RANDOM WALK METHOD, APPARATUS AND ELECTRONIC DEVICE FOR PARASITIC CAPACITANCE EXTRACTION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Chinese patent application No. 202210574732.6, filed on May 25, 2022, titled "RANDOM WALK METHOD, APPARATUS AND ELECTRONIC DEVICE FOR PARASITIC CAPACITANCE EXTRACTION". The content of the above application is hereby incorporated by reference.

TECHNICAL FIELD

[0002] The present invention relates to the field of integrated circuit technology, and in particular, to a random walk method, an apparatus and an electronic device for parasitic capacitance extraction.

BACKGROUND

[0003] In verification of integrated circuits layout, an important step is extraction of parasitic capacitance of conductors. As industry has increasing demand for accuracy, the extraction of parasitic capacitance often relies on a three-dimensional field solver for an accurate solution, among which a random walk algorithm is a popular method.

[0004] The random walk algorithm is different from conventional methods such as finite difference method and finite element method. It doesn't need to solve a system of linear equations, instead it relies on a process of first randomly selecting a sampling point from a Gaussian surface surrounding a conductor, and then constructing, centered on this point, a maximum cube (i.e., a maximum transfer cube) not intersecting with any conductor, and then taking a next point that falls randomly on a surface of the cube. This process is repeated until a position of a random point reaches a surface of a certain conductor or a boundary surface of layout, and the random walk process is completed (i.e., capacitance sampling is completed once).

[0005] When coupling capacitance between a target conductor and other conductors is calculated, sometimes at least hundreds of thousands of random walking processes need to be performed. Each random walking process requires searching all conductors on an integrated circuit layout for a conductor most proximal to a current random point, calculating a distance between the current random point and the most proximal conductor, and taking the distance between the current random point and the most proximal conductor as one of the conditions for constructing the maximum transfer cube. When a large number

of the random walking processes is required, such a search becomes the bottleneck for the calculation efficiency of the random walk algorithm.

[0006] At present, no effective solution has been proposed for a problem of low calculation efficiency of the random walk algorithm when parasitic capacitance of the target conductor is extracted.

SUMMARY

[0007] According to various embodiments of the present invention, a random walk method and apparatus for parasitic capacitance extraction, and an electronic apparatus are provided.

[0008] In a first aspect, the present invention provides a random walk method for parasitic capacitance extraction. The method includes: taking a conductor from a plurality of conductors that is most proximal to a boundary surface of an integrated circuit layout as a boundary conductor; determining a first region and a second region according to a Gaussian surface corresponding to the boundary conductor, the first region including all conductors in the integrated circuit layout, the second region being a region between the first region and the boundary surface, such that the second region not including any conductor; performing a random walk process, when a first hopping point corresponding to a target conductor is in the second region, constructing, centered on the first hopping point, a first maximum transfer cube not intersecting with any boundary surface, and randomly selecting a second hopping point from the first maximum transfer cube; and determining that a current random walk has been completed when the second hopping point is on a surface of any conductor or any boundary surface.

[0009] In an embodiment, subsequent to the performing the random walk process, the method further includes: determining a proximity conductor most proximal to the first hopping point when the first hopping point corresponding to the target conductor is in the first region; constructing, according to a distance between the first hopping point and the proximity conductor, a second maximum transfer cube centered on the first hopping point which does not include any conductor, and randomly selecting a third hopping point from the second maximum transfer cube; and determining that the current random walk has been completed when the third hopping point is on the surface of any conductor or any boundary surface.

[0010] In an embodiment, subsequent to the randomly selecting the second hopping point from the first maximum transfer cube, the method further includes: determining, when the

second hopping point is in the first region and inside any conductor, the conductor including the second hopping point to be a first proximity conductor most proximal to the second hopping point; taking interior of the first proximity conductor as a hollow region not including any conductor, constructing, inside the proximity conductor, a third maximum transfer cube centered on the second hopping point which does not include any conductor, and randomly selecting a fourth hopping point from the third maximum transfer cube; and determining that the current random walk has been completed when the fourth hopping point is on the surface of any conductor or any boundary surface.

[0011] In an embodiment, subsequent to the randomly selecting the second hopping point from the first maximum transfer cube, the method further includes: determining a second proximity conductor most proximal to the second hopping point when the second hopping point is in the first region but not inside any conductor, constructing, according to a distance between the second hopping point and the second proximity conductor, a fourth maximum transfer cube centered on the second hopping point which does not include any conductor, and randomly selecting a fifth hopping point from the fourth maximum transfer cube; and determining that the current random walk has been completed when the fifth hopping point is on the surface of any conductor or any boundary surface.

[0012] In an embodiment, the determining the first region and the second region according to the Gaussian surface corresponding to the boundary conductor includes: determining, in the Gaussian surface corresponding to the boundary conductor, a nearest surface most proximal to any boundary surface of the integrated circuit layout; determining the first region including all the conductors in the integrated circuit layout according to the nearest surface; and taking a region between the first region and the boundary surface of the integrated circuit layout as the second region.

[0013] In an embodiment, the determining the first region and the second region according to the Gaussian surface corresponding to the boundary conductor includes: determining, in the Gaussian surface corresponding to the boundary conductor, a nearest surface most proximal to any boundary surface of the integrated circuit layout, and acquiring position coordinates of the nearest surface; determining the first region including all the conductors in the integrated circuit layout according to the position coordinates of the nearest surface; and taking a region between the first region and the boundary surface of the integrated circuit layout as the second region.

[0014] In an embodiment, subsequent to the performing the random walk process, the method further includes: determining, when the target conductor is the boundary conductor and a starting point corresponding to the target conductor is in the second region, a proximity conductor most proximal to the starting point; and constructing, according to a distance between the starting point and the proximity conductor, a fifth maximum transfer cube centered on the starting point which does not include any conductor, and randomly selecting the first hopping point from the fifth maximum transfer cube.

[0015] In an embodiment, the method further includes: calculating a parasitic capacitance value of the target conductor according to a sampling value corresponding to each random walk when the number of random walk steps corresponding to the target conductor reaches a preset threshold.

[0016] In a second aspect, embodiments of the present invention provide a random walk apparatus for parasitic capacitance extraction. The apparatus includes a preprocessing module, a determination module, a hopping module, and an output module. The preprocessing module is configured for taking a conductor from a plurality of conductors that is most proximal to a boundary surface of an integrated circuit layout as a boundary conductor. The determination module is configured for determining a first region and a second region according to a Gaussian surface corresponding to the boundary conductor, the first region includes all conductors in the integrated circuit layout, the second region is a region between the first region and the boundary surface which does not include any conductor. The hopping module is configured for performing a random walk process, when a first hopping point corresponding to a target conductor is in the second region, constructing, centered on the first hopping point, a first maximum transfer cube not intersecting with any boundary surface, and randomly selecting a second hopping point from the first maximum transfer cube. The output module is configured for determining that a current random walk has been completed when the second hopping point is on a surface of any conductor or any boundary surface.

[0017] In a third aspect, embodiments of the present invention further provide an electronic device, including a memory and a processor. The memory stores a computer program, and the processor is configured to execute the computer program to perform the random walk method for parasitic capacitance extraction as described in the above first aspect.

[0018] In a fourth aspect, embodiments of the present invention further provide a storage medium, storing a computer program, and the computer program is executed by a processor to implement the random walk method for parasitic capacitance extraction as described in the above first aspect.

[0019] Details of one or more embodiments of the present invention are set forth in the following accompanying drawings and descriptions to make other features, objectives, and advantages of the present invention more concise and understandable.

[0020] Details of one or more embodiments of the present invention are set forth in the following accompanying drawings and descriptions. Other features, objectives, and advantages of the present invention become obvious with reference to the description, the accompanying drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] In order to better describe and illustrate embodiments and/or examples of those inventions disclosed herein, reference may be made to one or more accompanying drawings. Additional details or examples used to describe the accompanying drawings should not be considered as limitations on the scope of any of the disclosed inventions, the presently described embodiments and/or examples, and the presently understood best mode of these inventions.

[0022] FIG. 1 is a flowchart of a random walk method for parasitic capacitance extraction according to one or more embodiments.

[0023] FIG. 2 is a schematic diagram of a random walk process in a two-dimensional scenario according to one or more embodiments.

[0024] FIG. 3 is a schematic diagram of a random walk process in a two-dimensional scenario according to one or more embodiments.

[0025] FIG. 4 is a schematic diagram of a random walk process in a two-dimensional scenario according to one or more embodiments.

[0026] FIG. 5 is a structural block diagram of a random walk apparatus for parasitic capacitance extraction according to one or more embodiments.

[0027] FIG. 6 is a schematic diagram of an electronic apparatus according to one or more embodiments.

DETAILED DESCRIPTION OF THE EMBODIMENT

[0028] The technical solutions in embodiments of the present invention will be described clearly and completely below with reference to the accompanying drawings in the

embodiments of the present invention. Apparently, the described embodiments are merely some of rather than all of the embodiments of the present invention. All other embodiments acquired by those skilled in the art without creative efforts based on the embodiments of the present invention shall fall within the protection scope of the present invention.

[0029] The present embodiment provides a random walk method for parasitic capacitance extraction. FIG. 1 is a flowchart of the random walk method for parasitic capacitance extraction according to embodiments of the present invention. Referring to FIG. 1, the method includes step 101 to step 104.

[0030] Step 101 includes taking a conductor from a plurality of conductors that is most proximal to a boundary surface of an integrated circuit layout as a boundary conductor.

[0031] In the present embodiment, the integrated circuit layout may include six boundary surfaces. Each boundary surface corresponds to a boundary conductor. That is, each boundary surface corresponds to a nearest conductor.

[0032] Step 102 includes determining a first region and a second region according to a Gaussian surface corresponding to the boundary conductor. The first region includes all conductors in the integrated circuit layout, the second region is a region between the first region and the boundary surface, and the second region does not include any conductor.

[0033] In the present embodiment, the determining the first region and the second region according to the Gaussian surface corresponding to the boundary conductor may be implemented by the following step 1 to step 3.

[0034] Step 1 may include determining, in the Gaussian surface corresponding to the boundary conductor, a nearest surface most proximal to any boundary surface of the integrated circuit layout.

[0035] Step 2 may include determining the first region including all the conductors in the integrated circuit layout according to the nearest surface.

[0036] Step 3 may include taking a region between the first region and the boundary surface of the integrated circuit layout as the second region.

[0037] In the present embodiment, according to Gaussian surfaces of six boundary conductors, a nearest surface of the Gaussian surface of each boundary conductor most proximal to any boundary surface of the integrated circuit layout may be determined. An internal space encircled by all nearest surfaces may be the first region, and the internal space encircled by all the nearest surfaces may include all the conductors in the integrated circuit layout. Specifically, position coordinates of the nearest surface corresponding to each

Gaussian surface may be acquired, six coordinates of the six Gaussian surfaces most proximal to the six boundary surfaces of the integrated circuit layout may be obtained by unified calculation, and the first region may be determined according to the position coordinates of the nearest surface. That is, six coordinates corresponding to the first region may be (x1, y1, z1, x2, y2, z2), respectively. A cuboid region defined by a coordinate set (x1, y1, z1, x2, y2, z2) may include all the conductors in the integrated circuit layout, which is the first region. A region between an outside of the cuboid region defined by the coordinate set (x1, y1, z1, x2, y2, z2) and the boundary surfaces of the integrated circuit layout may be the second region, which does not include any conductor.

[0038] In the above embodiment, a boundary between the first region and the second region may be determined by the Gaussian surface of the boundary conductor rather than by a surface of the boundary conductor.

[0039] In the above embodiment, the Gaussian surface corresponding to the conductor may be a closed envelope surface surrounding the conductor. The Gaussian surface may include and only include the conductor, and the Gaussian surface may neither intersect with the conductor nor contact with any surface of the conductor. The Gaussian surface may be obtained by translating and extending the surface of the conductor outwards.

[0040] Step 103 may include performing a random walk process, when a first hopping point corresponding to a target conductor is in the second region, constructing, centered on the first hopping point, a first maximum transfer cube not intersecting with any boundary surface, and randomly selecting a second hopping point from the first maximum transfer cube.

[0041] In the present embodiment, since the first hopping point corresponding to the target conductor is in the second region, a proximity conductor most proximal to the first hopping point may not be searched for, which saves the time of search for the proximity conductor.

[0042] In the present embodiment, a starting point may be randomly selected from the Gaussian surface of the target conductor to start a random hop. The first hopping point may be a current coordinate point when any hopping occurs in the random walk process, and the first hopping point is not on the surface of any conductor or on any boundary surface.

[0043] In the above embodiments, since the proximity conductor most proximal to the first hopping point is not searched for, a size of the first maximum transfer cube constructed centered on the first hopping point may be determined by the boundary surface of the integrated circuit layout and has nothing to do with other conductors. The second hopping

point randomly selected from the first maximum transfer cube may have a high probability of falling directly on the boundary surface of the integrated circuit layout, which reduces a total number of hops in the random walk and further improves the calculation efficiency of the random walk algorithm.

[0044] It should be noted that, in the present invention, the first maximum transfer cube not intersecting with any boundary surface means that a boundary of the first maximum transfer cube coincides with the boundary surface of the integrated circuit layout or is separated by a certain distance from the boundary surface of the integrated circuit layout, but does not intersect with the boundary surface of the integrated circuit layout.

[0045] Step 104 may include determining that a current random walk has been completed when the second hopping point is on a surface of any conductor or any boundary surface.

[0046] FIG. 2 is a schematic diagram of a random walk process corresponding to a first embodiment in a two-dimensional scenario. Referring to FIG. 2, a Gaussian surface 22 corresponding to a boundary conductor 21 may be constructed, and on the Gaussian surface 22, a surface of coordinates most proximal to a boundary surface 23 of the integrated circuit layout may be a boundary of the first region, as shown by a black dotted line in FIG. 2. A region between the black dotted line and the boundary surface 23 of the integrated circuit layout may be the second region.

[0047] Referring to FIG. 2, when a certain target conductor 20 is the boundary conductor 21, starting from a certain point P1 on the Gaussian surface 22, in the related art, when a maximum transfer cube is constructed in each hop, it is needed to search for a proximity conductor most proximal to a current hopping point, a maximum transfer cube corresponding to the current hopping point may be constructed based on a distance between the hopping point and the most proximal proximity conductor, and a hop may be performed again by using the same principle after hopping to next hopping point, until hopping to the surface of any conductor or any boundary surface. In FIG. 2, the boundary surface 23 of the integrated circuit layout can be reached through P1, P2, P3, and P4 together. That is, a random walk may be completed after three hops through P1, P2, P3, and P4.

[0048] In the random walk method for parasitic capacitance extraction provided in the present embodiment, when hopping from P1 to P2, since the first hopping point P2 is in the second region, it is not needed to search for a proximity conductor most proximal to the first hopping point P2. A first maximum transfer cube 24 corresponding to the first hopping point P2 may be determined by the boundary surface 23 of the integrated circuit layout, a first

maximum transfer cube 24 not intersecting with any boundary surface 23 may be constructed centered on the first hopping point P2, then a second hopping point P5 randomly selected from the first maximum transfer cube 24 may fall directly on the boundary surface 23 of the integrated circuit layout, and a random walk process may be completed.

[0049] In the above embodiments, in the random walk method for parasitic capacitance extraction provided in the present embodiment, positions of all conductors in the integrated circuit layout may be analyzed to construct and mark out the second region not including any conductor. No proximity conductor is searched for a hopping point in the second region, thereby reducing the time to search twice for the proximity conductor most proximal to the current hopping point. In practical applications, when the hopping point falls in the second region, a probability of next hopping to the boundary surface 23 of the integrated circuit layout may also increase. Therefore, the number of hopping steps in a random walk may be reduced, thereby further improving the calculation efficiency of the random walk algorithm.

[0050] At step 101 to step 104 described above, the conductor of a plurality of conductors that is most proximal to the boundary surface 23 of the integrated circuit layout is taken as the boundary conductor 21. The first region and the second region are determined according to the Gaussian surface 22 corresponding to the boundary conductor 21, the first region includes all the conductors in the integrated circuit layout, the second region is a region between the first region and the boundary surface 23, and the second region does not include any conductor. A random walk process is performed, and when the first hopping point corresponding to the target conductor 20 is in the second region, the first maximum transfer cube 24 not intersecting with any boundary surface 23 is constructed centered on the first hopping point, and the second hopping point is randomly selected from the first maximum transfer cube 24. It is determined that the current random walk has been completed when the second hopping point is on the surface of any conductor or any boundary surface 23. The present invention can solve a problem of low calculation efficiency of the random walk algorithm in the related art when parasitic capacitance of the target conductor 20 is extracted, and achieve technical effect of improving the calculation efficiency of the random walk algorithm.

[0051] In some embodiments, during the performing the random walk process, the method further includes the following step 1 to step 3.

[0052] Step 1 may include determining a proximity conductor most proximal to the first hopping point when the first hopping point corresponding to the target conductor is in the first region.

[0053] Step 2 may include constructing, according to a distance between the first hopping point and the proximity conductor, a second maximum transfer cube 25 centered on the first hopping point which does not include any conductor, and a third hopping point is randomly selected from the second maximum transfer cube 25.

[0054] Step 3 may include determining that the current random walk has been completed when the third hopping point is on the surface of any conductor or any boundary surface 23.

[0055] In the present embodiment, in practical applications, the first hopping point corresponding to the target conductor may be in the first region. In this case, according to methods in the related art, firstly, the proximity conductor most proximal to the first hopping point may be searched for, then, according to a distance between the first hopping point and the proximity conductor, the second maximum transfer cube 25 not including any conductor may be constructed centered on the first hopping point, and the third hopping point is randomly selected from the second maximum transfer cube 25, so it is determined whether the current random walk has been completed by determining whether the third hopping point is on the surface of any conductor or any boundary surface.

[0056] When the third hopping point is not on the surface of any conductor or any boundary surface 23, a proximity conductor most proximal to the third hopping point may be continuously searched for, step 1 to step 3 above may be repeated to perform the random walk process, and it is determined that the current random walk has been completed until the current hopping point is on the surface of any conductor or any boundary surface 23.

[0057] In some embodiments, subsequent to the randomly selecting the second hopping point from the first maximum transfer cube, the method further includes the following step 1 to step 3.

[0058] Step 1 may include determining, when the second hopping point is in the first region and inside any conductor, the conductor including the second hopping point to be a first proximity conductor most proximal to the second hopping point.

[0059] Step 2 may include taking interior of the first proximity conductor as a hollow region not including any conductor, constructing, inside first the proximity conductor, a third maximum transfer cube centered on the second hopping point which does not include

any conductor, and randomly selecting a fourth hopping point from the third maximum transfer cube.

[0060] Step 3 may include determining that the current random walk has been completed when the fourth hopping point is on the surface of any conductor or any boundary surface 23.

[0061] FIG. 3 is a schematic diagram of a random walk process corresponding to a second embodiment in a two-dimensional scenario. Referring to FIG. 3, a Gaussian surface 22 corresponding to a boundary conductor 21 may be constructed, and on the Gaussian surface 22, the surface of coordinates most proximal to a boundary surface 23 of the integrated circuit layout may be the boundary of the first region, as shown by a black dotted line in FIG. 3. A region between the black dotted line and the boundary surface 23 of the integrated circuit layout may be the second region.

[0062] For a certain target conductor 20, according to the methods in the related art, a starting point M1 may be randomly selected from a Gaussian surface of the target conductor 20 to start a random hop, and a proximity conductor most proximal to the current hopping point may be searched for. Then, according to a distance between the current hopping point and the proximity conductor, a maximum transfer cube not including any conductor may be constructed centered on the current hopping point, next hopping point may be randomly selected from the maximum transfer cube, the above steps may be repeated to perform random hops from M1 to M5 until hopping to a first hopping point M5, and the first hopping point M5 is in the second region.

[0063] Referring to FIG. 3, in the related art, for the first hopping point M5, it is needed to search for a proximity conductor most proximal to M5, a maximum transfer cube may be constructed based on a distance between the first hopping point M5 and the proximity conductor most proximal to M5, and M6 may be selected from the maximum transfer cube. For M6, the above search and construction steps may also be repeated. That is, the step of searching for a proximity conductor may be performed twice to obtain M7, M7 may fall on the conductor, and a random walk is completed.

[0064] In the present embodiment, since the first hopping point M5 is in the second region, it is not needed to search for the proximity conductor most proximal to the first hopping point M5, the maximum transfer cube corresponding to the first hopping point M5 may be determined by the boundary surface 23 of the integrated circuit layout, the first maximum transfer cube 24 not intersecting with any boundary surface 23 may be constructed centered

on the first hopping point M5, and a second hopping point M8 randomly selected from the first maximum transfer cube 24 may be in the first region and inside a conductor. In this case, it may be determined that the conductor including the second hopping point M8 is a proximity conductor most proximal to the second hopping point M8 (in practical applications, it is found that the proximity conductor of the second hopping point M8 is generally the conductor including the second hopping point M8). That is, the step of searching for the proximity conductor is performed once.

[0065] In this case, interior of the proximity conductor of the second hopping point M8 may be taken as a hollow region not including any conductor, a third maximum transfer cube 26 not including any conductor may be constructed centered on the second hopping point M8 inside the proximity conductor, and a fourth hopping point M9 may be randomly selected from the third maximum transfer cube 26. Since the fourth hopping point M9 is on a surface of the proximity conductor of the second hopping point M8, it may be determined that the current random walk has been completed.

[0066] Upon comparison, it may be found that, compared with the related art, according to the random walk method for parasitic capacitance extraction provided in the present embodiment, the time required to search for the proximity conductor may be reduced for once, which can improve the calculation efficiency of the random walk algorithm during extraction of parasitic capacitance of the target conductor 20.

[0067] In some embodiments, subsequent to the randomly selecting the second hopping point from the first maximum transfer cube, the method further includes the following step 1 and step 2.

[0068] Step 1 may include determining a second proximity conductor most proximal to the second hopping point when the second hopping point is in the first region but not inside any conductor, constructing, according to a distance between the second hopping point and the second proximity conductor, a fourth maximum transfer cube centered on the second hopping point which does not include any conductor, and randomly selecting a fifth hopping point from the fourth maximum transfer cube.

[0069] Step 2 may include determining that the current random walk has been completed when the fifth hopping point is on the surface of any conductor or any boundary surface 23.

[0070] FIG. 4 is a schematic diagram of a random walk process corresponding to a third embodiment in a two-dimensional scenario. Referring to FIG. 4, a Gaussian surface 22 corresponding to a boundary conductor 21 may be constructed, and on the Gaussian surface

22, the surface of coordinates most proximal to a boundary surface 23 of the integrated circuit layout may be the boundary of the first region, as shown by a black dotted line in FIG. 4. A region between the black dotted line and the boundary surface 23 of the integrated circuit layout may be the second region.

[0071] For a certain target conductor 20, according to the methods in the related art, a starting point M1 may be randomly selected from a Gaussian surface of the target conductor 20 to start a random hop, and a proximity conductor most proximal to the current hopping point may be searched for. Then, according to a distance between the current hopping point and the proximity conductor, a maximum transfer cube not including any conductor may be constructed centered on the current hopping point, next hopping point may be randomly selected from the maximum transfer cube, the above steps may be repeated to perform random hops from N1 to N5 until hopping to a first hopping point N5, and the first hopping point N5 is in the second region.

[0072] Referring to FIG. 4, in the related art, for the first hopping point N5, it is needed to search for a proximity conductor most proximal to the first hopping point N5, the second maximum transfer cube 25 may be constructed based thereon, and a hopping point N6 may be selected from the second maximum transfer cube 25. For the hopping point N6, the above search and construction steps may also be repeated. That is, the step of searching for the proximity conductor may be performed twice to obtain a hopping point N7, the hopping point N7 may fall on the conductor, and a random walk is completed.

[0073] In the present embodiment, since the first hopping point N5 is in the second region, it is not needed to search for the proximity conductor most proximal to the first hopping point N5, the maximum transfer cube corresponding to the first hopping point N5 may be determined by the boundary surface 23 of the integrated circuit layout, the first maximum transfer cube 24 not intersecting with any boundary surface 23 may be constructed centered on the first hopping point N5, and a second hopping point N8 randomly selected from the first maximum transfer cube 24 may be in the first region but not inside any conductor. In this case, a fourth maximum transfer cube 27 corresponding to the second hopping point N8 and not including any conductor may be constructed according to the step of searching for the proximity conductor and the step of constructing a maximum transfer cube in the related art, that is, the step of searching for the proximity conductor may be performed once.

[0074] A fifth hopping point N9 may be randomly selected from the fourth maximum transfer cube 27. Since the fifth hopping point N9 is on a surface of a conductor, it may be determined that the current random walk has been completed.

[0075] Upon comparison, it may be found that, compared with the related art, according to the random walk method for parasitic capacitance extraction provided in the present embodiment, the time required to search for the proximity conductor may be reduced by once, which can improve the calculation efficiency of the random walk algorithm during extraction of parasitic capacitance of the target conductor 20.

[0076] In some embodiments, subsequent to the performing the random walk process, the method further includes the following step 1 and step 2.

[0077] Step 1 may include determining, when the target conductor is the boundary conductor 21 and a starting point corresponding to the target conductor is in the second region, a proximity conductor most proximal to the starting point.

[0078] Step 2 may include constructing, according to a distance between the starting point and the proximity conductor, a fifth maximum transfer cube not including any conductor centered on the starting point which does not include any conductor, and randomly selecting the first hopping point from the fifth maximum transfer cube.

[0079] In the present embodiment, when a target conductor from which parasitic capacitance is to be extracted is the boundary conductor 21 and a starting point corresponding to the target conductor is at a boundary of the second region, it is needed to determine a proximity conductor most proximal to the starting point according to the step of searching for the proximity conductor in the related art, then based on the step of constructing the maximum transfer cube in the related art, according to a distance between the starting point and the proximity conductor, a fifth maximum transfer cube not including any conductor may be constructed centered on the starting point, and the first hopping point may be randomly selected from the fifth maximum transfer cube.

[0080] In some embodiments, the method further includes: calculating a parasitic capacitance value of the target conductor according to a sampling value corresponding to each random walk when the number of random walk steps corresponding to the target conductor reaches a preset threshold.

[0081] In the present embodiment, the preset threshold may be configured by a user according to an actual requirement for calculation accuracy. When the number of random walk steps corresponding to the target conductor reaches the preset threshold, error statistics

and convergence judgment may also be performed, and when sampling values corresponding to random walks have converged, the parasitic capacitance value of the target conductor may be calculated according to the sampling value corresponding to each random walk, thereby ensuring accuracy of extraction of the parasitic capacitance of the target conductor.

[0082] This embodiment provides a random walk apparatus 100 for parasitic capacitance extraction. FIG. 5 is a structural block diagram of the random walk apparatus 100 for parasitic capacitance extraction according to embodiments of the present invention. Referring to FIG. 5, the apparatus includes a preprocessing module 502, a determination module 504, a hopping module 506, and an output module 508. The preprocessing module 502 is configured for taking a conductor from a plurality of conductors that is most proximal to a boundary surface of an integrated circuit layout as a boundary conductor. The determination module 504 is configured for determining a first region and a second region according to a Gaussian surface corresponding to the boundary conductor, the first region includes all conductors in the integrated circuit layout, the second region is a region between the first region and the boundary surface, and the second region does not include any conductor. The hopping module 506 is configured for performing a random walk process, when a first hopping point corresponding to a target conductor is in the second region, constructing, centered on the first hopping point, a first maximum transfer cube not intersecting with any boundary surface, and randomly selecting a second hopping point from the first maximum transfer cube. The output module 508 is configured for determining that a current random walk has been completed when the second hopping point is on a surface of any conductor or any boundary surface.

[0083] In some embodiments, the hopping module 506 is further configured for determining a proximity conductor most proximal to the first hopping point when the first hopping point corresponding to the target conductor is in the first region, constructing, according to a distance between the first hopping point and the proximity conductor, a second maximum transfer cube centered on the first hopping point which does not include any conductor, and randomly selecting a third hopping point from the second maximum transfer cube. The output module 508 is further configured for determining that the current random walk has been completed when the third hopping point is on the surface of any conductor or any boundary surface.

[0084] In some embodiments, the hopping module 506 is further configured for determining, when the second hopping point is in the first region and inside any conductor, the conductor including the second hopping point to be a first proximity conductor most proximal to the second hopping point, taking interior of the first proximity conductor as a hollow region not including any conductor, constructing, inside the proximity conductor, a third maximum transfer cube centered on the second hopping point which does not include any conductor, and randomly selecting a fourth hopping point from the third maximum transfer cube. The output module 508 is further configured for determining that the current random walk has been completed when the fourth hopping point is on the surface of any conductor or any boundary surface.

[0085] In some embodiments, the hopping module 506 is further configured for determining a second proximity conductor most proximal to the second hopping point when the second hopping point is in the first region but not inside any conductor, constructing, according to a distance between the second hopping point and the second proximity conductor, a fourth maximum transfer cube centered on the second hopping point which does not include any conductor, and randomly selecting a fifth hopping point from the fourth maximum transfer cube. The output module 508 is further configured for determining that the current random walk has been completed when the fifth hopping point is on the surface of any conductor or any boundary surface.

[0086] In some embodiments, the determination module 504 is further configured for determining, in the Gaussian surface corresponding to the boundary conductor, a nearest surface most proximal to any boundary surface of the integrated circuit layout, and acquiring position coordinates of the nearest surface; determining the first region including all the conductors in the integrated circuit layout according to the position coordinates of the nearest surface; and taking a region between the first region and the boundary surface of the integrated circuit layout as the second region.

[0087] In some embodiments, the hopping module 506 is further configured for determining, when the target conductor is the boundary conductor and a starting point corresponding to the target conductor is in the second region, a proximity conductor most proximal to the starting point; and constructing, according to a distance between the starting point and the proximity conductor, a fifth maximum transfer cube centered on the starting point which does not include any conductor, and randomly selecting the first hopping point from the fifth maximum transfer cube.

[0088] In some embodiments, the output module 508 is further configured for calculating a parasitic capacitance value of the target conductor according to a sampling value corresponding to each random walk when the number of random walk steps corresponding to the target conductor reaches a preset threshold.

[0089] It should be noted that specific examples in the present embodiment may be obtained with reference to the examples described in the above embodiments and alternative implementations. Details are not described herein again in the present embodiment.

[0090] This embodiment further includes an electronic device 200. FIG. 6 is a schematic diagram of a hardware structure of the electronic device 200 according to embodiments of the present invention. Referring to FIG. 6, the electronic device 200 includes a memory 604 and a processor 602. The memory 604 stores a computer program. The processor 602 is configured to execute the computer program to perform steps in any one of the above method embodiments.

[0091] Specifically, the processor 602 may include a central processing unit (CPU), or an Application Specific Integrated Circuit (ASIC), or may be configured to be one or more integrated circuits to implement the embodiments of the present invention.

[0092] The memory 604 may include a mass memory for data or instructions. As an example and not by way of limitation, the memory 604 may include a Hard Disk Drive (HDD), a floppy disk drive, a Solid State Drive (SDD), a flash memory, an optical disc, a magneto-optical disc, a magnetic tape, or a Universal Serial Bus (USB) drive or a combination of two or more thereof. In an appropriate case, the memory 604 may include removable or non-removable (or fixed) media. In an appropriate case, the memory 604 may be inside or outside a random walk apparatus 100 for parasitic capacitance extraction~~fault image generation apparatus~~. In a particular embodiment, the memory 604 may be a non-volatile memory. In a particular embodiment, the memory 604 may include a read-only memory (ROM), and a random access memory (RAM). In an appropriate case, the ROM may include a mask programmed ROM, a Programmable Read-Only Memory (PROM), an Erasable Programmable Read-Only Memory (EPROM), an Electrically Erasable Programmable Read-Only Memory (EEPROM), an Electrically Alterable Read-Only Memory (EAROM), a flash memory, or a combination of two or more thereof. In an appropriate case, the RAM may be a Static Random-Access Memory (SRAM) or a Dynamic Random Access Memory (DRAM). The DRAM may be a Fast Page Mode Dynamic Random Access Memory (FPMDRAM), an Extended Date Out Dynamic Random Access

Memory (EDODRAM), a Synchronous Dynamic Random-Access Memory (SDRAM), or the like.

[0093] The memory 604 may be configured to store or cache various data files required for processing and/or used for communication, as well as possible computer program instructions executed by the processor 602.

[0094] The processor 602 reads and executes the computer program instructions stored in the memory 604 to implement the random walk method for parasitic capacitance extraction in any one of the above embodiments.

[0095] Alternatively, the above electronic apparatus 200 may further include a transmission device 606 and an input/output device 608. The transmission device 606 is connected to the processor 602. The input/output device 608 is connected to the processor 602.

[0096] Alternatively, in this embodiment, the processor 602 may be configured to perform the following step 101 to step 104 by the computer program.

[0097] Step 101 includes taking a conductor from a plurality of conductors that is most proximal to a boundary surface of an integrated circuit layout as a boundary conductor.

[0098] Step 102 includes determining a first region and a second region according to a Gaussian surface corresponding to the boundary conductor. The first region includes all conductors in the integrated circuit layout, the second region is a region between the first region and the boundary surface, and the second region does not include any conductor.

[0099] Step 103 includes performing a random walk process, when a first hopping point corresponding to a target conductor is in the second region, constructing, centered on the first hopping point, a first maximum transfer cube not intersecting with any boundary surface, and randomly selecting a second hopping point from the first maximum transfer cube.

[0100] Step 104 includes determining that a current random walk has been completed when the second hopping point is on a surface of any conductor or any boundary surface.

[0101] It should be noted that specific examples in the present embodiment may be obtained with reference to the examples described in the above embodiments and alternative implementations. Details are not described herein again in the present embodiment.

[0102] In addition, in combination with the random walk method for parasitic capacitance extraction in the above embodiments, embodiments of the present invention may provide a storage medium for implementation. The storage medium stores a computer program. The

computer program is executed by a processor to implement the random walk method for parasitic capacitance extraction in any one of the above embodiments.

[0103] The technical features in the above embodiments may be randomly combined. For concise description, not all possible combinations of the technical features in the above embodiments are described. However, all the combinations of the technical features are to be considered as falling within the scope described in this description provided that they do not conflict with each other.

[0104] The above embodiments only describe several implementations of the present invention, and their description is specific and detailed, but cannot therefore be understood as a limitation on the patent scope of the application. It should be noted that those of ordinary skill in the art may further make variations and improvements without departing from the conception of the present invention, and these all fall within the protection scope of the present invention. Therefore, the patent protection scope of the present invention should be subject to the appended claims.