **244**. Parameters associated with the generation of the focal point map or other aspects of visualization, such as including selecting one or more time intervals, setting one or more thresholds, the type of information that is to be presented in the graphical map and the like, can be selected in response to a user input via a corresponding visualization GUI **190**, for example. The mapping system **224** thus can generate corresponding output data **224** that can in turn be rendered by the visualization

engine as a corresponding graphical output in a display **192**, such as including an electrocardiographic focal point map **194**.

In addition to the mapping system **212** generating one or more focal point maps, other types of electrocardiographic mapping can be implemented such as including activation maps, dominant frequency maps and the like. For example, the display **192** can include one or more regions for displaying composite singularity map data concurrently with corresponding activation or dominant frequency maps to facilitate diagnosis and treatment of AF or VF.

Additionally, the output data **224**, including information about the size and location of the focal points determined from the focal point map, can be provided to the therapy system **208**. The control **210** of the therapy system can utilize the output data to control one or more therapy parameters. As an example, the control **210** can control delivery of ablation therapy to a site of the heart (e.g., epicardial or endocardial wall) based on the location and size of a phase singularity determined from a composite phase singularity map. Other types of therapy can also be controlled based on the output data. The control that is implemented can be fully automated control, semi-automated control (partially automated and responsive to a user input) or manual control based on the output data **224**.

As a further example, the focal point detection approach, as disclosed herein, can be combined with other arrhythmia detection and mapping approaches as part of an integrated system (e.g., the system **200**). For example, the focal point detection can be combined with phase singularity detection that is disclosed in the above-incorporated PCT Application No. PCT/US13/60851.

In view of the foregoing structural and functional description, those skilled in the art will appreciate that portions of the systems and method disclosed herein may be embodied as a method, data processing system, or computer program product such as a non-transitory computer readable medium. Accordingly, these portions of the approach disclosed herein may take the form of an entirely hardware embodiment, an entirely software embodiment (e.g., in a non-transitory machine readable medium), or an embodiment combining software and hardware, such as shown and described with respect to the computer system of FIG. 11. Furthermore, portions of the systems and method disclosed herein may be a computer program product on a computer-usable storage medium having computer readable program code on the medium. Any suitable computer-readable medium may be utilized including, but not limited to, static and dynamic storage devices, hard disks, optical storage devices, and magnetic storage devices.

Certain embodiments have also been described herein with reference to block illustrations of methods, systems, and computer program products. It will be understood that blocks of the illustrations, and combinations of blocks in the illustrations, can be implemented by computer-executable instructions. These computer-executable instructions may be provided to one or more processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus (or a combination of devices and circuits) to produce a machine, such that the instructions, which execute via the processor, implement the functions specified in the block or blocks.

These computer-executable instructions may also be stored in computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory result in an article

of manufacture including instructions which implement the function specified in the flowchart block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions specified in the flowchart block or blocks.

In this regard, FIG. 11 illustrates one example of a computer system 300 that can be employed to execute one or more embodiments, such as including acquisition and processing of sensor data, processing of image data, as well as analysis of transformed sensor data and image data associated with the analysis of cardiac electrical activity. Computer system 300 can be implemented on one or more general purpose networked computer systems, embedded computer systems, routers, switches, server devices, client devices, various intermediate devices/nodes or stand alone computer systems. Additionally, computer system 300 can be implemented on various mobile clients such as, for example, a personal digital assistant (PDA), laptop computer, pager, smart phone and the like, provided it includes sufficient processing capabilities.

Computer system 300 includes processing unit 301, system memory 302, and system bus 303 that couples various system components, including the system memory, to processing unit 301. Dual microprocessors and other multi-processor architectures also can be used as processing unit 301. System bus 303 may be any of several types of bus structure including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. System memory 302 includes read only memory (ROM) 304 and random access memory (RAM) 305. A basic input/output system (BIOS) 306 can reside in ROM 304 containing the basic routines that help to transfer information among elements within computer system 300.

Computer system 300 can include a hard disk drive 307, magnetic disk drive 308, e.g., to read from or write to removable disk 309, and an optical disk drive 310, e.g., for reading CD-ROM disk 311 or to read from or write to other optical media. Hard disk drive 307, magnetic disk drive 308, and optical disk drive 310 are connected to system bus 303 by a hard disk drive interface 312, a magnetic disk drive interface 313, and an optical drive interface 314, respectively. The drives and their associated computer-readable media provide nonvolatile storage of data, data structures, and computer-executable instructions for computer system 300. Although the description of computer-readable media above refers to a hard disk, a removable magnetic disk and a CD, other types of media that are readable by a computer, such as magnetic cassettes, flash memory cards, digital video disks and the like, in a variety of forms, may also be used in the operating environment; further, any such media may contain computer-executable instructions for implementing one or more parts of the systems and method disclosed herein.

A number of program modules may be stored in drives and RAM 305, including operating system 315, one or more application programs 316, other program modules 317, and program data 318. The application programs and program data can include functions and methods programmed to acquire, process and display electrical data from one or more sensors, such as shown and described herein. The application programs and program data can include functions and methods programmed to process signals and compute a

phase data and identify one or more focal points as disclosed herein. The application programs and program data can also include functions and methods programmed to generate one or more focal point graphical maps as disclosed herein.

A user may enter commands and information into computer system 300 through one or more input devices 320, such as a pointing device (e.g., a mouse, touch screen), keyboard, microphone, joystick, gesture control, game pad, scanner, and the like. For instance, the user can employ input device 320 to edit or modify a domain model. These and other input devices 320 are often connected to processing unit 301 through a corresponding port interface 322 that is coupled to the system bus, but may be connected by other interfaces, such as a parallel port, serial port, or universal serial bus (USB). One or more output devices 324 (e.g., display, a monitor, printer, projector, or other type of displaying device) is also connected to system bus 303 via interface 326, such as a video adapter.

Computer system 300 may operate in a networked environment using logical connections to one or more remote computers, such as remote computer 328. Remote computer 328 may be a workstation, computer system, router, peer device, or other common network node, and typically includes many or all the elements described relative to computer system 300. The logical connections, schematically indicated at 330, can include a local area network (LAN) and a wide area network (WAN).

When used in a LAN networking environment, computer system 300 can be connected to the local network through a network interface or adapter 332. When used in a WAN networking environment, computer system 300 can include a modem, or can be connected to a communications server on the LAN. The modem, which may be internal or external, can be connected to system bus 303 via an appropriate port interface. In a networked environment, application programs 316 or program data 318 depicted relative to computer system 300, or portions thereof, may be stored in a remote memory storage device 340.

What have been described above are examples. It is, of course, not possible to describe every conceivable combination of structures, components, or methods, but one of ordinary skill in the art will recognize that many further combinations and permutations are possible. Accordingly, the invention is intended to embrace all such alterations, modifications, and variations that fall within the scope of this application, including the appended claims.

Where the disclosure or claims recite “a,” “an,” “a first,” or “another” element, or the equivalent thereof, it should be interpreted to include one or more than one such element, neither requiring nor excluding two or more such elements. As used herein, the term “includes” means includes but not limited to, and the term “including” means including but not limited to. The term “based on” means based at least in part on.

What is claimed is:

1. A non-transitory computer-readable medium having instructions executable by a processor for performing a method comprising:

- computing phase values for signals of each of a plurality of nodes on a geometric surface region associated with tissue of a patient;
- generating an activation mask based on the phase values computed for at least one of the plurality of nodes;
- applying the activation mask to the phase values computed for each of the plurality of nodes on the geometric surface region to identify a set of focal candidate nodes;

analyzing the computed phase value of a given focal candidate node in the set of focal candidate nodes relative to the computed phase values of other nodes in the set of focal candidate nodes over an activation time period associated with the given focal candidate node; 5
 computing a size of an activation region across the geometric surface region according to which of the plurality of nodes are activated for a respective activation time in a corresponding time interval for the given focal candidate node;
 determining if each of the focal candidate nodes is a focal point based on the computed size of the activation region for at least one time interval, thereby detecting one or more focal points; and
 displaying a graphical map on a display to visualize the one or more focal points detected on the geometric surface region based on the determining.

2. The medium of claim 1, the method further comprising repeating the analyzing for each focal candidate node in the set of focal candidate nodes to provide focal point data specifying a spatial location of each focal candidate node for the geometric surface region, the graphical map further being provided based on the focal point data.

3. The medium of claim 2, the method further comprising: 25
 assigning a score to each focal candidate node in the set of focal candidate nodes based on comparing the computed phase value for each given focal candidate node to the computed phase value of each focal candidate node in the set of focal candidate nodes over the activation time period, wherein each focal point for the geometric surface region is detected based on the scores assigned to each focal candidate node.

4. The medium of claim 3, the method further comprising: 30
 aggregating the scores assigned to each of the focal candidate nodes over a plurality of activation time periods; and
 generating the graphical map of the geometric surface region based on the focal point data including the aggregated scores assigned to each of the focal candidate nodes.

5. The medium of claim 3, wherein the score assigned to each of the focal candidate nodes comprises a value that varies as a function of a distance between each given focal candidate node and the focal candidate node to which the comparison is made.

6. The medium of claim 1, wherein activation mask is a temporal activation mask,
 wherein generating the activation mask further comprises generating a magnitude activation mask that specifies a minimum magnitude for the signals at each of the plurality of nodes on the geometric surface region, and wherein the set of focal candidate nodes is identified in response to applying both the temporal activation mask and the magnitude activation mask to phase values computed for each of the plurality nodes on the geometric surface region.

7. The medium of claim 1, the determining further comprising:
 detecting that a respective one of the given candidate nodes is a focal point if newly activated nodes for at least one other activation period following the respective activation time period are connected with the activation region that is activated for the respective activation time period and if the computed size of the activation region for the other activation time exceeds a minimum size parameter.

8. The medium of claim 1, the method further comprising determining that the given candidate node is not a focal point if nodes activated for a subsequent activation time are unconnected with the activation region that is activated for the respective activation time and the computed size has not changed over a predetermined time period.

9. The medium of claim 1, wherein the geometric surface region comprises one of an epicardial surface, an endocardial surface or another cardiac envelope.

10. The medium of claim 1, wherein the method further comprises solving an inverse problem to compute reconstructed electrical signals as the signals for each of the nodes on the geometric surface region based on electrical data acquired from the patient, the phase for each of the nodes being computed based on the reconstructed electrical signals for the respective nodes.

11. The medium of claim 1, wherein the signals for each of the plurality of nodes are derived based on at least one of invasively acquired electrical data for the patient or non-invasively acquired electrical data for the patient.

12. The medium of claim 1, wherein the activation mask specifies a set of at least one activation time period, each having a beginning and end time defined according to phase values of the signal at one of the plurality of nodes.

13. The medium of claim 12, wherein the beginning time corresponds to when a phase value of the signal at the least one of the plurality of nodes has a given value and the ending time corresponds to when the phase value of the signal at the least one of the plurality of nodes has another value.

14. The medium of claim 13, wherein the ending time is a predetermined phase value that is a fixed time from the beginning time.

15. A system comprising:

memory to store data and machine readable instructions; and

a processor to access the memory and execute the machine readable instructions, the machine readable instructions comprising:

a phase calculator programmed to compute phase values for signals of each of a plurality of nodes on a geometric surface region associated with tissue of a patient;

a mask generator programmed to generate an activation mask based on the phase values computed for at least one of the plurality of nodes;

a candidate selector programmed to apply the activation mask to the computed phase values to identify a set of focal candidate nodes;

a focal detector programmed to:

analyze the phase values computed for each of the plurality nodes in the set of focal candidate nodes relative to the computed phase values of other nodes in the set of focal candidate nodes over an activation time period associated with the given focal candidate node to identify at least one given focal candidate node,

compute a size of an activation region across the geometric surface region according to which of the plurality of nodes are activated for a respective activation time in a corresponding time interval for the at least one given focal candidate node,

determine whether or not each focal candidate node of the plurality of focal candidate nodes is a focal point based on the computed size of the activation region for at least one activation time interval, and store focal point data in the memory based on the determination by the focal detector;

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a map generator programmed to generate a graphical map representing one or more focal points detected on the geometric surface based on the focal point data; and

a display to provide a visualization of the graphical map across the geometric surface. 5

16. The system of claim 15, wherein focal detector further comprises a phase comparator programmed to compare the computed phase of each given candidate node relative to the phase of each node in its respective set of neighboring nodes over the activation time interval, the phase comparator to assign a score to one of the given candidate node and its neighboring node based on each comparison such that the focal detector determines which of the plurality of nodes are focal points for the geometric surface based on an aggregate score that is assigned to of each of the plurality of nodes and stored in the focal point data, 10

wherein the map generator is to generate a graphical map of the geometric surface based on the focal point data including the aggregated scores assigned to each of the nodes. 20

17. The system of claim 15, wherein the focal detector further comprises an activation detector programmed to determine the activation time interval for at least a substantial portion of the plurality of nodes, and wherein the mask generator is programmed to generate the activation mask for the given candidate node based on the activation time interval detected for the at least one given focal candidate node, the activation mask specifying a set of the at least one activation time interval having a beginning and ending time. 25

18. The system of claim 17, wherein the activation mask is a temporal activation mask, the mask generator further to 30

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provide a magnitude activation mask that specifies a minimum magnitude for the electrical signals at each of the plurality of nodes on the geometric surface, and

wherein the candidate selector is programmed to identify the set of focal candidate nodes in response to applying both the temporal activation mask to the computed activation time intervals for each of the plurality of nodes and the magnitude activation mask to the electrical signals at each of the plurality of nodes.

19. The system of claim 15, wherein the focal detector further comprises:

a continuity detector programmed to provide continuity data to indicate if newly activated focal candidate nodes for at least one other activation interval following the respective activation time interval are connected with the activation region that was activated for the respective activation time period, and 15

wherein the focal detector is programmed to determine that each focal candidate node is a focal point based on the continuity data and based on the computed size of the activation region for the other activation time exceeding a minimum size parameter.

20. The system of claim 19, wherein the focal detector is further programmed to determine that the at least one focal candidate node is not a focal point based on the continuity data indicating that newly activated focal candidate nodes for at least one other activation interval following the respective activation time interval are unconnected with the activation region that was activated for the respective activation time period and the computed size has not changed over a predetermined time period. 25

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摘要(译)

一种方法可以确定焦点激活的一个或多个起源。该方法可以包括基于跨时间的电数据计算分布在几何表面上的多个节点处的电信号的相位。该方法可以基于分析所计算的给定候选节点的相位和幅度来确定多个节点中的给定候选节点是否是焦点。可以生成图形地图以可视化在几何表面上检测到的焦点。

