

David A. Plaisted  
Yunshan Zhu

# The Efficiency of Theorem Proving Strategies

A Comparative and  
Asymptotic Analysis

2<sup>nd</sup> Edition



Computational Intelligence

# Efficiency Of Theorem Proving Strategies

**K Morrison**



## Efficiency Of Theorem Proving Strategies:

**The Efficiency of Theorem Proving Strategies** David A. Plaisted, Yunshan Zhu, 2013-11-11 This is the second and slightly revised edition of this book. A few errors have been fixed and some references to related work have been added. I thank the readers for their comments on the first edition. We analyze the search efficiency of a number of common refutational theorem proving strategies on propositional and near propositional problems. Search efficiency is concerned with the total number of proofs and partial proofs generated rather than with the sizes of the proofs. We show that most common strategies produce search spaces of exponential size even on simple sets of clauses or else are not sensitive to the goal. However, clause linking which uses a reduction to propositional calculus has behavior that is more favorable in some respects: a property that it shares with methods that cache subgoals. A strategy which is of interest for term rewriting based theorem proving is the A ordering strategy and we discuss it in some detail. We show some advantages of A ordering over other strategies which may help to explain its efficiency in practice. We also point out some of its combinatorial inefficiencies especially in relation to goal sensitivity and irrelevant clauses. In addition, SLD resolution which is of importance for Prolog implementation has combinatorial inefficiencies; this may suggest basing Prolog implementations on a different theorem proving strategy. We also develop techniques for studying the asymptotic complexity of first order theorem provers. This permits an analytic comparison of the worst case performances of various theorem proving methods. *The Efficiency of Theorem Proving Strategies* David A. Plaisted, Yunshan Zhu, 2014-01-15

**The Efficiency of Theorem Proving Strategies** David A. Plaisted, Yunshan Zhu, 2013-03-13 Dieses Buch in englischer Sprache widmet sich dem Thema der Effizienz von Beweisstrategien und bietet eine vergleichende und asymptotische Analyse. Das Werk stellt erstmalig asymptotische Schranken für die Größe der von vielen gebräuchlichen Beweisstrategien erzeugten Suchfelder bereit. Auf diese Weise erlaubt es ein theoretisches Verständnis der Effizienz unterschiedlicher Beweisverfahren. Es wird ein fundamentales neues Werkzeug für den Effizienzvergleich von Beweisstrategien bereitgestellt. This book is unique in that it gives asymptotic bounds on the sizes of the search spaces generated by many common theorem proving strategies. Thus it permits one to gain a theoretical understanding of the efficiencies of many different theorem proving methods. This is a fundamental new tool in the comparative study of theorem proving strategies. [The search efficiency of theorem proving strategies](#) David A.

Plaisted, 1994 **Conditional Term Rewriting Systems** Michael Rusinowitch, Jean-Luc Remy, 1993-01-29 This volume contains the papers presented at the Third International Workshop on Conditional Term Rewriting Systems held in Pont Mousson, France, July 8-10, 1992. Topics covered include conditional rewriting and its applications to programming languages, specification languages, automated deduction, constrained rewriting, typed rewriting, higher order rewriting, and graph rewriting. The volume contains 40 papers including four invited talks: Algebraic semantics of rewriting terms and types by K. Meinke, Generic induction proofs by P. Padawitz, Conditional term rewriting and first order theorem proving by D. Plaisted, and

Decidability of finiteness properties abstract by L Pacholski The first CTRS workshop was held at the University of Paris in 1987 and the second at Concordia University Montreal in 1990 Their proceedings are published as Lecture Notes in Computer Science Volumes 308 and 516 respectively Strategies for Improving the Efficiency of Automatic Theorem-proving Donald Grant Kuehner,1971 **Design and Application of Strategies/Tactics in Higher Order Logics** Myla Archer,2003 **Automated Deduction, Cade-12.** Alan Bundy,1994-06-08 This volume contains the reviewed papers presented at the 12th International Conference on Automated Deduction CADE 12 held at Nancy France in June July 1994 The 67 papers presented were selected from 177 submissions and document many of the most important research results in automated deduction since CADE 11 was held in June 1992 The volume is organized in chapters on heuristics resolution systems induction controlling resolutions ATP problems unification LP applications special purpose provers rewrite rule termination ATP efficiency AC unification higher order theorem proving natural systems problem sets and system descriptions **Automated Deduction - A Basis for Applications Volume I Foundations - Calculi and Methods Volume II Systems and Implementation Techniques Volume III Applications** Wolfgang Bibel,P.H. Schmitt,2013-03-09

1 BASIC CONCEPTS OF INTERACTIVE THEOREM PROVING Interactive Theorem Proving ultimately aims at the construction of powerful reasoning tools that let us computer scientists prove things we cannot prove without the tools and the tools cannot prove without us Interaction typically is needed for example to direct and control the reasoning to speculate or generalize strategic lemmas and sometimes simply because the conjecture to be proved does not hold In software verification for example correct versions of specifications and programs typically are obtained only after a number of failed proof attempts and subsequent error corrections Different interactive theorem provers may actually look quite different They may support different logics first or higher order logics of programs type theory etc may be generic or special purpose tools or may be targeted to different applications Nevertheless they share common concepts and paradigms e.g architectural design tactics tactical reasoning etc The aim of this chapter is to describe the common concepts design principles and basic requirements of interactive theorem provers and to explore the bandwidth of variations Having a person in the loop strongly influences the design of the proof tool proofs must remain comprehensible proof rules must be high level and human oriented persistent proof presentation and visualization becomes very important Collected Works Of Larry Wos, The (In 2 Vols), Vol I: Exploring The Power Of Automated Reasoning; Vol II: Applying Automated Reasoning To Puzzles, Problems, And Open Questions Gail W Pieper,Larry Wos,2000-01-21 Automated reasoning programs are successfully tackling challenging problems in mathematics and logic program verification and circuit design This two volume book includes all the published papers of Dr Larry Wos one of the world's pioneers in automated reasoning It provides a wealth of information for students teachers researchers and even historians of computer science about this rapidly growing field The book has the following special features 1 It presents the strategies introduced by Wos which have made automated reasoning a practical tool for

solving challenging puzzles and deep problems in mathematics and logic 2 It provides a history of the field from its earliest stages as mechanical theorem proving to its broad base now as automated reasoning 3 It illustrates some of the remarkable successes automated reasoning programs have had in tackling challenging problems in mathematics logic program verification and circuit design 4 It includes a CD ROM with a searchable index of all the papers enabling readers to peruse the papers easily for ideas

*Theorem Provers in Circuit Design* Ramayya Kumar, Thomas Kropf, 1995-03-06 This two volume set contains papers presented at the International Conference on Computational Engineering Science ICES 95 held in Mauna Lani Hawaii from 30 July to 3 August 1995 The contributions capture the state of the science in computational modeling and simulation in a variety of engineering disciplines civil mechanical aerospace materials and electronics engineering

**Strongly Correlated Fermions and Bosons in Low-Dimensional Disordered Systems** Igor V. Lerner, Boris L. Altshuler, Vladimir I. Fal'ko, Thierry Giamarchi, 2002-07-31 The physics of strongly correlated fermions and bosons in a disordered environment and confined geometries is at the focus of intense experimental and theoretical research efforts Advances in material technology and in low temperature techniques during the last few years led to the discoveries of new physical phenomena of atomic gases and a possible metal phenomena including Bose condensation insulator transition in two dimensional high mobility electron structures Situations where the electronic system is so dominated by interactions that the old concepts of a Fermi liquid do not necessarily make a good starting point are now routinely achieved This is particularly true in the theory of low dimensional systems such as carbon nanotubes or in two dimensional electron gases in high mobility devices where the electrons can form a variety of new structures In many of these systems disorder is an unavoidable complication and lead to a host of rich physical phenomena This has pushed the forefront of fundamental research in condensed matter towards the edge where the interplay between many body correlations and quantum interference enhanced by disorder has become the key to the understanding of novel phenomena

*Satisfiability Problem: Theory and Applications* Dingzhu Du, Jun Gu, Panos M. Pardalos, NSF Science and Technology Center in Discrete Mathematics and Theoretical Computer Science, 1997 The satisfiability SAT problem is central in mathematical logic computing theory and many industrial applications There has been a strong relationship between the theory the algorithms and the applications of the SAT problem This book aims to bring together work by the best theorists algorithmists and practitioners working on the SAT problem and on industrial applications as well as to enhance the interaction between the three research groups The book features the applications of theoretical algorithmic results to practical problems and presents practical examples for theoretical algorithmic study Major topics covered in the book include practical and industrial SAT problems and benchmarks significant case studies and applications of the SAT problem and SAT algorithms new algorithms and improved techniques for satisfiability testing specific data structures and implementation details of the SAT algorithms and the theoretical study of the SAT problem and SAT algorithms

*Logic, Rewriting, and Concurrency* Narciso Martí-Oliet, Peter Csaba

Ölveczky, Carolyn Talcott, 2015-08-26 This Festschrift volume contains 28 refereed papers including personal memories essays and regular research papers by close collaborators and friends of Jos Meseguer to honor him on the occasion of his 65th birthday These papers were presented at a symposium at the University of Illinois at Urbana Champaign on September 23 25 2015 The symposium also featured invited talks by Claude and H l ne Kirchner and by Patrick Lincoln The foreword of this volume adds a brief overview of some of Jos s many scientific achievements followed by a bibliography of papers written by Jos

**Scalable Search in Computer Chess** Ernst A. Heinz, 2013-12-01 Das Buch pr sentiert neue Ergebnisse der Computerschach Forschung in den Bereichen der selektiven Vorw rts Baumbeschneidung der effizienten Anwendung spieltheoretischen Wissens und des Suchverhaltens bei zunehmender Suchtiefe Es zeigt wie man die bereits gut abgestimmte Spielbaumsuche bei immer h heren Suchtiefen noch besser skalierbar macht

**Logics in Artificial Intelligence** Farinas Luis Del Cerro, Ulrich Furbach, 2003-05-20 This volume contains the papers selected for presentation at the conference and two abstracts from invited speakers The programme committee selected these 25 papers from 12 countries out of 65 submissions from 17 countries The rst JELIA meeting was in Rosco France ten years ago Afterwards it took place in the Netherlands Germany United Kingdom Portugal and now again in Germany The proceedings of the last four meetings appeared in the Springer Verlag LNCS series and a selected series of papers of the English and the Portuguese meeting appeared as special issues in the Journal of Applied Non Classical Logics and in the Journal of Automated Reasoning respectively The aim of JELIA was and still is to provide a forum for the exchange of ideas and results in the domain of foundations of AI focusing on rigorous descriptions of some aspects of intelligence These descriptions are promoted by applications and produced by logical tools and methods The papers contained in this volume cover the following topics 1 Logic programming 2 Epistemic logics 3 Theorem proving 4 Non monotonic reasoning 5 Non standard logics 6 Knowledge representation 7 Higher order logics We would like to warmly thank the authors the invited speakers the m bers of the program committee and the additional reviewers listed below They all have made these proceedings possible and ensured their quality

**Handbook of Automated Reasoning** Alan J.A. Robinson, Andrei Voronkov, 2001-06-22 Handbook of Automated Reasoning

**Automated Deduction - CADE-25** Amy P. Felty, Aart Middeldorp, 2015-07-30 This book constitutes the proceedings of the 25th International Conference on Automated Deduction CADE 25 held in Berlin Germany in August 2015 The 36 revised full papers presented 24 full papers and 12 system descriptions were carefully reviewed and selected from 85 submissions CADE is the major forum for the presentation of research in all aspects of automated deduction including foundations applications implementations and practical experience

**Theorem Proving in Higher Order Logics** Jim Grundy, Malcolm Newey, 1998-09-09 This book constitutes the refereed proceedings of the 11th International Conference on Theorem Proving in Higher Order Logics TPHOLs 98 held in Canberra Australia in September October 1998 The 26 revised full papers presented were carefully reviewed and selected from a total of 52 submissions Also included are

two invited papers The papers address all current aspects of theorem proving in higher order logics and formal verification and program analysis Besides the HOL system the theorem provers Coq Isabelle LAMBDA LEGO NuPrl and PVS are discussed

STACS 93 Patrice Enjalbert, Alain Finkel, 1993-02-19 This volume contains the proceedings of the tenth annual Symposium on Theoretical Aspects of Computer Science STACS 93 held in Würzburg February 25-27 1993 The STACS symposia are held alternately in Germany and France and organized jointly by the Special Interest Group for Theoretical Computer Science of the Gesellschaft für Informatik GI and the Special Interest Group for Applied Mathematics of the Association Française des Sciences et Technologies de l'Information et des Systèmes AFCET The volume includes the three invited talks which opened the three days of the symposium Causal and distributed semantics for concurrent processes I Castellani Parallel architectures design and efficient use B Monien et al and Transparent proofs L Babai The selection of contributed papers is organized into parts on computational complexity logic in computer science efficient algorithms parallel and distributed computation language theory computational geometry automata theory semantics and logic of programming languages automata theory and logic circuit complexity omega automata non classical complexity learning theory and cryptography and systems

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web fig 2 2 division of panels in flat slabs a column strip is a design strip with a width on each side of a column centerline equal to  $0.25 l_x$  or if drops with dimension not less than  $l_x/3$  are used a width equal to the drop dimension a middle strip is a design strip bounded by two column strips

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web dec 9 2017 contd design moments in braced columns maximum design column moment greatest of a  $m_2$  b  $m_1$  c  $m_1$  d  $m_2$  e  $m_1$  f  $m_2$  g  $m_1$  h  $m_2$  i  $m_1$  j  $m_2$  k  $m_1$  l  $m_2$  m  $m_1$  n  $m_2$  o  $m_1$  p  $m_2$  q  $m_1$  r  $m_2$  s  $m_1$  t  $m_2$  u  $m_1$  v  $m_2$  w  $m_1$  x  $m_2$  y  $m_1$  z  $m_2$  aa  $m_1$  ab  $m_2$  ac  $m_1$  ad  $m_2$  ae  $m_1$  af  $m_2$  ag  $m_1$  ah  $m_2$  ai  $m_1$  aj  $m_2$  ak  $m_1$  al  $m_2$  am  $m_1$  an  $m_2$  ao  $m_1$  ap  $m_2$  aq  $m_1$  ar  $m_2$  as  $m_1$  at  $m_2$  au  $m_1$  av  $m_2$  aw  $m_1$  ax  $m_2$  ay  $m_1$  az  $m_2$  ba  $m_1$  bb  $m_2$  bc  $m_1$  bd  $m_2$  be  $m_1$  bf  $m_2$  bg  $m_1$  bh  $m_2$  bi  $m_1$  bj  $m_2$  bk  $m_1$  bl  $m_2$  bm  $m_1$  bn  $m_2$  bo  $m_1$  bp  $m_2$  bq  $m_1$  br  $m_2$  bs  $m_1$  bt  $m_2$  bu  $m_1$  bv  $m_2$  bw  $m_1$  bx  $m_2$  by  $m_1$  bz  $m_2$  ca  $m_1$  cb  $m_2$  cc  $m_1$  cd  $m_2$  ce  $m_1$  cf  $m_2$  cg  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$m_2$  fu  $m_1$  fv  $m_2$  fw  $m_1$  fx  $m_2$  fy  $m_1$  fz  $m_2$  ga  $m_1$  gb  $m_2$  gc  $m_1$  gd  $m_2$  ge  $m_1$  gf  $m_2$  gh  $m_1$  gi  $m_2$  gi  $m_1$  gj  $m_2$  gj  $m_1$  gk  $m_2$  gk  $m_1$  gl  $m_2$  gl  $m_1$  gm  $m_2$  gm  $m_1$  gn  $m_2$  gn  $m_1$  go  $m_2$  go  $m_1$  gp  $m_2$  gp  $m_1$  gq  $m_2$  gq  $m_1$  gr  $m_2$  gr  $m_1$  gs  $m_2$  gs  $m_1$  gt  $m_2$  gt  $m_1$  gu  $m_2$  gu  $m_1$  gv  $m_2$  gv  $m_1$  gw  $m_2$  gw  $m_1$  gx  $m_2$  gx  $m_1$  gy  $m_2$  gy  $m_1$  gz  $m_2$  ha  $m_1$  hb  $m_2$  hb  $m_1$  hc  $m_2$  hc  $m_1$  hd  $m_2$  hd  $m_1$  he  $m_2$  he  $m_1$  hf  $m_2$  hf  $m_1$  hg  $m_2$  hg  $m_1$  hh  $m_2$  hh  $m_1$  hi  $m_2$  hi  $m_1$  hj  $m_2$  hj  $m_1$  hk  $m_2$  hk  $m_1$  hl  $m_2$  hl  $m_1$  hm  $m_2$  hm  $m_1$  hn  $m_2$  hn  $m_1$  ho  $m_2$  ho  $m_1$  hp  $m_2$  hp  $m_1$  hq  $m_2$  hq  $m_1$  hr  $m_2$  hr  $m_1$  hs  $m_2$  hs  $m_1$  ht  $m_2$  ht  $m_1$  hu  $m_2$  hu  $m_1$  hv  $m_2$  hv  $m_1$  hw  $m_2$  hw  $m_1$  hx  $m_2$  hx  $m_1$  hy  $m_2$  hy  $m_1$  hz  $m_2$  ia  $m_1$  ib  $m_2$  ib  $m_1$  ic  $m_2$  ic  $m_1$  id  $m_2$  id  $m_1$  ie  $m_2$  ie  $m_1$  if  $m_2$  if  $m_1$  ig  $m_2$  ig  $m_1$  ih  $m_2$  ih  $m_1$  ii  $m_2$  ii  $m_1$  ij  $m_2$  ij  $m_1$  ik  $m_2$  ik  $m_1$  il  $m_2$  il  $m_1$  im  $m_2$  im  $m_1$  in  $m_2$  in  $m_1$  io  $m_2$  io  $m_1$  ip  $m_2$  ip  $m_1$  iq  $m_2$  iq  $m_1$  ir  $m_2$  ir  $m_1$  is  $m_2$  is  $m_1$  it  $m_2$  it  $m_1$  iu  $m_2$  iu  $m_1$  iv  $m_2$  iv  $m_1$  iw  $m_2$  iw  $m_1$  ix  $m_2$  ix  $m_1$  iy  $m_2$  iy  $m_1$  iz  $m_2$  ja  $m_1$  jb  $m_2$  jb  $m_1$  jc  $m_2$  jc  $m_1$  jd  $m_2$  jd  $m_1$  je  $m_2$  je  $m_1$  jf  $m_2$  jf  $m_1$  jg  $m_2$  jg  $m_1$  jh  $m_2$  jh  $m_1$  ji  $m_2$  ji  $m_1$  jj  $m_2$  jj  $m_1$  jk  $m_2$  jk  $m_1$  jl  $m_2$  jl  $m_1$  jm  $m_2$  jm  $m_1$  jn  $m_2$  jn  $m_1$  jo  $m_2$  jo  $m_1$  jp  $m_2$  jp  $m_1$  jq  $m_2$  jq  $m_1$  jr  $m_2$  jr  $m_1$  js  $m_2$  js  $m_1$  jt  $m_2$  jt  $m_1$  ju  $m_2$  ju  $m_1$  jv  $m_2$  jv  $m_1$  jw  $m_2$  jw  $m_1$  jx  $m_2$  jx  $m_1$  jy  $m_2$  jy  $m_1$  jz  $m_2$  ka  $m_1$  kb  $m_2$  kb  $m_1$  kc  $m_2$  kc  $m_1$  kd  $m_2$  kd  $m_1$  ke  $m_2$  ke  $m_1$  kf  $m_2$  kf  $m_1$  kg  $m_2$  kg  $m_1$  kh  $m_2$  kh  $m_1$  ki  $m_2$  ki  $m_1$  kj  $m_2$  kj  $m_1$  kk  $m_2$  kj  $m_1$  kl  $m_2$  kl  $m_1$  km  $m_2$  km  $m_1$  kn  $m_2$  km  $m_1$  ko  $m_2$  ko  $m_1$  kp  $m_2$  kp  $m_1$  kq  $m_2$  kp  $m_1$  kr  $m_2$  kr  $m_1$  ks  $m_2$  ks  $m_1$  kt  $m_2$  ks  $m_1$  ku  $m_2$  ku  $m_1$  kv  $m_2$  kv  $m_1$  kw  $m_2$  kw  $m_1$  kx  $m_2$  kx  $m_1$  ky  $m_2$  ky  $m_1$  kz  $m_2$  la  $m_1$  lb  $m_2$  lb  $m_1$  lc  $m_2$  lb  $m_1$  ld  $m_2$  lc  $m_1$  le  $m_2$  lc  $m_1$  lf  $m_2$  lf  $m_1$  lg  $m_2$  lf  $m_1$  lh  $m_2$  lg  $m_1$  li  $m_2$  lg  $m_1$  lj  $m_2$  lj  $m_1$  lk  $m_2$  lj  $m_1$  ll  $m_2$  ll  $m_1$  lm  $m_2$  ll  $m_1$  ln  $m_2$  ln  $m_1$  lo  $m_2$  ln  $m_1$  lp  $m_2$  lp  $m_1$  lq  $m_2$  lp  $m_1$  lr  $m_2$  lr  $m_1$  ls  $m_2$  ls  $m_1$  lt  $m_2$  ls  $m_1$  lu  $m_2$  lu  $m_1$  lv  $m_2$  lv  $m_1$  lw  $m_2$  lv  $m_1$  lx  $m_2$  lx  $m_1$  ly  $m_2$  ly  $m_1$  lz  $m_2$  ma  $m_1$  mb  $m_2$  mb  $m_1$  mc  $m_2$  mb  $m_1$  md  $m_2$  mc  $m_1$  me  $m_2$  mc  $m_1$  mf  $m_2$  md  $m_1$  mg  $m_2$  md  $m_1$  mh  $m_2$  md  $m_1$  mi  $m_2$  me  $m_1$  mj  $m_2$  me  $m_1$  mk  $m_2$  me  $m_1$  ml  $m_2$  mf  $m_1$  mm  $m_2$  mf  $m_1$  mn  $m_2$  mf  $m_1$  mo  $m_2$  mg  $m_1$  mp  $m_2$  mg  $m_1$  mq  $m_2$  mg  $m_1$  mr  $m_2$  mg  $m_1$  ms  $m_2$  mh  $m_1$  mt  $m_2$  mh  $m_1$  mu  $m_2$  mh  $m_1$  mv  $m_2$  mi  $m_1$  mw  $m_2$  mi  $m_1$  mx  $m_2$  mi  $m_1$  my  $m_2$  mj  $m_1$  mz  $m_2$  nk  $m_1$  nl  $m_2$  nk  $m_1$  nm  $m_2$  nk  $m_1$  no  $m_2$  nl  $m_1$  np  $m_2$  nl  $m_1$  nq  $m_2$  nm  $m_1$  nr  $m_2$  nm  $m_1$  ns  $m_2$  nm  $m_1$  nt  $m_2$  no  $m_1$  nu  $m_2$  no  $m_1$  nv  $m_2$  no  $m_1$  nw  $m_2$  np  $m_1$  nx  $m_2$  np  $m_1$  ny  $m_2$  np  $m_1$  nz  $m_2$  oa  $m_1$  ob  $m_2$  ob  $m_1$  oc  $m_2$  ob  $m_1$  od  $m_2$  oc  $m_1$  oe  $m_2$  oc  $m_1$  of  $m_2$  od  $m_1$  og  $m_2$  od  $m_1$  oh  $m_2$  oe  $m_1$  oi  $m_2$  oe  $m_1$  oj  $m_2$  oe  $m_1$  ok  $m_2$  of  $m_1$  ol  $m_2$  of  $m_1$  om  $m_2$  of  $m_1$  on  $m_2$  og  $m_1$  oo  $m_2$  og  $m_1$  op  $m_2$  og  $m_1$  oq  $m_2$  oh  $m_1$  or  $m_2$  oh  $m_1$  os  $m_2$  oh  $m_1$  ot  $m_2$  oi  $m_1$  ou  $m_2$  oi  $m_1$  ov  $m_2$  oi  $m_1$  ow  $m_2$  oj  $m_1$  ox  $m_2$  oj  $m_1$  oy  $m_2$  oj  $m_1$  oz  $m_2$  pa  $m_1$  pb  $m_2$  pb  $m_1$  pc  $m_2$  pb  $m_1$  pd  $m_2$  pc  $m_1$  pe  $m_2$  pc  $m_1$  pf  $m_2$  pd  $m_1$  pg  $m_2$  pd  $m_1$  ph  $m_2$  pe  $m_1$  pi  $m_2$  pe  $m_1$  pj  $m_2$  pe  $m_1$  pk  $m_2$  pf  $m_1$  pl  $m_2$  pf  $m_1$  pm  $m_2$  pf  $m_1$  pn  $m_2$  pg  $m_1$  po  $m_2$  pg  $m_1$  pp  $m_2$  pg  $m_1$  pq  $m_2$  ph  $m_1$  pr  $m_2$  ph  $m_1$  ps  $m_2$  ph  $m_1$  pt  $m_2$  pi  $m_1$  pu  $m_2$  pi  $m_1$  pv  $m_2$  pi  $m_1$  pw  $m_2$  pj  $m_1$  px  $m_2$  pj  $m_1$  py  $m_2$  pj  $m_1$  pz  $m_2$  qa  $m_1$  qb  $m_2$  qb  $m_1$  qc  $m_2$  qb  $m_1$  qd  $m_2$  qc  $m_1$  qe  $m_2$  qc  $m_1$  qf  $m_2$  qd  $m_1$  qg  $m_2$  qd  $m_1$  qh  $m_2$  qe  $m_1$  qi  $m_2$  qe  $m_1$  qj  $m_2$  qe  $m_1$  qk  $m_2$  qf  $m_1$  ql  $m_2$  qf  $m_1$  qm  $m_2$  qf  $m_1$  qn  $m_2$  qg  $m_1$  qo  $m_2$  qg  $m_1$  qp  $m_2$  qg  $m_1$  qq  $m_2$  qh  $m_1$  qr  $m_2$  qh  $m_1$  qs  $m_2$  qh  $m_1$  qt  $m_2$  qi  $m_1$  qu  $m_2$  qi  $m_1$  qv  $m_2$  qi  $m_1$  qw  $m_2$  qj  $m_1$  qx  $m_2$  qj  $m_1$  qy  $m_2$  qj  $m_1$  qz  $m_2$  ra  $m_1$  rb  $m_2$  rb  $m_1$  rc  $m_2$  rb  $m_1$  rd  $m_2$  rc  $m_1$  re  $m_2$  rc  $m_1$  rf  $m_2$  rd  $m_1$  rg  $m_2$  rd  $m_1$  rh  $m_2$  re  $m_1$  ri  $m_2$  re  $m_1$  rj  $m_2$  re  $m_1$  rk  $m_2$  rf  $m_1$  rl  $m_2$  rf  $m_1$  rm  $m_2$  rf  $m_1$  rn  $m_2$  rg  $m_1$  ro  $m_2$  rg  $m_1$  rp  $m_2$  rg  $m_1$  rq  $m_2$  rh  $m_1$  rr  $m_2$  rh  $m_1$  rs  $m_2$  rh  $m_1$  rt  $m_2$  ri  $m_1$  ru  $m_2$  ri  $m_1$  rv  $m_2$  ri  $m_1$  rw  $m_2$  rj  $m_1$  rx  $m_2$  rj  $m_1$  ry  $m_2$  rj  $m_1$  rz  $m_2$  sa  $m_1$  sb  $m_2$  sb  $m_1$  sc  $m_2$  sb  $m_1$  sd  $m_2$  sc  $m_1$  se  $m_2$  sc  $m_1$  sf  $m_2$  sd  $m_1$  sg  $m_2$  sd  $m_1$  sh  $m_2$  se  $m_1$  si  $m_2$  se  $m_1$  sj  $m_2$  se  $m_1$  sk  $m_2$  sf  $m_1$  sl  $m_2$  sf  $m_1$  sm  $m_2$  sf  $m_1$  sn  $m_2$  sg  $m_1$  so  $m_2$  sg  $m_1$  sp  $m_2$  sg  $m_1$  sq  $m_2$  sh  $m_1$  sr  $m_2$  sh  $m_1$  ss  $m_2$  sh  $m_1$  st  $m_2$  si  $m_1$  su  $m_2$  si  $m_1$  sv  $m_2$  si  $m_1$  sw  $m_2$  sj  $m_1$  sx  $m_2$  sj  $m_1$  sy  $m_2$  sj  $m_1$  sz  $m_2$  ta  $m_1$  tb  $m_2$  tb  $m_1$  tc  $m_2$  tb  $m_1$  td  $m_2$  tc  $m_1$  te  $m_2$  tc  $m_1$  tf  $m_2$  td  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