

7th Slide Set Cloud Computing

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Agenda for Today

- MapReduce/Hadoop
 - Basic information
 - Basics
 - Operation steps
 - Fields of application
 - Google PageRank
 - Components and extensions
 - Hadoop Distributed File System (HDFS)
 - Pig
 - Hive
 - HBase
 - Cloudera
 - Installation guide
 - Examples with the installation
 - Amazon Elastic MapReduce
 - Other MapReduce implementations

Data Storage and Processing

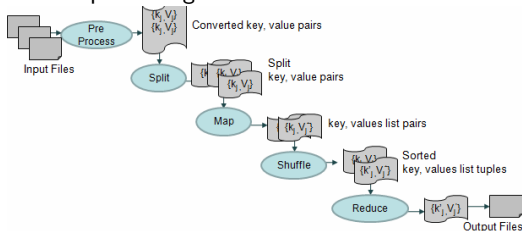
- In order to efficiently store data, Google developed the distributed Cluster file system **Google File System** (GFS)
 - GFS operates according to the Master-Slave principle
 - Fault tolerance in case of hardware failures achieves GFS via replication

S. Ghemawat, H. Gobioff, S. Leung. **The Google File System**. Google. 2003
<http://labs.google.com/papers/gfs-sosp2003.pdf>

- The standard procedure for distributed systems is typically: Data, which needs to be processed, is transferred to the program
 - A program is executed on a computer and fetches the required input data from a source (e.g. FTP server or database)
 - This procedure is not optimal for large amounts of data, because a bottleneck occurs
 - Solution: The data processing must take place where the data is stored
⇒ This is possible with the **MapReduce programming model**

Image Source: <http://www.pnexpert.com>

- ## 1 MapReduce programming model



- ## 2 MapReduce frameworks (e.g. Hadoop)

Since Hadoop 2 (released in 2013), developers that use the Hadoop Framework are not forced to use the MapReduce programming model any more because Hadoop 2 has the YARN (Yet Another Resource Manager), which is also called MapReduce 2.0 (MRv2). YARN took over the task of cluster management from MapReduce. The job tracker, resource management and job scheduling/monitoring have been split into separate daemons. MRv2 maintains API compatibility with Hadoop 1. All MapReduce jobs should still run unchanged on top of MRv2 with just a recompile.

Great Source: <https://developer.ibm.com/tutorials/bd-yarn-intro/>

Basic information about MapReduce

J. Dean, S. Ghemawat. **MapReduce: Simplified Data Processing on Large Clusters**. Google 2004
<http://labs.google.com/papers/mapreduce-osdi04.pdf>

- The MapReduce programming model splits tasks into smaller parts and distributes them for parallel processing to different compute nodes
- The final result is created by merging the partial results

Oliver Fischer. **Verarbeiten großer verteilter Datenmengen mit Hadoop**. heise Developer. 2010
<http://heise.de/-964755>

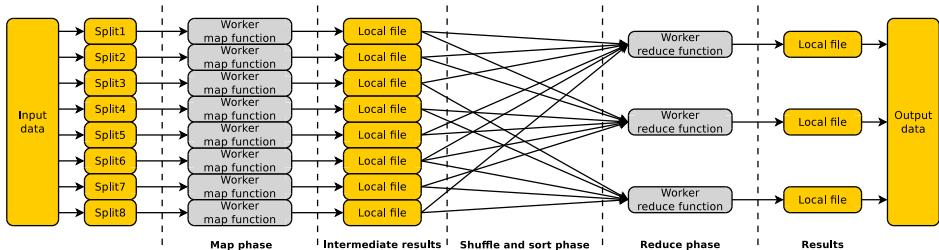
- Google presented MapReduce in 2003 and the Google File System in 2004
 - The implementations of Google were never published
 - This resulted in the emergence of free (open source) re-implementations

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- The MapReduce concept has its roots in Lisp
 - Lisp implements the functions `map()` and `reduce()`
 - The `map`-function of Lisp is called with a list of input values and a function as parameter
 - The supplied function is applied to each value in the list
 - The `reduce`-function of Lisp is also called with a function and a list of input values
 - `reduce` operates similar to `map`, but it combines the results to a single one

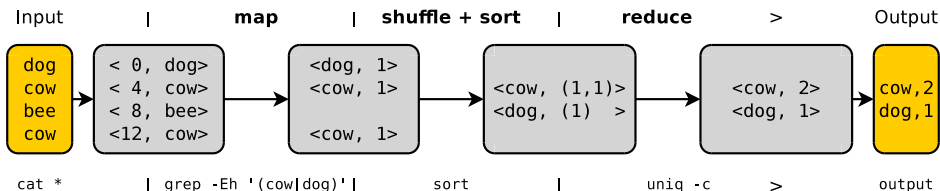
1. *Journal of the American Medical Association*, 2000; 284: 2689-2695.

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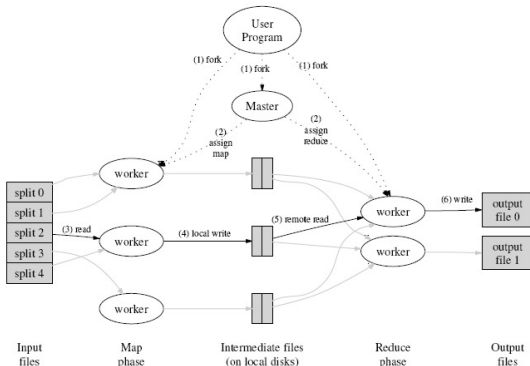
MapReduce – Operation Steps

- The Map phase and the Reduce phase can be executed in parallel on the nodes of a cluster
 - A master coordinates and monitors the MapReduce applications
- The diagram shows that the data processing via MapReduce is similar with the processing in a UNIX pipe



Source: Christophe Bisciglia, Tob White, An Introduction to Hadoop, 2009

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1

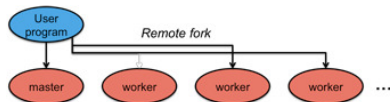
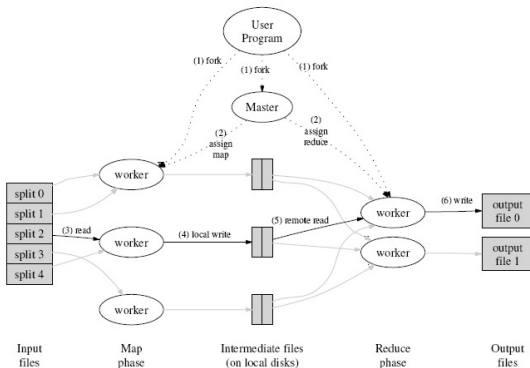


- First, the MapReduce library of the user program splits the input data into m parts
 - The parts are called *split* or *shard*
 - It is useful to have at least as many splits as map workers in the cluster exist, in order that they are all busy

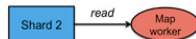
Sources: *Jeffrey Dean, Sanjay Ghemawat*. MapReduce: Simplified Data Processing on Large Clusters. 2004 and <http://www.cs.rutgers.edu/~pxk/417/notes/content/mapreduce.html>



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1



- The master assigns the `map` tasks to the workers
- Each `map` worker reads a split part of the input data and extracts the key-value pairs



Sources: *Jeffrey Dean, Sanjay Ghemawat*. MapReduce: Simplified Data Processing on Large Clusters. 2004 and <http://www.cs.rutgers.edu/~pxk/417/notes/content/mapreduce.html>

Map function

```
1 map(String key, String value):
2   // key: document name
3   // value: document contents
4   for each word w in value:
5     EmitIntermediate(w, "1");
```

- `map` gets a document name key and a document value provided as strings
 - `map` scans the document word by word

- The map-process inserts for each word w a 1 into the intermediate result list of the word
 - At the end of the map phase, for a text with n different words, n intermediate result lists exist
 - Each intermediate result list contains as many 1 entries, as the corresponding word exists in the document

Source: *Jeffrey Dean, Sanjay Ghemawat*. MapReduce: Simplified Data Processing on Large Clusters. 2004

Example: Distributed Frequency Analysis with MapReduce (4/9)

```
Text = "Fest gemauert in der Erden  
steht die Form, aus Lehm gebrannt.  
Heute muß die Glocke werden,  
frisch, Gesellen, seid zur Hand.  
Von der Stirne heiß  
rinnen muß der Schweiß,  
soll das Werk den Meister loben,  
doch der Segen kommt von oben."
```

- The text is split into sentences
- It is also useful to convert all uppercase characters to lowercase characters and to remove the punctuation symbols

```
Input_list = [ (sentence_1, "fest gemauert in der erden steht die form aus lehm gebrannt"),  
               (sentence_2, "heute muß die glocke werden frisch gesellen seid zur hand"),  
               (sentence_3, "von der stirne heiß rinnen muß der schweiß soll das werk den meister loben  
                           doch der segen kommt von oben") ]
```

- The input list contains three key-value pairs
 - Therefore 3 map processes can be started

```
Process_1 = map(sentence_1, "fest gemauert in der erden steht die form aus lehm gebrannt")  
Process_2 = map(sentence_2, "heute muß die glocke werden frisch gesellen seid zur hand")  
Process_2 = map(sentence_3, "von der stirne heiß rinnen muß der schweiß soll das werk den meister loben  
                           doch der segen kommt von oben") ]
```

Source of this example: <http://de.m.wikipedia.org/wiki/MapReduce>

Example: Distributed Frequency Analysis with MapReduce (5/9)

- The map processes generate lists with intermediate result pairs:

```
P1 = [ ("fest", 1), ("gemauert", 1), ("in", 1), ("der", 1), ("erden", 1), ("steht", 1), ("die", 1),
      ("form", 1), ("aus", 1), ("lehm", 1), ("gebrannt", 1) ]
P2 = [ ("heute", 1), ("muß", 1), ("die", 1), ("glocke", 1), ("werden", 1), ("frisch", 1), ("gesellen", 1),
      ("seid", 1), ("zur", 1), ("hand", 1) ]
P3 = [ ("von", 1), ("der", 1), ("stirne", 1), ("heiß", 1), ("rinnen", 1), ("muß", 1), ("der", 1),
      ("schweiß", 1), ("soll", 1), ("das", 1), ("werk", 1), ("den", 1), ("meister", 1), ("loben", 1),
      ("doch", 1), ("der", 1), ("segnet", 1), ("kommt", 1), ("von", 1), ("oben", 1) ]
```

- Each map worker sorts its local list of the intermediate result pairs
 - This is carried out by the MapReduce framework automatically
- Next, each map worker groups inside its local list of intermediate result pairs those key-value pairs, which have the same key
 - This is carried out by the MapReduce framework automatically too

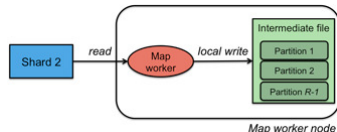
Sources: <https://www.inkling.com/read/hadoop-definitive-guide-tom-white-3rd/chapter-6/shuffle-and-sort>
and <http://de.m.wikipedia.org/wiki/MapReduce>

Example: Distributed Frequency Analysis with MapReduce (6/9)

- The following output shows the result of the map phase

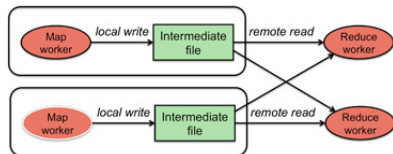
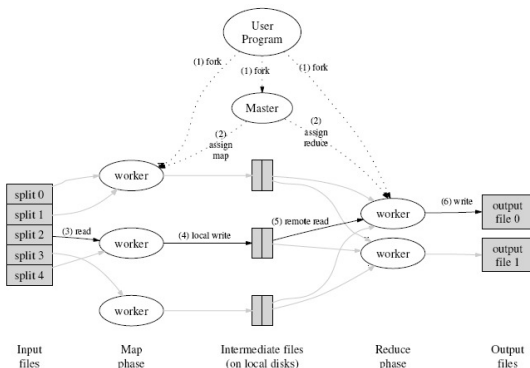
```
P1 = [ ("aus", 1), ("in", 1), ("der", 1), ("die", 1), ("erden", 1), ("fest", 1), ("form", 1),
      ("gebrannt", 1), ("gemauert", 1), ("lehm", 1), ("steht", 1) ]
P2 = [ ("die", 1), ("frisch", 1), ("gesellen", 1), ("glocke", 1), ("hand", 1), ("heute", 1), ("muß", 1),
      ("seid", 1), ("werden", 1), ("zur", 1) ]
P3 = [ ("das", 1), ("den", 1), ("der", (1, 1, 1)), ("doch", 1), ("heiß", 1), ("kommt", 1), ("loben", 1),
      ("meister", 1), ("muß", 1), ("oben", 1), ("rinnen", 1), ("schweiß", 1), ("segne", 1), ("soll", 1),
      ("stirne", 1), ("von", (1, 1)), ("werk", 1) ]
```

- The result of this phase is the intermediate result of MapReduce
 - Each map process stores its intermediate result to a local file
 - Each key-value pair in the intermediate result is called *partition*
- Each map worker informs the master about the file name with the intermediate result and the partitions
- If all map processes have finished execution, the shuffle phase starts



Example: Distributed Frequency Analysis with MapReduce (7/9)

- The master allocates partitions and file names with intermediate results on map workers to the individual reduce workers



- Each reduce worker accesses via Remote Procedure Calls the files to receive the intermediate results
- Next, it sorts the key-value pairs according to their keys

Sources: Jeffrey Dean, Sanjay Ghemawat. MapReduce: Simplified Data Processing on Large Clusters. 2004 and <http://www.cs.rutgers.edu/~pxk/417/notes/content/mapreduce.html>

Reduce function

```
1 reduce(String key, Iterator values):
2     // key: a word
3     // values: a list of counts
4 for 'word'
5     int result = 0;
6     for each v in values:
7         result += ParseInt(v);
8     Emit(AsString(result));
```

- reduce is executed for each word key and for the intermediate result list values
- reduce adds all numbers

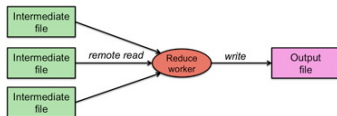
- Using the example of key "der":

Input:

Output:

```
P1 = [ ("der", 1) ]
P3 = [ ("der", (1, 1, 1)) ]
```

```
Output = [ ("der", 4) ]
```



Sources: *Jeffrey Dean, Sanjay Ghemawat*. MapReduce: Simplified Data Processing on Large Clusters. 2004 and <http://www.cs.rutgers.edu/~pxk/417/notes/content/mapreduce.html>

Country	Year	Population (millions)	Urban population (millions)	Urban population (%)	Population growth rate (%)	Urban population growth rate (%)	Population density (per sq km)	Urban population density (per sq km)	Population density (per sq km)	Urban population density (per sq km)
Algeria	1980	10.5	4.5	42.9	1.8	2.5	10.5	4.5	10.5	4.5
Algeria	1985	11.5	5.5	47.8	2.5	3.5	11.5	5.5	11.5	5.5
Algeria	1990	12.5	6.5	52.0	3.2	4.5	12.5	6.5	12.5	6.5
Algeria	1995	13.5	7.5	55.6	3.9	5.5	13.5	7.5	13.5	7.5
Algeria	2000	14.5	8.5	58.6	4.6	6.5	14.5	8.5	14.5	8.5
Algeria	2005	15.5	9.5	61.3	5.3	7.5	15.5	9.5	15.5	9.5
Algeria	2010	16.5	10.5	63.6	6.0	8.5	16.5	10.5	16.5	10.5
Algeria	2015	17.5	11.5	65.7	6.7	9.5	17.5	11.5	17.5	11.5
Algeria	2020	18.5	12.5	67.6	7.4	10.5	18.5	12.5	18.5	12.5
Algeria	2025	19.5	13.5	69.2	8.1	11.5	19.5	13.5	19.5	13.5
Algeria	2030	20.5	14.5	70.7	8.8	12.5	20.5	14.5	20.5	14.5
Algeria	2035	21.5	15.5	72.1	9.5	13.5	21.5	15.5	21.5	15.5
Algeria	2040	22.5	16.5	73.3	10.2	14.5	22.5	16.5	22.5	16.5
Algeria	2045	23.5	17.5	74.5	10.9	15.5	23.5	17.5	23.5	17.5
Algeria	2050	24.5	18.5	75.5	11.6	16.5	24.5	18.5	24.5	18.5
Algeria	2055	25.5	19.5	76.5	12.3	17.5	25.5	19.5	25.5	19.5
Algeria	2060	26.5	20.5	77.4	13.0	18.5	26.5	20.5	26.5	20.5
Algeria	2065	27.5	21.5	78.2	13.7	19.5	27.5	21.5	27.5	21.5
Algeria	2070	28.5	22.5	78.9	14.4	20.5	28.5	22.5	28.5	22.5
Algeria	2075	29.5	23.5	79.7	15.1	21.5	29.5	23.5	29.5	23.5
Algeria	2080	30.5	24.5	80.3	15.8	22.5	30.5	24.5	30.5	24.5
Algeria	2085	31.5	25.5	81.0	16.5	23.5	31.5	25.5	31.5	25.5
Algeria	2090	32.5	26.5	81.6	17.2	24.5	32.5	26.5	32.5	26.5
Algeria	2095	33.5	27.5	82.1	17.9	25.5	33.5	27.5	33.5	27.5
Algeria	2100	34.5	28.5	82.6	18.6	26.5	34.5	28.5	34.5	28.5
Algeria	2105	35.5	29.5	83.1	19.3	27.5	35.5	29.5	35.5	29.5
Algeria	2110	36.5	30.5	83.6	20.0	28.5	36.5	30.5	36.5	30.5
Algeria	2115	37.5	31.5	84.0	20.7	29.5	37.5	31.5	37.5	31.5
Algeria	2120	38.5	32.5	84.4	21.4	30.5	38.5	32.5	38.5	32.5
Algeria	2125	39.5	33.5	84.8	22.1	31.5	39.5	33.5	39.5	33.5
Algeria	2130	40.5	34.5	85.2	22.8	32.5	40.5	34.5	40.5	34.5
Algeria	2135	41.5	35.5	85.6	23.5	33.5	41.5	35.5	41.5	35.5
Algeria	2140	42.5	36.5	85.9	24.2	34.5	42.5	36.5	42.5	36.5
Algeria	2145	43.5	37.5	86.2	24.9	35.5	43.5	37.5	43.5	37.5
Algeria	2150	44.5	38.5	86.5						

- Output of the user program

Sources: *Jeffrey Dean, Sanjay Ghemawat*. MapReduce: Simplified Data Processing on Large Clusters. 2004 and <http://www.cs.rutgers.edu/~pxk/417/notes/content/mapreduce.html>

-
- The diagram illustrates the MapReduce process flow:
- map task:** Starts with an **input split**, which is processed by a **map** function. The output is stored in a **buffer in memory**. This buffer is then used for **partition, sort, and spill to disk**, creating **partitions** on disk. A **fetch** operation is shown between the map task and the reduce task.
 - Copy phase:** This phase involves the transfer of data from the map task to the reduce task, represented by a large green arrow.
 - "Sort" phase:** This phase involves the merging of data from the map task into a **merge** operation, which is then stored in a **merge** operation. This phase is labeled as a **mixture of in-memory and on-disk data**.
 - Reduce phase:** This phase involves the **reduce** operation, which takes the merged data and produces the final **output**.
- Additional labels include **Other maps** and **Other reduces**, indicating the broader context of the MapReduce job.

How many times do words exist in a long text?

- **Map-function:** Writes $\langle \text{Word}, 1 \rangle$ into an intermediate memory
- **Reduce-function:** Sums the values of a word to $\langle \text{Word}, \text{Sum} \rangle$

Which lines of text contain a search pattern?

- **Map-function:** Writes rows detected into an intermediate memory
- **Reduce-function:** Forwards the intermediate results for output through

- **Map-function:** Scans the web server log data and writes key-value pairs

- **Map function:** Scans the web server log data and writes key value pairs $\langle \text{URL}, 1 \rangle$ into an intermediate memory
- **Reduce-function:** Sums the values for an URL to $\langle \text{URL}, \text{Sum} \rangle$

Google PageRank

- The PageRank algorithm rates linked documents (web pages)
- Developed and patented by Larry **Page** and Sergei Brin
- Basis of the Google search engine for the ranking of web pages
- Principle: The numerical weight (**PageRank**) PR_p of a web page p depends of the number and the numerical weight of the web pages, which refer to p

PageRank Algorithm

Source: Lars Kolb (Universität Leipzig) and Wikipedia

- PR_p = PageRank of a web page p
- $L_{IN}(p)$ = Set of documents, which refer to p
 \implies incoming links
- $L_{OUT}(p)$ = Set of documents, to which p refers
 \implies outgoing links

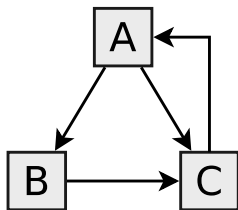
$$PR(p) = (1 - d) + d * \sum_{p_i \in L_{IN}(p)} \frac{PR(p_i)}{\text{amount } L_{OUT}(p_i)}$$

- d = damping factor between 0 and 1 (usually 0.85)
 - A small portion of the weight $(1 - d)$ is withdrawn from any web page and distributed equally among all detected web pages
 - This prevents, that the weight *flows away* to websites, which do not contain links to other websites

Source: http://dbs.uni-leipzig.de/file/CDM_WS_2013_14_03_MapReduce.pdf

PageRank Example

Source: Lars Kolb (Universität Leipzig)



$$PR(p) = (1 - d) + d * \sum_{p_i \in L_{IN}(p)} \frac{PR(p_i)}{\text{amount } L_{OUT}(p_i)}$$

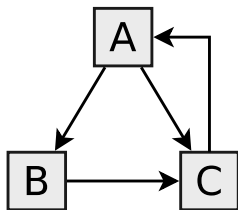
- $PR(A) = (1 - d) + d * PR(C)$
- $PR(B) = (1 - d) + d * \frac{PR(A)}{2}$
- $PR(C) = (1 - d) + d * (\frac{PR(A)}{2} + PR(B))$

- Conversion to iteration equations with $d = 0.5$:
- $PR_{n+1}(A) = 0.5 + 0.5 * PR_n(C)$
- $PR_{n+1}(B) = 0.5 + 0.5 * \frac{PR_n(A)}{2}$
- $PR_{n+1}(C) = 0.5 + 0.5 * (\frac{PR_n(A)}{2} + PR_n(B))$
- Result of the iteration with $PR_0(A) = PR_0(B) = PR_0(C) = 1$

	0	1	2	3	4	5	6	PR
A	1							
B	1							
C	1							

PageRank Example (Result)

Source: Lars Kolb (Universität Leipzig)



- For examples with just a few documents, < 10 iterations are required to compute the PageRank of the documents
- For calculating the PageRank for the entire WWW, around 100 iterations are required

- Conversion to iteration equations with $d = 0.5$:
- $PR_{n+1}(A) = 0.5 + 0.5 * PR_n(C)$
- $PR_{n+1}(B) = 0.5 + 0.5 * \frac{PR_n(A)}{2}$
- $PR_{n+1}(C) = 0.5 + 0.5 * (\frac{PR_n(A)}{2} + PR_n(B))$
- Result of the iteration with $PR_0(A) = PR_0(B) = PR_0(C) = 1$

	0	1	2	3	4	5	6	PR
A	1	1	1.125	1.0625	1.078125	1.078125	1.076171875	1.077
B	1	0.75	0.75	0.78125	0.765625	0.76953125	0.76953125	0.769
C	1	1.25	1.125	1.15625	1.15625	1.15234375	1.154296875	1.154

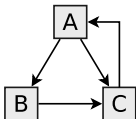
PageRank and MapReduce

Source: Lars Kolb (Universität Leipzig)

- PageRank can be parallelized because:
 - Iteration $n + 1$ depends only of the values of iteration n
 - The calculations of the PR values of different documents are independent of each other
- Map phase:
 - Input: Document X , PR_n , **outgoing** links $L_{OUT}(X)$
 - Calculate for each link $X \rightarrow Y$ the *sum component*, which X contributes for Y
 \Rightarrow Output: $Y, \frac{PR_n(X)}{\text{amount } L_{OUT}(X)}$
 - Additional output: List of outgoing links: $X, L_{OUT}(X)$
- Reduce phase:
 - Input: Document X , sum components of the **incoming** links and the list of outgoing links $X, L_{OUT}(X)$
 - Calculate PR_{n+1}
 - Output: $X, PR_{n+1}, L_{OUT}(X)$
- A predetermined number of iterations is carried out

PageRank and MapReduce – Example

Source: Lars Kolb (Universität Leipzig)

X, PR_n, list of outgoing links in X

For each outgoing link $X \rightarrow Y$:
Y, PR(X)/amount of outgoing links in X

Additionally:
X, list of outgoing links in X

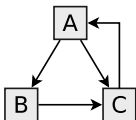
For each incoming link to X:
X, sum component of the incoming link

Additionally:
X, list of outgoing links in X

X, PR_{n+1}, list of outgoing links in XI
T
E
R
A
T
I
O
N
1M
A
PS
H
U
F
F
L
ER
E
D
U
C
EI
T
E
R
A
T
I
O
N
2M
A
PS
H
U
F
F
L
ER
E
D
U
C
E

PageRank and MapReduce – Result

Source: Lars Kolb (Universität Leipzig)

X, PR_n, list of outgoing links in X

For each outgoing link $X \rightarrow Y$:
Y, PR(X)/amount of outgoing links in X

Additionally:
X, list of outgoing links in X

For each incoming link to X:
X, sum component of the incoming link

Additionally:
X, list of outgoing links in X

X, PR_{n+1}, list of outgoing links in XI
T
E
R
A
T
I
O
N
1

A, 1, (B,C)

B, 1, C

C, 1, A

M
A
PB, 0.5
C, 0.5
A, B, CC, 1
B, CA, 1
C, AS
H
U
F
F
L
EA, 1
A, B, CB, 0.5
B, CC, 0.5
C, 1
C, AR
E
D
U
C
E

A, 1, (B,C)

B, 0.75, C

C, 1.25, A

I
T
E
R
A
T
I
O
N
2

A, 1, (B,C)

B, 0.75, C

C, 1.25, A

M
A
PB, 0.5
C, 0.5
A, B, CC, 0.75
B, CA, 1.25
C, AS
H
U
F
F
L
EA, 1.25
A, B, CB, 0.5
B, CC, 0.5
C, 0.75
C, AR
E
D
U
C
E

A, 1.125, (B,C)

B, 0.75, C

C, 1.125, A

Hadoop – Components and Extensions

- **Hadoop Distributed File System** (HDFS)
- **Pig**: Database language of Yahoo
- **Hive**: Data Warehouse of Facebook
- **HBase**: Database for managing very large amounts of data
- This is just a selection of popular components/extensions
 - Further extensions, such as Chukwa and ZooKeeper exist
 - Chukwa is used for real-time monitoring of very large distributed systems
 - ZooKeeper simplifies the configuration of distributed systems

Good introduction to Pig and Hive in German language

Ralf Falk, David Knaak, Michael Köster, Marko Salchow

http://wiki.fh-stralsund.de/index.php/Vergleich_Hive_vs._Pig

Hadoop Distributed File System (HDFS)

- Hadoop contains that Hadoop Distributed File System (HDFS)
 - Open-Source re-implementation of the Google File System (GFS)
 - Fault-tolerant, distributed file system

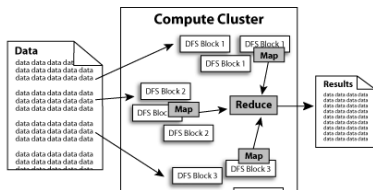


Image source:

<http://hadoop.apache.org>

Further details:

<http://hadoop.apache.org/hdfs/>

- The Google Clusters consist of low-cost commodity hardware
 - Failure of individual nodes is not an exception, but rather the usual case
 ⇒ Fault tolerance is an important goal of GFS and HDFS
 - New nodes can be added easily
 - Amounts of data in the petabyte range need to be managed

Helpful Source: Ghemawat, Gobioff, Leung. The Google file system (2003)

Architecture of HDFS (follows the Master/Slave Principle)

- **Namenode** (Master) stores the metadata, and reacts to failures
 - Exists exactly one time in a HDFS Cluster
⇒ Single Point of Failure
 - Does not store any user data, but only metadata
 - Knows all files and directories, which exist in the HDFS Cluster
 - Stores the numbers of chunks of the files, the number of copies and their locations (Datanodes)
 - Monitors the availability of the individual Datanodes, and redistributes the chunks, in case a Datanode fails
- **Datanodes** (Slaves) only store the user data
 - Special feature of HDFS and GFS: Chunk size is 64 MB
 - The resulting internal fragmentation is accepted for the benefit of a lower network overhead
- **Clients** communicate with the Namenode and the Datanodes
 - The Namenode only operates as a directory service
 - Provides the information, on which Datanodes, a searched file is stored
 - Read and write requests send Clients directly to the Datanodes

Security against Data Loss at HDFS

HDFS Architecture

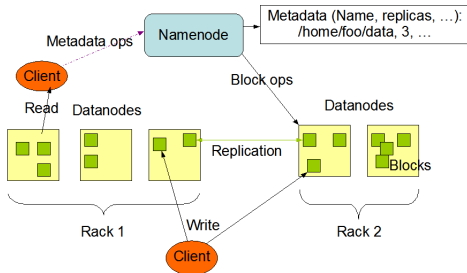


Image source:

http://hadoop.apache.org/common/docs/current/hdfs_design.html

- Datanodes inform the Namenode regularly via heartbeat about their existence
 - If a Namenode does not receive any more messages of a Datanode, the Namenode declares the Datanode as failed
 - Next, the Namenode orders the replication of the affected Chunks, in order not to fall below the minimum number of replications

Read Accesses at HDFS

- The HDFS client calls a web service (for read access) on the Namenode with the desired filename as a parameter
- The Namenode checks the namespace, to find out which Datanodes store the chunks
 - The namespace resides inside the main memory of the Namenode
- The Namenode provides the Client:
 - Unique 64-bit identifiers (*chunk handles*) of the chunks on the Datanodes
 - a list of Datanodes, which store the chunks
- The HDFS client calls the web service of one or more Datanodes, to obtain the user data
- By using the 64-bit identifiers, the Datanodes read the HDFS chunks on their HDD and transfer them as the result to the client

Write Accesses at HDFS (1/2)

- The HDFS client calls a web service (for write access) on the Namenode with the desired filename as a parameter
- The Namenode checks, if the client has write permissions and if the file already exists
 - If the verifications for the client are positive, the Namenode stores the meta-information of the file in the namespace
 - If the file already exists, or if the client does not have write permissions, the Namenode interrupts the process with an exception
- It is impossible to overwrite files in HDFS
 - Overwriting files is only possible by deleting and re-creating them
- The client splits the file to be stored into chunks and places them in a local a queue
- For each chunk in the queue, the client calls the web service interface of the Namenode, which returns a list of Datanodes, to store the chunk
 - Additionally, the client receives an identifier for the chunk

Write Accesses at HDFS (2/2)

- The choice of the Datanodes to store a chunk depends on the configuration
 - Several configuration options exist, e.g. the definition of racks to join physically neighboring servers to a virtual rack (\implies *rack-awareness*)
 - Objective: Reduce network traffic
- The HDFS client transmits the chunk and the list of Datanodes to a single Datanode, which stores them locally with the identifier
- After the successful transmission of the chunk, the Datanode forwards the chunk to another Datanode in the list, to get the chunk stored there too
 - This process is repeated with another Datanode from the list, until the specified number of chunk replications is reached

File system alternatives in Hadoop

It is not absolutely necessary to use HDFS. Alternatives are among others S3 and FTP

Secondary Namenode at HDFS

- In order to ensure data integrity and a fast restart of the Namenode after a failure, the secondary Namenode exists
 - It can not replace the Namenode in case of failure
- The Secondary Namenode never communicates with the clients
- The Namenode stores the metadata in form of an image (= namespace), and a list of transactions which need to be applied to the image
 - In case the Namenode fails, it needs to virtually carry out all the transactions on the image to obtain the latest state
 - That takes a long time for large file systems
- The Secondary Namenode stores the image (namespace) as backup in intervals
- If the the Namenode fails, during reboot, it can fetch the latest image checkpoint from the Secondary Namenode

Image Source: Google



Pig (1/2)

- Can be used for the analysis of very large amounts of semi-structured, structured or relational data
 - Includes a programming language and a compiler for queries on data
- The programming language is Pig Latin
 - Pig Latin is called a *Dataflow Language*
 - It is used to specify sequences of individual transformations on data
 - Thus, doing ad-hoc analyzing of large amounts of data is possible
- The compiler translates Pig Latin statements into MapReduce jobs
 - Pig also orchestrates the execution of the jobs in the Hadoop Cluster
- Pig is used with the Pig shell (Grunt)
 - Grunt can also load scripts to execute commands in batch mode

Pig (2/2)

- Pig reads all data formats, regardless of their structure
 - By default, Pig expects the data as plain text and tab separated
 - For the interpretation of different formatted data, the users can specify User Defined Functions (UDF)
 - With UDF, users can integrate own code into Pig programs
 - Apache offers with Piggybank an open repository
<http://svn.apache.org/repos/asf/pig/trunk/contrib/piggyban>
 - UDFs are written in Java and integrated as a JAR file into Pig
- Advantage of Pig: Reduced complexity compared to MapReduce queries

Pig Commands

Command	Meaning
load	Read data from the file system
store	Write data into the file system
foreach	Apply an expression to all records
filter	Discard all records, which do not match the filter rules
group/cogroup	Collect records with the same key from one or more input sources
join	Combine two or more input sources according to a key
order	Sort records according to a key
distinct	Erase duplicate records
union	Merge two records
split	Split data into two or more records, using filter rules
stream	Transfer all records to a specified binary file
dump	Write the output to stdout
limit	Limit the number of records



Source: Introduction to Pig. Cloudera (2009)
http://www.cloudera.com/videos/introduction_to_pig

Example of a Job in Pig Latin

- This example shows the complexity reduction of MapReduce queries compared to Pig Latin queries
 - Query for the 5 most frequently visited web pages from people, which are 18-25 years old
 - The user information and data of the web pages are located in 2 different files

```

Users    = load 'users' as (name, age);
Filtered = filter Users by
              age >= 18 and age <= 25;
Pages    = load 'pages' as (user, url);
Joined   = join Filtered by name, Pages by user;
Grouped  = group Joined by url;
Summed   = foreach Grouped generate group,
              count(Joined) as clicks;
Sorted   = order Summed by clicks desc;
Top5     = limit Sorted 5;

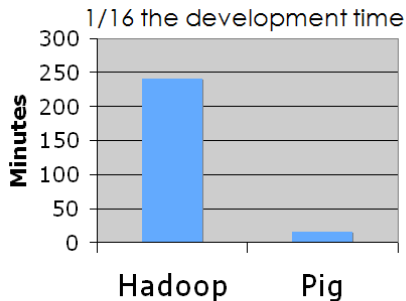
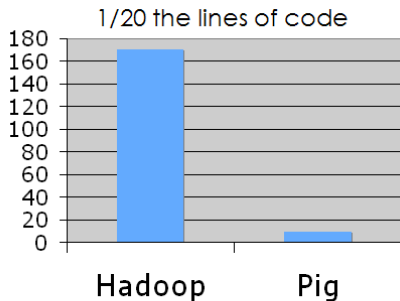
store Top5 into 'top5sites';

```

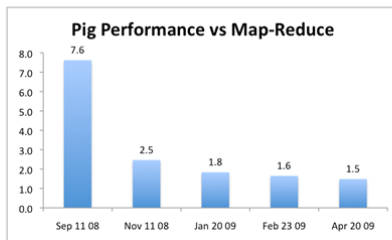
Source of the example and the images: ApacheCon Europe 2009

[illegible]

Savings because of using Pig



Performance:
1.5x Hadoop



Pig – Helpful Summary of Cloudera

Pig Latin

```
A = LOAD 'myfile'
  AS (x, y, z);
B = FILTER A by x > 0;
C = GROUP B BY x;
D = FOREACH A GENERATE
  x, COUNT(B);
STORE D INTO 'output';
```



pig.jar:

- parses
- checks
- optimizes
- plans execution
- submits jar to Hadoop
- monitors job progress

Execution Plan

Map:

Filter

Reduce:

Count



Hive

- Data warehouse system on the basis of Hadoop
- A data warehouse. . .
 - is a data collection site in form of a database
 - obtains data from different sources (e.g. other databases)
- Data model is analogous to relational database systems with tables
 - Payload stores Hive in HDFS
 - Tables are represented by folder in HDFS
 - The data inside the tables are stored serialized in files inside the folders
 - Metadata is stored in the relational database Metastore
- Supports different column types (e.g. integer, string, date, boolean)
- For Queries, the declarative language HiveQL is used
 - Query language which provides a SQL-like syntax
 - Hive translates HiveQL statements into MapReduce jobs
 - Hive also orchestrates the execution of the jobs in the Hadoop Clusters
- Controlled via a command line interface, web interface or JDBC/ODBC interface



Load Text Data into Hive Tables and analyze them

- For each access to a web server, these information is recorded:
 - Hostname or IP address of the accessing client
 - Date and time
 - Time zone
 - File
 - Result of the access (HTTP status message)
 - Bytes transferred

```
client.anbieter.de - - [08/Oct/2010:22:35:51 -0100] "GET /pfad/index.html HTTP/1.1" 200 1832
```

- Import log data from `access.log` into a table:
- Print the first 20 rows of the tables, sorted according the IP addresses:
- Print all records, which contain the IP address 84.171.184.103:

```
LOAD DATA LOCAL INPATH 'access.log' OVERWRITE INTO TABLE apachelog;
```

```
SELECT * FROM apachelog SORT BY ipaddress LIMIT 20;
```

```
SELECT * FROM apachelog WHERE ipaddress = '84.171.184.103';
```

Source: Ramin Wartala. Analyse großer Datenmengen mit Hive. iX 12/2010

Hive Examples

(Source: <http://wiki.apache.org/hadoop/Hive/LanguageManual/DDL>)

- Create table `page_view`:

```
CREATE TABLE page_view(viewTime INT, userid BIGINT,
    page_url STRING, referrer_url STRING,
    ip STRING COMMENT 'IP Address of the User')
COMMENT 'This is the page view table'
PARTITIONED BY(dt STRING, country STRING)
ROW FORMAT DELIMITED
    FIELDS TERMINATED BY '\001'
    LINES TERMINATED BY '\012'
STORED AS SEQUENCEFILE;
```

- Erase table:

```
DROP TABLE [IF EXISTS] table_name
```

- Print table name:

```
SHOW TABLES identifier_with_wildcards
```

- Print partitions of a table:

```
SHOW PARTITIONS table_name
```

- Rename table:

```
ALTER TABLE table_name RENAME TO new_table_name
```

- Add or replace columns:

```
ALTER TABLE table_name ADD|REPLACE COLUMNS (col_name data_type [COMMENT col_comment], ...)
```

Distinction between Pig and Hive

Criterion	Pig	Hive
Typical application scenarios	logfile analysis	logfile analysis, data mining, web analytics in real time, data warehousing
Objectives	simplification of MapReduce queries with a scripting language	simplification of MapReduce with a SQL style
Query language	Pig Latin (procedural)	HiveQL9 (declarative)
Metadata	none	stored in Metastore
User interfaces	command line interface (Grunt)	command line interface, web interface
Export interfaces	none	ODBC/JDBC
Input data structure	unstructured	structured
Input data formats	raw data	raw data
Output data formats	raw data	raw data
Main developer	Yahoo	Facebook

Source: http://wiki.fh-stralsund.de/index.php/Vergleich_Hive_vs._Pig

HBase

<http://hbase.apache.org>

- Column-oriented database to manage very large amounts of data in Hadoop Clusters
 - Suited for large amounts of data, which are rarely changed, but often added with additional data
 - Suited for billions of rows and millions of columns, distributed over many servers from commodity hardware
- Free re-implementation of Google BigTable
 - Googles BigTable runs on top of the GFS
 - HBase runs on top of HDFS (free re-implementation of the GFS)

Chang, Dean, Ghemawat, Hsieh, Wallach, Burrows, Chandra, Fikes, Gruber.
Bigtable: A Distributed Storage System for Structured Data. Google (2006)
<http://labs.google.com/papers/bigtable-osdi06.pdf>

Hadoop Success Stories

(<http://wiki.apache.org/hadoop/PoweredBy>)

- **EBay**

- Clusters with 532 nodes (4,256 CPU cores, 5.3 PB memory)
- Task: Optimization of the search functionality

- **Facebook**

- Clusters with 1,100 nodes (8,800 CPU cores, 12 PB memory)
- Clusters with 300 nodes (2,400 CPU cores, 3 PB memory)
- Task: Log data storage and analysis

- **Last.fm**

- Clusters with 44 nodes (352 CPU cores, 176 PB memory)
- Task: Log data storage and analysis, calculation of charts

- **Twitter**

- Task: Log data storage and analysis, storing the Tweets

- **Yahoo**

- Multiple Clusters, together with > 40,000 nodes and > 100,000 CPUs
- Largest Cluster: 4,500 nodes (each with 8 CPUs and 4 TB Storage)
- Task: Web search and advertising
- Further information: <http://developer.yahoo.com/blogs/hadoop/>

Hadoop and IBM Watson vs. Mankind

FEBRUARY 18, 2011

6:44 PM, UTC | LAST UPDATED: FEBRUARY 25, 2011 AT: 9:49 PM, UTC

Watson Powered by Apache Hadoop Defeated Jeopardy! Defenders Ken Jennings and Brad Rutter

This week on 17th, IBM's supercomputer, Watson (named after IBM's founder, Thomas J. Watson), took on two of the most championed Jeopardy! contestants of all time in an exhilarating \$1 million Jeopardy! face-off between man and machine.

Watson defeated Jeopardy! defenders Ken Jennings and Brad Rutter, amassing \$77,147 in winnings in a nail-biting three-night tournament that sparked interest around the field of artificial intelligence and data analytics.



IBM explained, that by matching the text in a question to the text in its vast memory, Watson can analyze and recite an accurate answer in less than three seconds. If there's no match in Watson's "brain," it takes a guess based on a confidence level that's calculated on probabilities.

So what makes Watson's genius possible? A whole lot of storage, sophisticated hardware, super fast processors and **Apache Hadoop, the open source technology pioneered by Yahoo! and at the epicenter of big data and cloud computing.**

Hadoop was used to create Watson's "brain," or the database of knowledge and facilitation of Watson's processing of enormously large volumes of data in milliseconds. Watson depends on 200 million pages of content and 500 gigabytes of preprocessed information to answer Jeopardy questions. That huge catalog of documents has to be searchable in seconds. On a single computer, it would be impossible to do, but by using Hadoop and dividing the work on to many computers it can be done.

<http://www.ditii.com/2011/02/18/watson-powered-by-apache-hadoop-defeated-jeopardy-defenders-ken-jennings-and-brad-rutter/>

Cloudera

<http://www.cloudera.com>

- Cloudera is a powerful Hadoop distribution
 - Contains Hadoop and among others the programming language Pig, the SQL database Hive, the columns-oriented database HBase, Apache Zookeeper and Hadoop browser frontend Hue
 - Packages for Debian, Ubuntu, RedHat and SuSE are available
- 03/2009: Cloudera's Distribution for Hadoop (CDH1)
- 03/2009: \$5 Millions venture capital from Accel Partners
- 06/2009: \$11 Millions venture capital from Greylock Partners
- 08/2009: Doug Cutting leaves Yahoo and becomes an employee of Cloudera
- 10/2010: \$25 Millions venture capital from Meritech Capital Partners
- 03/2013: Intel invests \$740 Millions for an 18% investment



Current version of Cloudera's Distribution for Hadoop (State: January 2018)

<https://www.cloudera.com/downloads/cdh/5-13-1.html>

Install Cloudera (CDH3) in Ubuntu 10.10 (1/2)

- These instructions install a Cluster on a single node
 - **Pseudo Distributed Mode**
- These instructions base of <http://cloudera-tutorial.blogspot.com>
- Start an instance with Ubuntu 10.10 (ami-08f40561) in US-East
- Allow access via the ports 22, 50030 und 50070 in the security group
 - DNS: `ec2-50-17-58-144.compute-1.amazonaws.com`
- Insert the package sources in
`/etc/apt/sources.list.d/cloudera.list`
`$ sudo add-apt-repository "deb http://archive.canonical.com/ubuntu maverick partner"`
`$ sudo add-apt-repository "deb http://archive.cloudera.com/debian maverick-cdh3 contrib"`
- Import the key of the Cloudera repository
`$ sudo curl -s http://archive.cloudera.com/debian/archive.key | sudo apt-key add -`
- Install packages
`$ sudo apt-get update`
`$ sudo apt-get install sun-java6-jdk`
`$ sudo apt-get install hadoop-0.20-conf-pseudo`
- Start Cloudera services
`$ for service in /etc/init.d/hadoop-0.20-*; do sudo $service start; done`

Install Cloudera (CDH3) in Ubuntu 10.10 (2/2)

- Check, which files Cloudera did install

```
$ dpkg -L hadoop-0.20-conf-pseudo
```

- Check, if the Cloudera services are running

```
$ sudo jps
2232 SecondaryNameNode
2539 Jps
1994 DataNode
2074 JobTracker
2154 NameNode
2317 TaskTracker
```

- If the list of services is complete, the installation was successful!

- Web interface of the Namenode

```
http://ec2-50-17-58-144.compute-1.amazonaws.com:50070
```

- Web interface of the Job Trackers

```
http://ec2-50-17-58-144.compute-1.amazonaws.com:50030
```

- Terminate the Cloudera services

```
$ for x in /etc/init.d/hadoop-* ; do sudo $x stop ; done
```

Web Interface of the Namenode



NameNode 'localhost:8020'

Started:	Mon Jun 06 19:16:23 UTC 2011
Version:	0.20.2-cdh3u0, r81256ad0f2e4ab2bd34b04f53d25a6c23686dd14
Compiled:	Sat Mar 26 00:14:04 UTC 2011 by root
Upgrades:	There are no upgrades in progress.

[Browse the filesystem](#)
[NameNode Logs](#)

Cluster Summary

46 files and directories, 70 blocks = 116 total. Heap Size is 141.19 MB / 888.94 MB (15%)

Configured Capacity	:	9.84 GB
DFS Used	:	390.57 KB
Non DFS Used	:	1.4 GB
DFS Remaining	:	8.44 GB
DFS Used%	:	0 %
DFS Remaining%	:	85.75 %
Live Nodes	:	1
Dead Nodes	:	0
Decommissioning Nodes	:	0
Number of Under-Replicated Blocks	:	1

NameNode Storage:

Storage Directory	Type	State
/var/lib/hadoop-0.20/cache/hadoop/dfs/name	IMAGE_AND_EDITS	Active

[Cloudera's Distribution including Apache Hadoop, 2011.](#)

Web Interface of the Job Tracker

Datei Bearbeiten Ansicht Chronik Lesezeichen Extras Hilfe

http://ec2-50-17-58-144.compute-1.amazonaws.com:50030/jobtracker.jsp Google.de

localhost Hadoop Map/Reduce Administration

State: RUNNING
 Started: Mon Jun 06 19:16:27 UTC 2011
 Version: 0.20.2-ubuntu r11254ad024cab2b394b4f59425af6c29686d434
 Compiled: Sat Mar 26 00:34:04 UTC 2011 by rsr
 Identifier: 201106061916

Cluster Summary (Heap Size is 109.38 MB/888.94 MB)

Running Map Tasks	Running Reduce Tasks	Total Submissions	Nodes	Occupied Map Slots	Occupied Reduce Slots	Reserved Map Slots	Reserved Reduce Slots	Map Task Capacity	Reduce Task Capacity	Avg. Tasks/Node	Blacklisted Nodes	Excluded Nodes
0	0	6	1	0	0	0	0	2	2	4.00	0	0

Scheduling Information

Queue Name	State	Scheduling Information
default	running	N/A

Filter (Jobid, Priority, User, Name)

Example: 'user:smith 3200' will filter by 'smith' only in the user field and '3200' in all fields

Running Jobs

Completed Jobs

Jobid	Priority	User	Name	Map % Complete	Map Total	Maps Completed	Reduce % Complete	Reduce Total	Reduces Completed	Job Scheduling Information	Diagnostic Info
job_201106061916_0001	NORMAL	ubuntu	PIEstimator	100.00%	5	5	100.00%	1	1	NA	NA
job_201106061916_0002	NORMAL	ubuntu	grep-search	100.00%	7	7	100.00%	1	1	NA	NA
job_201106061916_0003	NORMAL	ubuntu	grep-sort	100.00%	1	1	100.00%	1	1	NA	NA
job_201106061916_0004	NORMAL	ubuntu	grep-search	100.00%	7	7	100.00%	1	1	NA	NA
job_201106061916_0005	NORMAL	ubuntu	grep-sort	100.00%	1	1	100.00%	1	1	NA	NA
job_201106061916_0006	NORMAL	ubuntu	grep-search	100.00%	7	7	100.00%	1	1	NA	NA

Retired Jobs

Local Logs

Log directory: job Tracker History

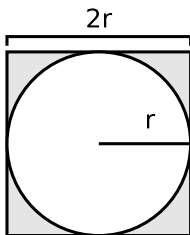
Cloudera's Distribution including Apache Hadoop, 2011.

Simple Examples with the Cloudera Installation (1/5)

● Example for the calculation of π

```
$ hadoop jar /usr/lib/hadoop/hadoop-examples.jar pi 10 100
Number of Maps = 5
Samples per Map = 1000
Wrote input for Map #0
Wrote input for Map #1
Wrote input for Map #2
Wrote input for Map #3
Wrote input for Map #4
Starting Job
11/06/06 19:18:15 INFO mapred.FileInputFormat: Total input paths to process : 5
11/06/06 19:18:16 INFO mapred.JobClient: Running job: job_201106061916_0001
11/06/06 19:18:17 INFO mapred.JobClient: map 0% reduce 0%
11/06/06 19:18:23 INFO mapred.JobClient: map 40% reduce 0%
11/06/06 19:18:27 INFO mapred.JobClient: map 60% reduce 0%
11/06/06 19:18:28 INFO mapred.JobClient: map 80% reduce 0%
11/06/06 19:18:29 INFO mapred.JobClient: map 100% reduce 0%
11/06/06 19:18:36 INFO mapred.JobClient: map 100% reduce 100%
11/06/06 19:18:36 INFO mapred.JobClient: Job complete: job_201106061916_0001
...
11/06/06 19:18:36 INFO mapred.JobClient: Launched reduce tasks=1
...
11/06/06 19:18:36 INFO mapred.JobClient: Launched map tasks=5
...
Job Finished in 20.638 seconds
Estimated value of Pi is 3.14160000000000000000
```

Calculation of π via Monte Carlo Simulation



A = Surface ratio
 r = Radius
 C = Circle
 S = Square

- π can be approximated via Monte Carlo simulation
- Inscribe a circle of radius r inside a square with side length $2r$
- $A_S = (2r)^2 = 4r^2$
- $A_C = \pi r^2 \implies \pi = \frac{A_C}{r^2}$
- How can we approximate π ?

- 1 Generate random dots in the square
- 2 The number of dots in A_C in relation to the number of dots in A_S is equal to the surface ratio

$$\frac{A_C}{A_S} = \frac{\pi r^2}{4r^2} \implies \frac{A_C}{A_S} = \frac{\pi}{4} \implies 4 * \frac{A_C}{A_S} = \pi$$

- The dots can be generated in parallel by the workers
- The master receives the dots and calculates π

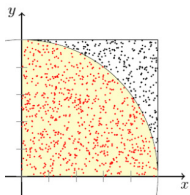


Image source: Wikipedia

Calculation of π via MapReduce

```
1 NUMPOINTS = 100000; // some large number - the bigger, the closer the approximation
2
3 p = number of WORKERS;
4 numPerWorker = NUMPOINTS / p;
5 countCircle = 0; // one of these for each WORKER
6
7 // each WORKER does the following:
8 for (i = 0; i < numPerWorker; i++) {
9     generate 2 random numbers that lie inside the square;
10    xcoord = first random number;
11    ycoord = second random number;
12    if (xcoord, ycoord) lies inside the circle
13        countCircle++;
14 }
15
16 MASTER:
17     receives from WORKERS their countCircle values
18     computes PI from these values: PI = 4.0 * countCircle / NUMPOINTS;
```

Source: **Introduction to Parallel Programming and MapReduce**

<http://code.google.com/edu/parallel/mapreduce-tutorial.html>

Simple Examples with the Cloudera Installation (2/5)

• grep example

```
$ hadoop-0.20 fs -mkdir input
$ hadoop-0.20 fs -put /etc/hadoop-0.20/conf/*.xml input
$ hadoop-0.20 jar /usr/lib/hadoop-0.20/hadoop-*.examples.jar grep input output 'dfs[a-z.]+'
11/06/06 20:05:49 INFO mapred.FileInputFormat: Total input paths to process : 7
11/06/06 20:05:49 INFO mapred.JobClient: Running job: job_201106061916_0010
11/06/06 20:05:50 INFO mapred.JobClient: map 0% reduce 0%
11/06/06 20:05:55 INFO mapred.JobClient: map 28% reduce 0%
11/06/06 20:05:59 INFO mapred.JobClient: map 42% reduce 0%
11/06/06 20:06:00 INFO mapred.JobClient: map 57% reduce 0%
11/06/06 20:06:02 INFO mapred.JobClient: map 71% reduce 0%
11/06/06 20:06:03 INFO mapred.JobClient: map 85% reduce 0%
11/06/06 20:06:05 INFO mapred.JobClient: map 100% reduce 0%
11/06/06 20:06:10 INFO mapred.JobClient: map 100% reduce 28%
11/06/06 20:06:11 INFO mapred.JobClient: map 100% reduce 100%
11/06/06 20:06:12 INFO mapred.JobClient: Job complete: job_201106061916_0010
...
11/06/06 20:06:12 INFO mapred.JobClient: Launched reduce tasks=1
...
11/06/06 20:06:12 INFO mapred.JobClient: Launched map tasks=7
...
```

Simple Examples with the Cloudera Installation (3/5)

• Output of the grep example

```
$ hadoop fs -ls output
Found 3 items
-rw-r--r--   1 ubuntu supergroup          0 2011-06-06 19:33 /user/ubuntu/output/_SUCCESS
drwxr-xr-x   - ubuntu supergroup          0 2011-06-06 19:32 /user/ubuntu/output/_logs
-rw-r--r--   1 ubuntu supergroup       129 2011-06-06 19:33 /user/ubuntu/output/part-00000
```

• Result of the grep example

```
$ hadoop-0.20 fs -cat output/part-00000
1      dfs.datanode.plugins
1      dfs.name.dir
1      dfs.namenode.plugins
1      dfs.permissions
1      dfs.replication
1      dfs.thrift.address
1      dfsadmin
```

• For control...

```
$ grep dfs[a-z.] /etc/hadoop-0.20/conf/*.xml
/etc/hadoop-0.20/conf/hadoop-policy.xml:    dfsadmin and mradmin commands to refresh the security...
/etc/hadoop-0.20/conf/hdfs-site.xml:    <name>dfs.replication</name>
/etc/hadoop-0.20/conf/hdfs-site.xml:    <name>dfs.permissions</name>
/etc/hadoop-0.20/conf/hdfs-site.xml:    <name>dfs.name.dir</name>
/etc/hadoop-0.20/conf/hdfs-site.xml:    <name>dfs.namenode.plugins</name>
/etc/hadoop-0.20/conf/hdfs-site.xml:    <name>dfs.datanode.plugins</name>
/etc/hadoop-0.20/conf/hdfs-site.xml:    <name>dfs.thrift.address</name>
```

Simple Examples with the Cloudera Installation (4/5)

• Word count example

```
$ hadoop-0.20 fs -mkdir inputwords
$ hadoop-0.20 fs -put /etc/hadoop-0.20/conf/*.xml inputwords
$ hadoop-0.20 jar /usr/lib/hadoop-0.20/hadoop-*.jar wordcount inputwords outputwords
11/06/06 20:46:59 INFO input.FileInputFormat: Total input paths to process : 7
11/06/06 20:46:59 INFO mapred.JobClient: Running job: job_201106061916_0014
11/06/06 20:47:00 INFO mapred.JobClient: map 0% reduce 0%
11/06/06 20:47:05 INFO mapred.JobClient: map 28% reduce 0%
11/06/06 20:47:08 INFO mapred.JobClient: map 42% reduce 0%
11/06/06 20:47:10 INFO mapred.JobClient: map 57% reduce 0%
11/06/06 20:47:11 INFO mapred.JobClient: map 71% reduce 0%
11/06/06 20:47:13 INFO mapred.JobClient: map 85% reduce 0%
11/06/06 20:47:14 INFO mapred.JobClient: map 100% reduce 0%
11/06/06 20:47:17 INFO mapred.JobClient: map 100% reduce 100%
11/06/06 20:47:17 INFO mapred.JobClient: Job complete: job_201106061916_0014
...
11/06/06 20:18:20 INFO mapred.JobClient: Launched reduce tasks=1
...
11/06/06 20:18:20 INFO mapred.JobClient: Launched map tasks=7
...
```

Simple Examples with the Cloudera Installation (5/5)

• Output of the word count example

```
$ hadoop-0.20 fs -ls outputwords
```

```
Found 3 items
```

```
-rw-r--r--    1 ubuntu supergroup          0 2011-06-06 20:47 /user/ubuntu/outputwords/_SUCCESS
drwxr-xr-x    - ubuntu supergroup          0 2011-06-06 20:46 /user/ubuntu/outputwords/_logs
-rw-r--r--    1 ubuntu supergroup    7913 2011-06-06 20:47 /user/ubuntu/outputwords/part-00000
```

• Result of the word count example

```
$ hadoop-0.20 fs -cat outputwords/part-00000
```

```
...
```

```
based    1
be       20
being    1
below    3
below    2
between  1
beyond   1
blank    12
block    1
by       26
...
```

Setting up a Hadoop Cluster with Cloudera CDH3 (1/5)

- This installation guide installs a distributed Hadoop Cluster

- **Distributed Mode (Multi Node Cluster)**

- These instructions base of <http://cloudera-tutorial.blogspot.com>

- Stop running Cloudera services

```
$ for x in /etc/init.d/hadoop-* ; do sudo $x stop ; done
```

- List alternative Hadoop configurations

```
$ update-alternatives --display hadoop-0.20-conf
```

- Copy the default configuration

```
$ sudo cp -r /etc/hadoop-0.20/conf.empty /etc/hadoop-0.20/conf.cluster
```

- Activate the new configuration

```
$ sudo update-alternatives --install /etc/hadoop-0.20/conf hadoop-0.20-conf
/etc/hadoop-0.20/conf.cluster 50
```

- Check the new configuration

```
$ update-alternatives --display hadoop-0.20-conf
```

```
hadoop-0.20-conf - auto mode
```

link currently points to `/etc/hadoop-0.20/conf.cluster`

```
/etc/hadoop-0.20/conf.cluster - priority 50
```

```
/etc/hadoop-0.20/conf.empty - priority 10
```

```
/etc/hadoop-0.20/conf.pseudo - priority 30
```

Current 'best' version is '/etc/hadoop-0.20/conf.cluster'.

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- Start an additional instance (ami-08f40561) (\implies Slave)
 - DNS: ec2-50-17-77-111.compute-1.amazonaws.com
- Insert alias entries for the nodes in /etc/hosts

```
10.122.67.221 ec2-50-17-58-144.compute-1.amazonaws.com master
10.120.69.158 ec2-50-17-77-111.compute-1.amazonaws.com slave1
```
- Install SSH client and server

```
$ sudo apt-get install openssh-server openssh-client
```
- Generate ssh keys to login without a password

```
$ ssh-keygen -t rsa -P ""
```
- Copy SSH key in \$HOME/.ssh/id_rsa.pub to the Slave node into \$HOME/.ssh/authorized_keys
- /etc/hadoop-0.20/conf.cluster/masters
 - One line with the public DNS or alias for each Master (Namenode)
 - If multiple Masters exist (\implies adjust the file masters)
 - In this example, the file masters contains only master

Setting up a Hadoop Cluster with Cloudera CDH3 (3/5)

- `/etc/hadoop-0.20/conf.cluster/slaves`
 - One line with the public DNS or alias for each Slave node
 - Slaves are nodes which run the Datanode and/or Tasktracker services
 - In this example, the file `slaves` contains only `slave1`

- `/etc/hadoop-0.20/conf.cluster/core-site.xml`

```
<configuration>
<property>
  <name>fs.default.name</name>
  <value>hdfs://master:54310</value>
</property>
</configuration>
```

- `/etc/hadoop-0.20/conf.cluster/mapred-site.xml`

```
<configuration>
<property>
  <name>mapred.job.tracker</name>
  <value>master:54311</value>
</property>
</configuration>
```

Setting up a Hadoop Cluster with Cloudera CDH3 (4/5)

- /etc/hadoop-0.20/conf.cluster/hdfs-site.xml

- <value>1</value> is the number of Slaves

```
<configuration>
<property>
  <name>dfs.replication</name>
  <value>1</value>
</property>
</configuration>
```

- Import the package sources and keys on the Slave and install the Hadoop packages

```
$ sudo add-apt-repository "deb http://archive.canonical.com/ubuntu maverick partner"
$ sudo add-apt-repository "deb http://archive.cloudera.com/debian maverick-cdh3 contrib"
$ sudo curl -s http://archive.cloudera.com/debian/archive.key | sudo apt-key add -
$ sudo apt-get update
$ sudo apt-get install sun-java6-jdk
$ sudo apt-get install hadoop-0.20-conf-pseudo
```

- Copy the directory /etc/hadoop-0.20/conf.cluster to the Slave

- On the Master:

```
$ sudo apt-get install zip
$ sudo zip -r conf.cluster.zip /etc/hadoop-0.20/conf.cluster
$ scp conf.cluster.zip slave1:~
```

- On the Slave:

```
$ sudo apt-get install zip
$ sudo unzip -d / conf.cluster.zip
```

Setting up a Hadoop Cluster with Cloudera CDH3 (5/5)

- Insert alias entries for the nodes into `/etc/hosts` on the Slave

```
10.122.67.221 ec2-50-17-58-144.compute-1.amazonaws.com master
10.120.69.158 ec2-50-17-77-111.compute-1.amazonaws.com slave1
```

- Activate new configuration on the slave

```
$ sudo update-alternatives --install /etc/hadoop-0.20/conf hadoop-0.20-conf
/etc/hadoop-0.20/conf.cluster 50
```

- Start the services on all nodes to activate the configuration

```
$ for x in /etc/init.d/hadoop-0.20-*; do sudo $x start; done
```

- Stop the services on all nodes

```
$ for x in /etc/init.d/hadoop-0.20-*; do sudo $x stop ; done
```

- Format the Namenode

```
$ sudo -u hdfs hadoop namenode -format
```

- Start the services on the Master (Namenode)

```
$ sudo /etc/init.d/hadoop-0.20-namenode start
$ sudo /etc/init.d/hadoop-0.20-secondarynamenode start
$ sudo /etc/init.d/hadoop-0.20-jobtracker start
```

- Start the services on the Slave (Datanode)

```
$ sudo /etc/init.d/hadoop-0.20-datanode start
$ sudo /etc/init.d/hadoop-0.20-tasktracker start
```

- If all services start, the installation of the Cluster was successful

Datei
Bearbeiten
Ansicht
Chronik
Lesezeichen
Extras
Hilfe

http://ec2-50-17-58-144.compute-1.amazonaws.com:50070/dfshealth.jsp
Google.de

NameNode 'ec2-50-17-58-144.compute-1.amazonaws.com:54310'

Started:	Tue Jun 07 13:08:30 UTC 2011
Version:	0.20.2-cdh3u0, rB1256ad0f2e4ab2bd34b04f53d25a6c23686dd1.4
Compiled:	Sat Mar 26 00:14:04 UTC 2011 by root
Upgrades:	There are no upgrades in progress.

[Browse the filesystem](#)
[NameNode Logs](#)

Cluster Summary

1 files and directories, 0 blocks = 1 total. Heap Size is 141.19 MB / 888.94 MB (15%)

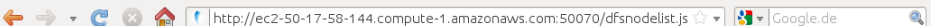
Configured Capacity	:	9.84 GB
DFS Used	:	28 KB
Non DFS Used	:	1.4 GB
DFS Remaining	:	8.44 GB
DFS Used%	:	0 %
DFS Remaining%	:	85.77 %
Live Nodes	:	1
Dead Nodes	:	0
Decommissioning Nodes	:	0
Number of Under-Replicated Blocks	:	0

NameNode Storage:

Storage Directory	Type	State
/tmp/hadoop-hdfs/dfs/name	IMAGE_AND_EDITS	Active

Cloudera's Distribution including Apache Hadoop, 2011.

- The Datanode was detected



Started:	Tue Jun 07 13:08:30 UTC 2011
Version:	0.20.2-cdh3u0, r81256ad0f2e4ab2bd34b04f53d25a6c23686dd14
Compiled:	Sat Mar 26 00:14:04 UTC 2011 by root
Upgrades:	There are no upgrades in progress.

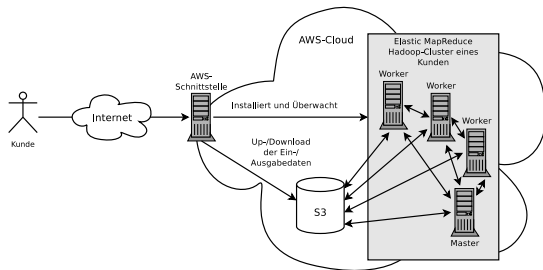
[Namenode Logs](#)
[Go back to DFS home](#)

Node	Last Contact	Admin State	Configured Capacity (GB)	Used (GB)	Non DFS Used (GB)	Remaining (GB)	Used (%)	Used (%)	Remaining (%)	Blocks
ec2-50-17-77-111	0	In Service	9.84	0	1.4	8.44	0	<div></div>	85.77	0

- Prof. Dr. Christian Baun – 7th Slide Set Cloud Computing – Frankfurt University of Applied Sciences – WS2021 70/73

Amazon Elastic MapReduce

- Elastic MapReduce (EMR) is a service for virtual Hadoop Clusters
- It's easier/faster to start with EMR MapReduce jobs compared with manually creating a Hadoop Cluster in EC2
- Input data and results are stored inside S3
- Information about the current state of the Hadoop jobs are stored inside SimpleDB



Maximilian Hoecker. Hadoop as a Service (HaaaS) auf Basis von Eucalyptus und Cludera. Bachelorthesis. HS-Mannheim (2011)

Amazon Elastic MapReduce (EMR)

- For starting a MapReduce application, a **Job-Flow** must be specified
 - A Job-Flow is a configuration of a Hadoop Cluster (in EC2)
 - The configuration contains among others the instance type and MapReduce parameters
- Each Job-Flow is split into **Steps**
 - A step is either a **MapReduce-Step** (MapReduce application) or a **Configuration-Step** (configure script or configuration command to configure the EC2 instances)
- EMR executes all steps in sequential order
- First, EMR executes the configuration steps to configure the Cluster and next executes the MapReduce applications
- Job-Flows can be created and executed either via command-line tools, via the web interface, or via the SOAP and REST interfaces

- Besides Hadoop, other MapReduce implementations exist
- Examples:
 - **Quizmt** from MySpace
 - Framework, developed with .NET
 - Free software (GPLv3)
 - <http://qizmt.myspace.com>
 - **Disco**
 - Framework, developed with Erlang and Python
 - Free software (BSD License) of the Nokia Research Center
 - <http://discoproject.org>
 - **Skynet**
 - Framework, developed with Ruby
 - Free software (MIT License)
 - <http://skynet.rubyforge.org>
 - **Plasma**
 - Framework, developed with Ocaml
 - Uses the distributed filesystem PlasmaFS
 - Free software (GPL)
 - <http://plasma.camlcity.org/plasma/>