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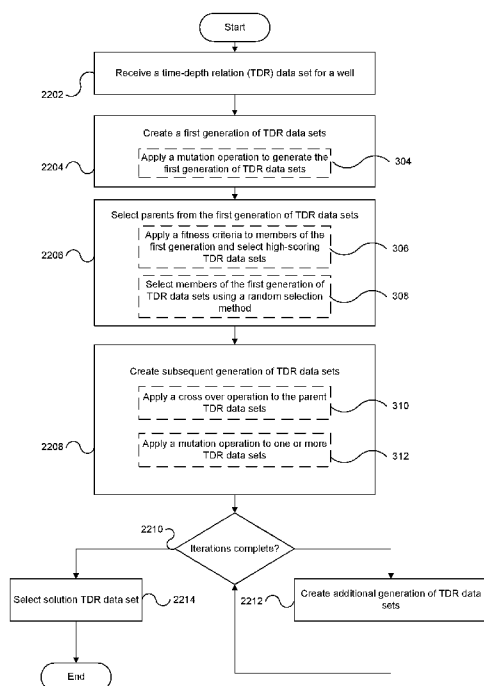
(54) **Title:** APPROACHES TO TYING WELL LOGS TO SEISMIC DATA

FIG. 3

(57) **Abstract:** Methods, computing systems, and computer-readable media for automatically creating seismic well ties. The approach involves receiving a time-depth relation (TDR), generating a first generation of possible solutions, selecting parent TDR solutions that meet fitness criteria, and creating a subsequent generation by using the parent TDR solutions to create child TDR solutions and introducing mutations. The creation of the child TDR solutions can be accomplished using a crossover operation. The process continues and, when complete, a solution TDR data set is selected.



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APPROACHES TO TYING WELL LOGS TO SEISMIC DATA

Cross-Reference to Related Applications

[0001] This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 62/103,913 entitled “Approaches to Seismic Well Ties” filed on 15 January 2015. U.S. provisional patent application serial no. 62/103,913 is incorporated herein by reference in its entirety.

Background

[0002] Integrating well logs and seismic data is often a valuable exercise when estimating the nature of the subsurface. The process of tying well logs to seismic data (often referred to as seismic well tying) commonly involves manually adjusting the time-depth relation, also known as stretching and squeezing a synthetic to fit a seismic trace. This process can be tedious and difficult, and also relies on the experience and expertise of the user doing the seismic well ties.

Summary

[0003] Embodiments of the present disclosure provide methods, computing systems, and computer-readable media for creating seismic well ties. The approach may involve receiving a time-depth relation (TDR) data set for a well and creating a first generation of TDR data sets for the well that are possible solutions. The approach may also involve selecting, from the first generation, the TDR data sets that meet a fitness criteria and creating a next generation using those TDR data sets. The approach may further involve selecting a solution TDR data set from a subsequent generation.

[0004] The computer-readable media may include instructions for receiving a TDR data set for a well and applying operations to the TDR data set to create a first generation of additional TDR data sets. The instructions may also include selecting parent TDR data sets from the first generation and applying one or more operations to the parent TDR data sets to create a subsequent generation. The instructions may also cause creating additional generations of TDR data sets and selecting a solution TDR data set.

[0005] A system may include one or more processors and a memory system comprising one or more non-transitory computer-readable media. The process may cause the system to apply

mutations to generate a first generation of TDR data sets and select those members of the first generation that meet fitness criteria. The process may also cause creating a second generation of TDR data sets using the members of the first generation that meet the fitness criteria, and repeatedly creating additional generations using members of the previous generation. The solution data set may be selected from the final generation.

[0006] The foregoing summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

Brief Description of the Drawings

[0007] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the present teachings and together with the description, serve to explain the principles of the present teachings. In the figures:

[0008] Figure 1 illustrates a conceptual view of an oilfield and oilfield data being collected.

[0009] Figure 2 illustrates a flow chart diagram for creating a solution TDR data set.

[0010] Figure 3 illustrates an embodiment of a method for creating a solution TDR data set.

[0011] Figure 4 illustrates one embodiment of a genetic well tie component.

[0012] Figure 5 illustrates an embodiment of parent TDR data sets creating child TDR data sets for a next generation.

[0013] Figure 6 illustrates a schematic view of a processor system.

Detailed Description

[0014] The following detailed description refers to the accompanying drawings. Wherever convenient, the same reference numbers are used in the drawings and the following description to refer to the same or similar parts. While several embodiments and features of the present disclosure are described herein, modifications, adaptations, and other implementations are possible, without departing from the spirit and scope of the present disclosure.

[0015] In general, embodiments of the present disclosure may provide systems, methods, and computer-readable media for generating seismic well ties. Embodiments are shown in the above-identified drawings and described below. In describing the embodiments, like or identical

reference numerals are used to identify common or similar elements. The drawings are not necessarily to scale and certain features and certain views of the drawings may be shown exaggerated in scale or in schematic in the interest of clarity and conciseness.

[0016] During the field operations, data may be collected for analysis and/or monitoring of the operations. Such data may include, for instance, information regarding subterranean formations, equipment, and historical and/or other data. Data concerning the subterranean formation may be collected using a variety of sources. Such formation data may be static or dynamic. Static data relates to, for instance, formation structure and geological stratigraphy that define geological structures of the subterranean formation. Dynamic data relates to, for instance, fluids flowing through the geologic structures of the subterranean formation over time. Such static and/or dynamic data may be collected to learn more about the formations and the valuable assets contained therein.

[0017] Collecting data may be performed using seismic surveying. Seismic surveying may be performed by imparting energy to the earth at one or more source locations, for example, by way of controlled explosion, mechanical input etc. Return energy is then measured at surface receiver locations at varying distances and azimuths from the source location. The travel time of energy from source to receiver, via reflections and refractions from interfaces of subsurface strata, indicates the depth and orientation of such strata. Seismic data, as collected via the receiver, within a volume of interest may be referred to as seismic volume. A seismic volume may be displayed as seismic images based on different sampling resolutions and viewing orientations as well as subject to various different seismic amplitude processing techniques to enhance or highlight seismic reflection patterns.

[0018] The data may be used to predict downhole conditions and make decisions concerning field operations. Such decisions may involve well planning, well targeting, well completions, operating levels, production rates and other operations and/or operating parameters. A large number of variables and large quantities of data to consider in analyzing field operations may exist. Because of the large number of variables and large quantities of data, modeling the behavior of the field operation to determine the desired course of action may be useful. Various aspects of field operations, such as geological structures, downhole reservoirs, wellbores, surface facilities, as well as other portions of the field operation, may be modeled. The modeling may

be used to perform field operations. Further, during the ongoing operations, the operating parameters may be adjusted as field conditions change and new information is received.

[0019] FIG. 1 depicts a schematic view, partially in cross section, of a field (100) in which one or more embodiments of quality control of 3D horizon auto-tracking in seismic volume may be implemented. In one or more embodiments, one or more of the modules and elements shown in FIG. 1 may be omitted, repeated, and/or substituted. Accordingly, embodiments of quality control of three dimensional (3D) horizon auto-tracking in seismic volume should not be considered limited to the specific arrangements of modules shown in FIG. 1.

[0020] As shown in FIG. 1, the field (100) includes the subterranean formation (104), data acquisition tools (102-1), (102-2), (102-3), and (102-4), wellsite system A (204-1), wellsite system B (204-2), wellsite system C (204-3), a surface unit (202), and an exploration and production (E&P) computer system (208). The subterranean formation (104) includes several geological structures, such as a sandstone layer (106-1), a limestone layer (106-2), a shale layer (106-3), a sand layer (106-4), and a fault line (107).

[0021] In one or more embodiments, data acquisition tools (102-1), (102-2), (102-3), and (102-4) are positioned at various locations along the field (100) for collecting data of the subterranean formation (104), referred to as survey operations. In particular, these data acquisition tools are adapted to measure the subterranean formation (104) and detect the characteristics of the geological structures of the subterranean formation (104). For example, data plots (108-1), (108-2), (108-3), and (108-4) are depicted along the field (100) to demonstrate the data generated by these data acquisition tools. Specifically, the static data plot (108-1) is a seismic two-way response time. Static plot (108-2) is core sample data measured from a core sample of the formation (104). Static data plot (108-3) is a logging trace, referred to as a well log. Production decline curve or graph (108-4) is a dynamic data plot of the fluid flow rate over time. Other data may also be collected, such as historical data, user inputs, economic information, and/or other measurement data and other parameters of interest.

[0022] To capture the seismic two-way response time in the static data plot (108-1), the data acquisition tools (102-1) may be a seismic truck that is adapted to measure properties of the subterranean formation based on sound vibrations. One such sound vibration (e.g., 186, 188, 190) generated by a source (170) reflects off a plurality of horizons (e.g., 172, 174, 176) in the subterranean formation (104). Each of the sound vibrations (e.g., 186, 188, 190) are received by

one or more sensors (e.g., 180, 182, 184), such as geophone-receivers, situated on the earth's surface. The geophones produce electrical output signals, which may be transmitted, for example, as input data to a computer (192) on the seismic truck (102-1). Responsive to the input data, the computer (192) may generate a seismic data output, such as the seismic two-way response time.

[0023] Further as shown in FIG. 1, each of the wellsite system A (204-1), wellsite system B (204-2), and wellsite system C (204-3) is associated with a rig, a wellbore, and other wellsite equipment configured to perform wellbore operations, such as logging, drilling, fracturing, production, or other applicable operations. For example, the wellsite systems (204-1), (204-2), (204-3) is associated with a rig (101), a wellbore (103), and drilling equipment to perform drilling operation. Similarly, the wellsite system B (204-2) and wellsite system C (204-3) are associated with respective rigs, wellbores, other wellsite equipment, such as production equipment and logging equipment to perform production operations and logging operations, respectively. Generally, survey operations and wellbore operations are referred to as field operations of the field (100). In addition, data acquisition tools and wellsite equipment are referred to as field operation equipment. These field operations may be performed as directed by a surface unit (202). For example, the field operation equipment may be controlled by a field operation control signal sent from the surface unit (202).

[0024] In one or more embodiments, the surface unit (202) is operatively coupled to the data acquisition tools (102-1), (102-2), (102-3), (102-4), and/or the wellsite systems (204-1), (204-2), (204-3). In particular, the surface unit (202) is configured to send commands to the data acquisition tools (102-1), (102-2), (102-3), (102-4), and/or the wellsite systems (204-1), (204-2), (204-3) and to receive data therefrom. In one or more embodiments, the surface unit (202) may be located at the wellsite systems (204-1), (204-2), (204-3) and/or remote locations. The surface unit (202) may be provided with computer facilities for receiving, storing, processing, and/or analyzing data from the data acquisition tools (102-1), (102-2), (102-3), (102-4), the wellsite systems (204-1), (204-2), (204-3), and/or other part of the field (100). The surface unit (202) may also be provided with or functionally for actuating mechanisms at the field (100). The surface unit (202) may then send command signals to the field (100) in response to data received, for example to control and/or optimize various field operations described above.

[0025] In one or more embodiments, the surface unit (202) is communicatively coupled to an E&P computer system (208). In one or more embodiments, the data received by the surface unit (202) may be sent to the E&P computer system (208) for further analysis. Generally, the E&P computer system (208) is configured to analyze, model, control, optimize, or perform management tasks of the aforementioned field operations based on the data provided from the surface unit (202). In one or more embodiments, the E&P computer system (208) is provided with functionality for manipulating and analyzing the data, such as performing seismic interpretation or borehole resistivity image log interpretation to identify geological surfaces in the subterranean formation (104) or performing simulation, planning, and optimization of production operations of the wellsite systems (204-1), (204-2), (204-3). In one or more embodiments, the result generated by the E&P computer system (208) may be displayed for user viewing using a two-dimensional (2D) display, 3D display, or other suitable displays. Although the surface unit (202) is shown as separate from the E&P computer system (208) in FIG. 1, in other examples, the surface unit (202) and the E&P computer system (208) may also be combined.

[0026] The description in connection with FIG. 1 illustrates various types of data that may be collected. The tying process relates data from a well, commonly measured in depth, with data from seismic, commonly measured in time or velocity. The TDR adjustments allow users to correlate events measured in the well with events detected in the seismic. The disclosed approach uses genetic algorithm approaches to help generate the seismic well tie. This may aid the user by providing a better initial product for manual refinement, may replace manual activity altogether, and/or may also allow faster well tying, particularly in environments with many wells.

[0027] Genetic algorithms broadly refer to a collection of techniques that can be used to solve problems by using population-based techniques that operate on a population of potential solutions. Genetic algorithms are search heuristics that mimic the process of natural selection in biology. In many embodiments, a pool of potential solutions is created that serves as a first generation. The fitness of one or more of the first generation solutions may be calculated, and those that have a certain level of fitness are permitted to propagate their “genetic material” to the next generation. This may involve recombining member materials to form members of a next generation of potential solutions. The recombination may be accomplished using a crossover

operation (also commonly referred to as recombination operations) or other recombination approaches. The recombination operation may combine two parents by picking a crossover point, then swapping sections after that crossover point. Additional variance may be introduced using a mutation operation. The mutation operation may modify a solution at one or more points without recombining with another potential solution as in a crossover operation.

[0028] The creation of new generations of solutions continues until a termination condition is reached. The termination condition may be that a satisfactory solution is found, that a fixed number of generations is reached, that the solutions have converged or plateaued such that additional iterations are not likely to produce better results, or other criteria. Examples of additional criteria include computation cost and time.

[0029] Figure 2 illustrates one embodiment of an approach to generating a seismic well tie using genetic techniques. In the depicted embodiment, the method begins with receiving 2202 a time-depth relation (TDR) data set for a well. The TDR may be expressed as data from the well, measured in depth, with data from seismic, measured in time or velocity. For example, the TDR may include a time-depth pair. The TDR may include a velocity-depth pair.

[0030] The method may continue with creating 2204 a first generation of TDR data sets. The first generation comprises a set of at least two TDR data sets for a well. In one embodiment, one hundred TDR data sets are created to serve as the initial population of the first generation. The method continues with selecting 2206 parents from the first generation of TDR sets and creating 2208 a subsequent generation of TDR data sets using the parents from the first generation.

[0031] The method may involve determining 2210 whether the iterations of creating generations is complete. In one embodiment, the iterations are deemed complete after a set number of generations has been created. In another embodiment, the iterations are deemed complete after a solution TDR data set with a particular fitness level is identified. Other factors (including those described above) may be used to determine whether the iterations are complete.

[0032] If the iterations are not complete, the method may involve creating 2212 additional generations of TDR data sets. This process of iteratively creating additional generations continues until the condition specified at step 2210 is satisfied. Once the iterations are complete, the method involves selecting 2214 the solution TDR data set.

[0033] Figure 3 illustrates one embodiment of an implementation of the method described in connection with Figure 2. The method step 2204, creating a first generation of TDR data sets,

may involve applying 304 a mutation operation to generate the first generation of TDR data sets. In one embodiment, the mutation operation involves selecting a position within the received TDR data set (such as a particular depth) and applying a time shift at the position. The amount of time shift may be randomly defined. In certain embodiments, the amount of time is also constrained such that it is proportional to the average of delta time between samples. This may allow the time shift to create an appropriately sized disturbance that is sufficient to escape any local maximums.

[0034] The mutation operation may be applied to the TDR data set received in step 2202, which may be the initial existent TDR data set in the well. This TDR data set may act as the base to compound the first generation. Thus, in one embodiment, the first generation includes the initial TDR data set and mutations of the initial TDR data set.

[0035] Figure 2 also described a step 2206 of selecting parents from the first generation of TDR data sets. Selecting parents may involve applying 306 a fitness criteria to members of the first generation. The fitness criteria evaluates how well a particular TDR data set solves the problem. In one embodiment, applying the fitness criteria involves transforming the input well log (sonic and density or acoustic impedance, for example) from the depth domain to the time domain using the TDR data set under evaluation. The fitness criteria may also involve computing the reflectivity coefficient in the seismic sample interval. In one embodiment, using a given wavelet, the approach involves convolving it with the reflectivity coefficient to generate a synthetic seismogram. The fitness criteria may also involve computing the correlation coefficient between synthetic and seismic trace. The coefficient may serve as a TDR score that can still suffer some penalization due to the constraint of the velocity model.

[0036] In one embodiment, the following equation may be used:

$$tdrScore = \frac{\sum_{i=1}^n (syn[i] - synAvg)(seis[i] - seisAvg)}{\sqrt{\sum_{i=1}^n (syn[i] - synAvg)^2} \sqrt{\sum_{i=1}^n (seis[i] - seisAvg)^2}}$$

[0037] Where $syn[i]$ and $seis[i]$ mean synthetic and seismic trace at index i , and $synAvg$ and $seisAvg$ represent the average of all synthetic samples and all seismic trace samples respectively.

[0038] The method may involve selecting high-scoring TDR data sets from the first generation to be parents for a subsequent generation of TDR data sets. In one embodiment, a set number of high-scoring TDR data sets is selected (for example, the top 10). In another embodiment, all those TDR data sets with a score above a threshold amount are selected, regardless of number.

[0039] The method may also involve selecting 308 members of the first generation of TDR data sets using a random selection method. In one embodiment, about 10% of the parent TDR data sets are selected based on high scores after application of the fitness criteria. The remaining parents may be selected using the random selection method. In another embodiment, under 50% of the parents are selected based on high scores after application of the fitness criteria. The parent population may also be designed to contain a number of TDR data sets from the previous generation that are subjected to a mutation operation.

[0040] The random selection method may be unweighted such that all members of the first generation have an equal chance of being selected. In another embodiment, the random selection method is weighted such that it favors those TDR data sets having a higher score from the fitness criteria. In such embodiments, those TDR data sets with high scores have a greater chance of being selected than those TDR data sets with low scores. In one embodiment, the random selection method is a roulette wheel selection method.

[0041] The method step 2208, creating a subsequent generation of TDR data sets, may involve applying 310 a crossover operation to the parent TDR data sets. Figure 5 illustrates one embodiment of a crossover operation on parent TDR data sets 510 and 520. The crossover operation may involve selecting a depth at random and splitting the TDR data sets 510 and 520 at that depth. In Figure 5, the parent TDR data set is split into sections 502 and 504. Parent TDR data set 520 is split into sections 506 and 508.

[0042] The crossover operation may then involve mixing the four parts 502, 504, 506, and 508 to create new TDR data sets 550 and 560 that become members of the next generation of TDR data sets. The new TDR data sets 550 and 560 each contains part of the time-depth relation information from both parents. This crossover operation may be repeated on a plurality of parent TDR data sets from the first generation. The crossover operation may be constrained such that a lower, or “tail” section of a parent TDR data set does not become an upper, or “head” section of a child TDR data set.

[0043] Creating the subsequent generation of TDR data sets may also involve applying 312 a mutation operation to one or more TDR data sets from the previous generation. The mutation operation may be applied at one depth or multiple depths. The TDR data sets to be mutated may be selected according to the fitness criteria, the random selection method, or other. Thus, the subsequent generation of TDR data sets may include TDR data sets created by crossover

operations and by mutation operations. In certain embodiments, members of the previous generation may be selected to become members of the subsequent generation as well.

[0044] Figure 4 illustrates one embodiment of a genetic well tie component 400. In the depicted embodiment, the genetic well tie component 400 includes an initialization component 402, a mutation component 404, a parent selection component 406, a generation creation component 408, and a solution selection component 410.

[0045] The initialization component 402 is configured to receive a TDR data set for a well. The initialization component 402 may be further configured to begin the process of creating a seismic well tie using a genetic algorithm approach. In one embodiment, the initialization component 402 begins the process automatically in response to receiving a TDR data set. In another embodiment, the initialization component 402 may begin the process in response to a user input. The initialization component 402 may initiate the process for a single well; the initialization component 402 may also initiate a batch process for multiple wells for a reservoir or other area with associated seismic data.

[0046] The mutation component 404 is configured to apply one or more mutation operations to TDR data sets. In one embodiment, the mutation component 404 creates a first generation that includes the initial TDR data set and additional TDR data sets. The mutation component 404 may create the additional TDR data sets by applying a mutation operation on the initial TDR data set. As noted above, the mutation operation may involve selecting a position (such as a depth) within a TDR data set and applying a time shift, or a velocity shift, at the position. As such, the mutation component may apply mutations to generate the first generation of TDR data sets. The mutation component 404 may create members of subsequent generations as well.

[0047] The parent selection component 406 is configured to select a subset of the previous generation to act as parents to the next generation. The parent selection component 406 may apply a fitness criteria and select from the generations TDR data sets that meet the fitness criteria. The parent selection component 406 may use multiple approaches to selecting parent TDR data sets. For example, the parent selection component 406 may select a first set of TDR data sets using an elitist selection method such as the one described above. The parent selection component 406 may select a second set of TDR data sets using a random selection method. The random selection method may select completely at random; in another embodiment, the process is weighted to favor higher scoring TDR data sets. Other approaches may be used to increase the

probability that TDR data sets with high fitness scores are selected by the random selection method. In one embodiment, about 10% of the parent TDR data sets are selected using the elitist selection method, and the remaining parent TDR data sets are selected using a random selection method.

[0048] The generation creation component 408 may create subsequent generations by applying one or more operations to parent TDR data sets. In one embodiment, the operation is a crossover operation. The generation creation component 408 may select two parent TDR data sets, select a depth, split the two parent TDR data sets at the depth to create four sections, and combine the four sections to create new TDR data sets for the next generation. In certain embodiments, the depth is selected at random.

[0049] The generation creation component 408 may also introduce mutations into the next generation. The generation creation component 408 may select child TDR data sets and introduce mutations. The generation creation component 408 may select a parent TDR data set, introduce mutations, and add the mutated parent TDR data set to the next generation. The generation creation component 408 may select a TDR data set from the previous generation at random, apply a mutation operation, and introduce the mutated version of the TDR data set to the next generation.

[0050] The generation creation component 408 may produce a set number of members of each generation. For example, in one embodiment, the generation creation component 408 creates at least fifty TDR data sets in each generation.

[0051] The solution selection component 410 selects a solution TDR data set from one of the subsequent generations. In certain embodiments, the process of creating generations iterates over a set number of generations. In one embodiment, the process iterates over at least fifty generations. In other embodiment, the solution selection component 410 can end the process in response to detecting one or more conditions. For example, the solution selection component 410 may test for convergence to determine whether the TDR data sets are converging towards a solution. In response to detecting convergence, the solution selection component 410 may end the iteration process.

[0052] The solution selection component 410 may end the process in response to detecting a suitable answer. For example, the solution selection component 410 may have a minimum level of fitness. Once a TDR data set equals or exceeds the minimum level of fitness, the solution

selection component 410 may deem the TDR data set an acceptable solution and end the process. In other embodiments, the solution selection component 410 may determine that no TDR data set equals or exceeds the minimum level of fitness and may end the process after a set period of time is complete. Other criteria that may cause the solution selection component 410 to end the process without a solution include, but are not limited to, computing resources used, number of iterations, or others.

[0053] Embodiments of the disclosure may also include one or more systems for implementing one or more embodiments of the method for creating seismic well ties. Figure 6 illustrates a schematic view of such a computing or processor system 700, according to an embodiment. The processor system 700 may include one or more processors 702 of varying core configurations (including multiple cores) and clock frequencies. The one or more processors 702 may be operable to execute instructions, apply logic, etc. It will be appreciated that these functions may be provided by multiple processors or multiple cores on a single chip operating in parallel and/or communicably linked together. In at least one embodiment, the one or more processors 702 may be or include one or more GPUs.

[0054] The processor system 700 may also include a memory system, which may be or include one or more memory devices and/or computer-readable media 704 of varying physical dimensions, accessibility, storage capacities, etc. such as flash drives, hard drives, disks, random access memory, etc., for storing data, such as images, files, and program instructions for execution by the processor 702. In an embodiment, the computer-readable media 704 may store instructions that, when executed by the processor 702, are configured to cause the processor system 700 to perform operations. For example, execution of such instructions may cause the processor system 700 to implement one or more portions and/or embodiments of the method(s) described above.

[0055] The processor system 700 may also include one or more network interfaces 706. The network interfaces 706 may include any hardware, applications, and/or other software. Accordingly, the network interfaces 706 may include Ethernet adapters, wireless transceivers, PCI interfaces, and/or serial network components, for communicating over wired or wireless media using protocols, such as Ethernet, wireless Ethernet, etc.

[0056] As an example, the processor system 700 may be a mobile device that includes one or more network interfaces for communication of information. For example, a mobile device may

include a wireless network interface (e.g., operable via one or more IEEE 802.11 protocols, ETSI GSM, BLUETOOTH®, satellite, etc.). As an example, a mobile device may include components such as a main processor, memory, a display, display graphics circuitry (e.g., optionally including touch and gesture circuitry), a SIM slot, audio/video circuitry, motion processing circuitry (e.g., accelerometer, gyroscope), wireless LAN circuitry, smart card circuitry, transmitter circuitry, GPS circuitry, and a battery. As an example, a mobile device may be configured as a cell phone, a tablet, etc. As an example, a method may be implemented (e.g., wholly or in part) using a mobile device. As an example, a system may include one or more mobile devices.

[0057] The processor system 700 may further include one or more peripheral interfaces 708, for communication with a display, projector, keyboards, mice, touchpads, sensors, other types of input and/or output peripherals, and/or the like. In some implementations, the components of processor system 700 need not be enclosed within a single enclosure or even located in close proximity to one another, but in other implementations, the components and/or others may be provided in a single enclosure. As an example, a system may be a distributed environment, for example, a so-called “cloud” environment where various devices, components, etc. interact for purposes of data storage, communications, computing, etc. As an example, a method may be implemented in a distributed environment (e.g., wholly or in part as a cloud-based service).

[0058] As an example, information may be input from a display (e.g., a touchscreen), output to a display or both. As an example, information may be output to a projector, a laser device, a printer, etc. such that the information may be viewed. As an example, information may be output stereographically or holographically. As to a printer, consider a 2D or a 3D printer. As an example, a 3D printer may include one or more substances that can be output to construct a 3D object. For example, data may be provided to a 3D printer to construct a 3D representation of a subterranean formation. As an example, layers may be constructed in 3D (e.g., horizons, etc.), geobodies constructed in 3D, etc. As an example, holes, fractures, etc., may be constructed in 3D (e.g., as positive structures, as negative structures, etc.).

[0059] The memory device 704 may be physically or logically arranged or configured to store data on one or more storage devices 710. The storage device 710 may include one or more file systems or databases in any suitable format. The storage device 710 may also include one or more software programs 712, which may contain interpretable or executable instructions for

performing one or more of the disclosed processes. When requested by the processor 702, one or more of the software programs 712, or a portion thereof, may be loaded from the storage devices 710 to the memory devices 704 for execution by the processor 702.

[0060] Those skilled in the art will appreciate that the above-described componentry is merely one example of a hardware configuration, as the processor system 700 may include any type of hardware components, including any accompanying firmware or software, for performing the disclosed implementations. The processor system 700 may also be implemented in part or in whole by electronic circuit components or processors, such as application-specific integrated circuits (ASICs) or field-programmable gate arrays (FPGAs).

[0061] The foregoing description of the present disclosure, along with its associated embodiments and examples, has been presented for purposes of illustration. It is not exhaustive and does not limit the present disclosure to the precise form disclosed. Those skilled in the art will appreciate from the foregoing description that modifications and variations are possible in light of the above teachings or may be acquired from practicing the disclosed embodiments.

[0062] For example, the same techniques described herein with reference to the processor system 700 may be used to execute programs according to instructions received from another program or from another processor system altogether. Similarly, commands may be received, executed, and their output returned entirely within the processing and/or memory of the processor system 700. Accordingly, neither a visual interface command terminal nor any terminal at all is strictly necessary for performing the described embodiments.

[0063] Likewise, the steps described need not be performed in the same sequence discussed or with the same degree of separation. Various steps may be omitted, repeated, combined, or divided, as appropriate to achieve the same or similar objectives or enhancements. Accordingly, the present disclosure is not limited to the above-described embodiments, but instead is defined by the appended claims in light of their full scope of equivalents. Further, in the above description and in the below claims, unless specified otherwise, the term “execute” and its variants are to be interpreted as pertaining to any operation of program code or instructions on a device, whether compiled, interpreted, or run using other techniques. In the claims that follow, section 112 paragraph sixth is not invoked unless the phrase “means for” is used.

CLAIMS

What is claimed is:

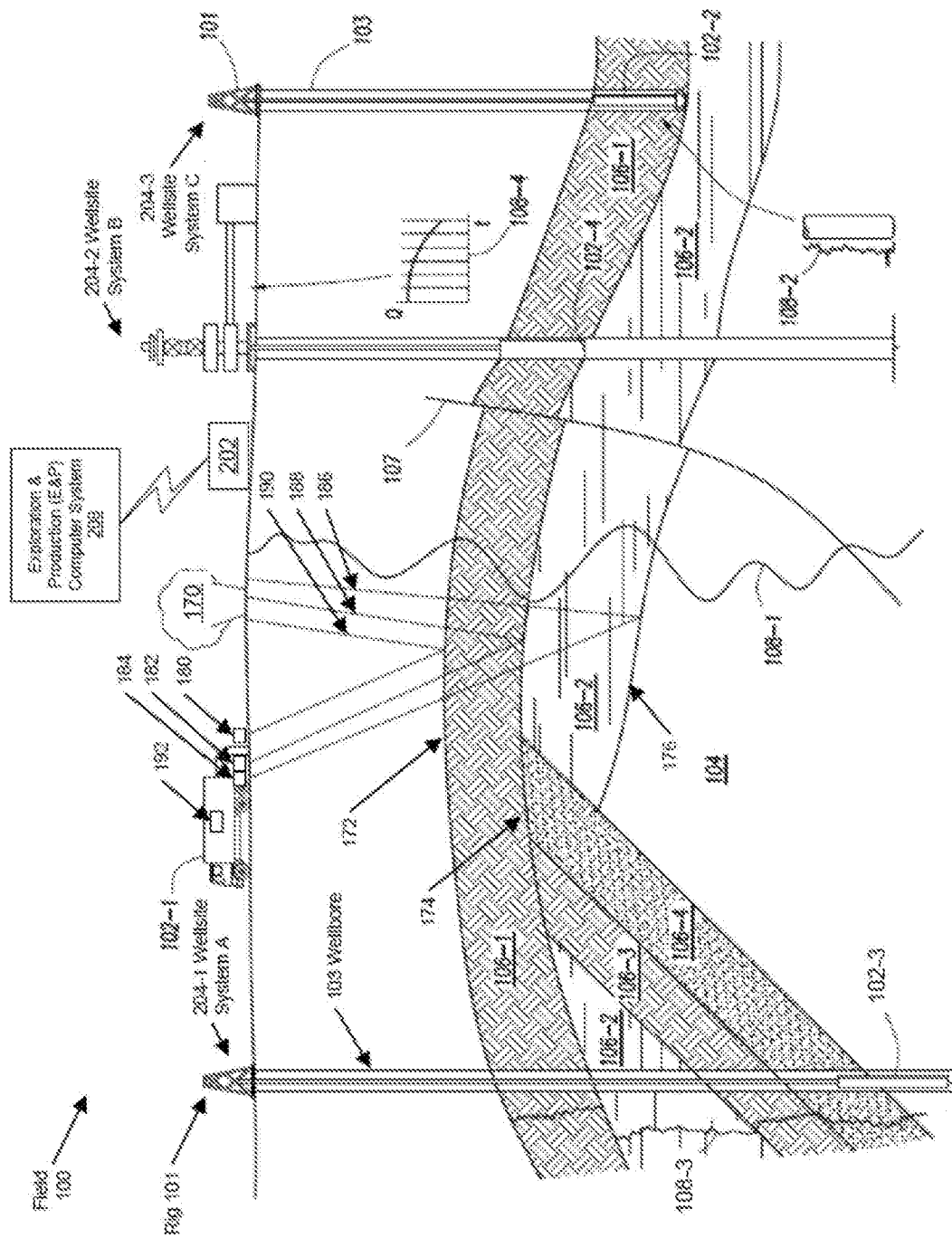
1. A method comprising:
receiving a time-depth relation (TDR) data set for a well;
creating a first generation comprising a set of two or more additional TDR data sets for the well;
selecting, from the first generation, TDR data sets that meet a fitness criteria;
creating a next generation using the TDR data sets that meet the fitness criteria;
selecting a solution TDR data set from a subsequent generation.
2. The method of claim 1, wherein creating the next generation comprises:
selecting two parent TDR data sets from the first generation;
selecting a depth;
splitting the two parent TDR data sets at the depth to create four sections; and
combining the four sections to create new TDR data sets.
3. The method of claim 2, wherein the depth is selected at random.
4. The method of claim 2, wherein creating the next generation further comprises introducing mutations.
5. The method of claim 1, wherein the method iterates over at least fifty generations.
6. The method of claim 5, wherein each generation comprises at least fifty TDR data sets.
7. The method of claim 1, further comprising:
testing for convergence; and
ending an iteration process in response to detecting convergence.

9. A non-transitory computer-readable medium storing instructions that, when executed by a processor, cause the processor to perform operations, the operations comprising:
- receiving a time-depth relation (TDR) data set for a well;
 - applying one or more operations to the TDR data set to create a first generation comprising a plurality of additional TDR data sets;
 - selecting parent TDR data sets from the first generation;
 - applying one or more operations to the parent TDR data sets to create a subsequent generation;
 - creating a plurality of additional generations comprising TDR data sets; and
 - selecting a solution TDR data set.
10. The non-transitory computer-readable medium of claim 9, wherein the one or more operations to create the subsequent generation comprise:
- a crossover operation;
 - a mutation operation.
11. The non-transitory computer-readable medium of claim 10, wherein the crossover operation comprises:
- selecting two parent TDR data sets;
 - selecting a depth; and
 - switching portions of the parent TDR data sets below the depth.
12. The non-transitory computer-readable medium of claim 10, wherein the mutation operation comprises:
- selecting a position within a selected parent TDR data set;
 - applying a time shift at the position.
13. The non-transitory computer-readable medium of claim 10, wherein selecting the parent TDR data sets comprises:
- selecting a first set of TDR data sets using an elitist selection method; and
 - selecting a second set of TDR data sets using a random selection method.

14. The non-transitory computer-readable medium of claim 13, wherein:
about 10% of the parent TDR data sets are selected using the elitist selection method; and
remaining TDR data sets are selected using the random selection method.
15. The non-transitory computer-readable medium of claim 14, further comprising increasing the probability that TDR data sets with high fitness scores are selected by the random selection method.
16. A system, comprising:
one or more processors;
a memory system comprising one or more non-transitory computer-readable media comprising instructions that, when executed by at least one of the one or more processors, cause the computing system to perform operations, the operations comprising:
applying mutations to generate a first generation of TDR data sets;
selecting those members of the first generation that meet fitness criteria;
creating a second generation of TDR data sets using the members of the first generation that meet the fitness criteria;
repeatedly creating additional generations using members of a previous generation; and
selecting a solution TDR data set from a last generation.
17. The system of claim 16, wherein a number of additional generations to be generated is preset and a number of members in the additional generations is preset.
18. The system of claim 16, wherein the second generation of TDR data sets further comprises TDR data sets created through mutation.

19. The system of claim 16, wherein the second generation of TDR data sets further comprises TDR data sets that do not meet the fitness criteria that are selected through a roulette wheel selection method.

20. The system of claim 16, further comprising applying the operations to a plurality of wells for a reservoir.



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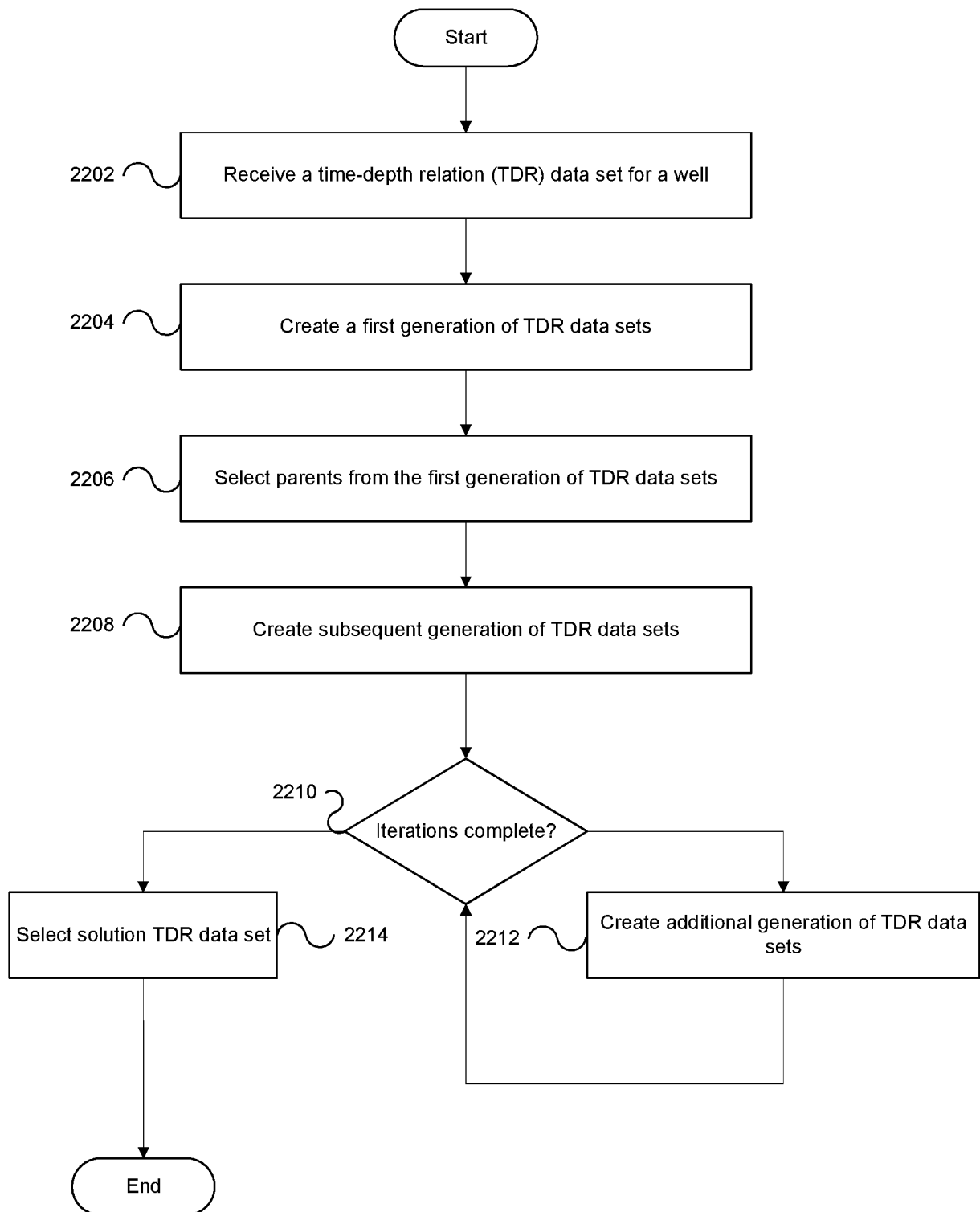


FIG. 2

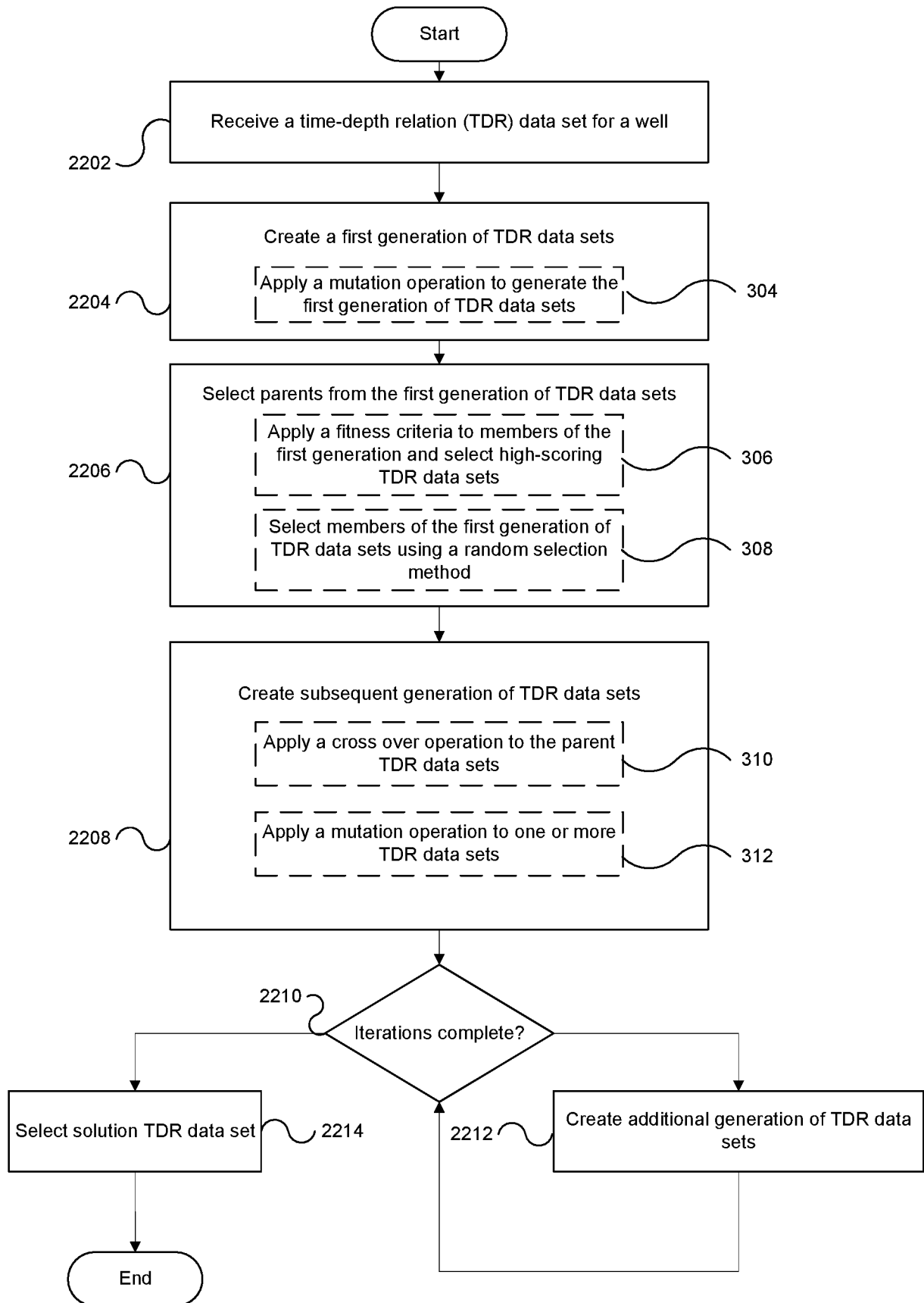


FIG. 3

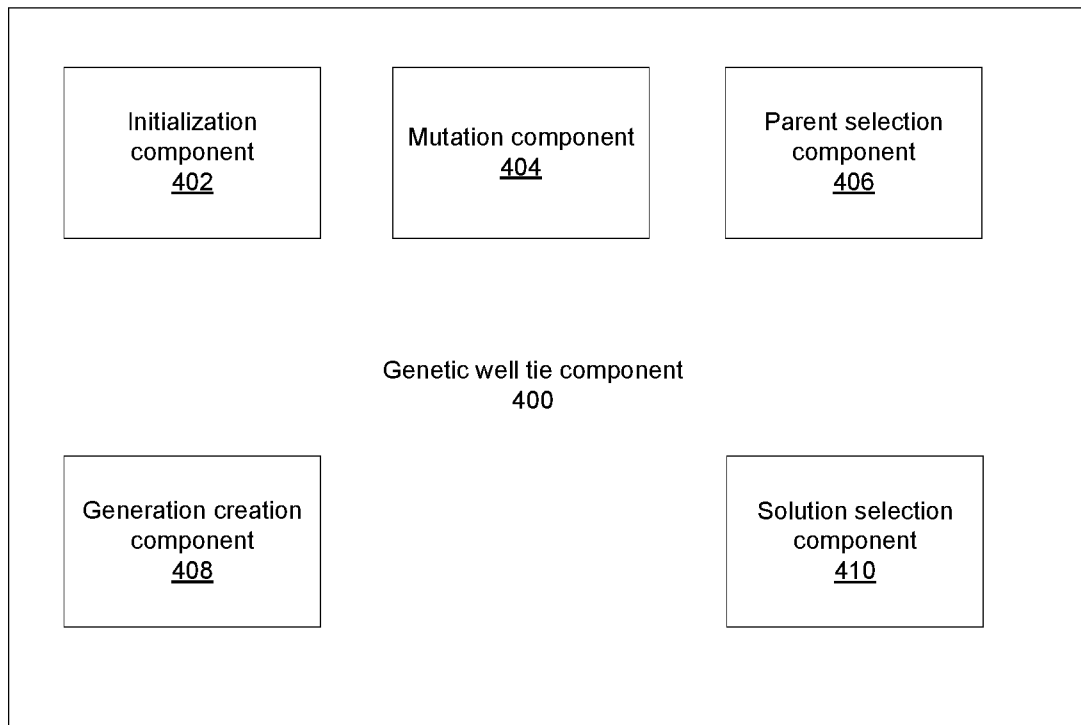


FIG. 4

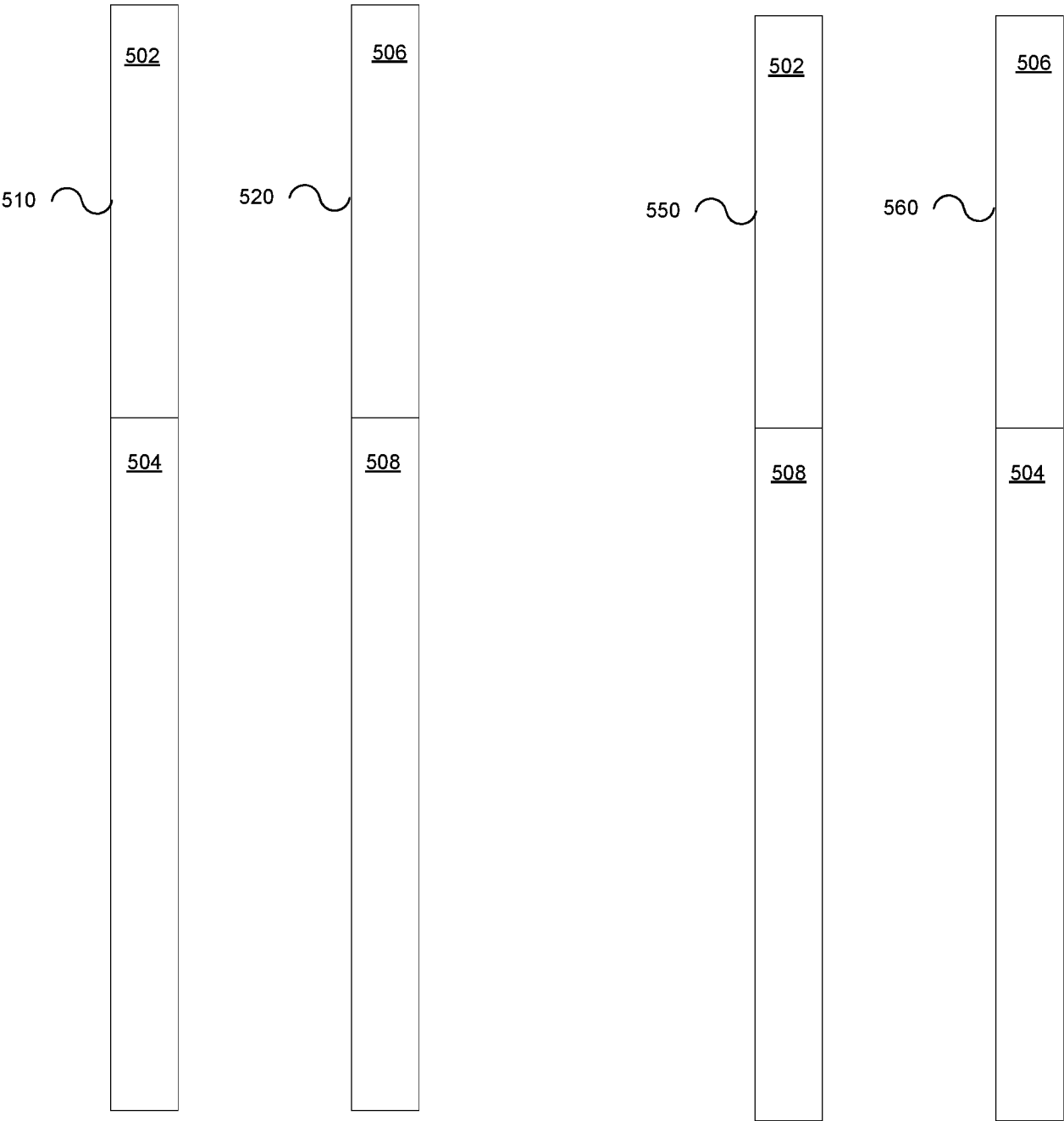


FIG. 5

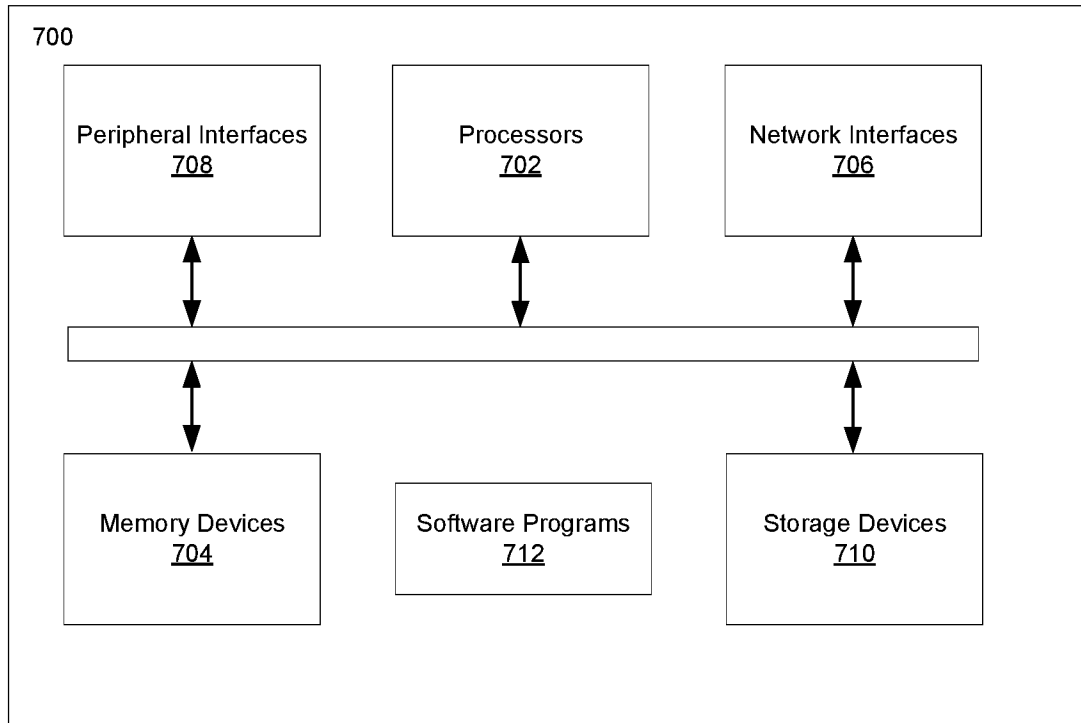


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/013557**A. CLASSIFICATION OF SUBJECT MATTER****E21B 47/00(2006.01)i, G01V 1/40(2006.01)i, G01V 1/48(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21B 47/00; G01V 3/00; G01V 1/28; G01V 1/40; G01V 1/48

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: time-depth relation (TDR), seismic data set, parent data, generation data set, detecting convergence and introducing mutation

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011-0025525 A1 (AKIMOV et al.) 03 February 2011 See paragraphs [0019]-[0026] and figures 1-4.	1-7, 9-20
A	US 2006-0256657 A1 (ROBINSON, GARY CHARLES) 16 November 2006 See paragraphs [0020]-[0040] and figure 3.	1-7, 9-20
A	US 2006-0190181 A1 (DEFFENBAUGH et al.) 24 August 2006 See paragraphs [0036]-[0070] and figures 3-4.	1-7, 9-20
A	US 2010-0195437 A1 (BJERKHOLT, BORRE) 05 August 2010 See paragraphs [0023]-[0142] and figures 1-3, 14-15.	1-7, 9-20
A	US 2004-0117121 A1 (GRAY et al.) 17 June 2004 See paragraphs [0019]-[0064] and figure 1.	1-7, 9-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

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14 June 2016 (14.06.2016)

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Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/013557

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