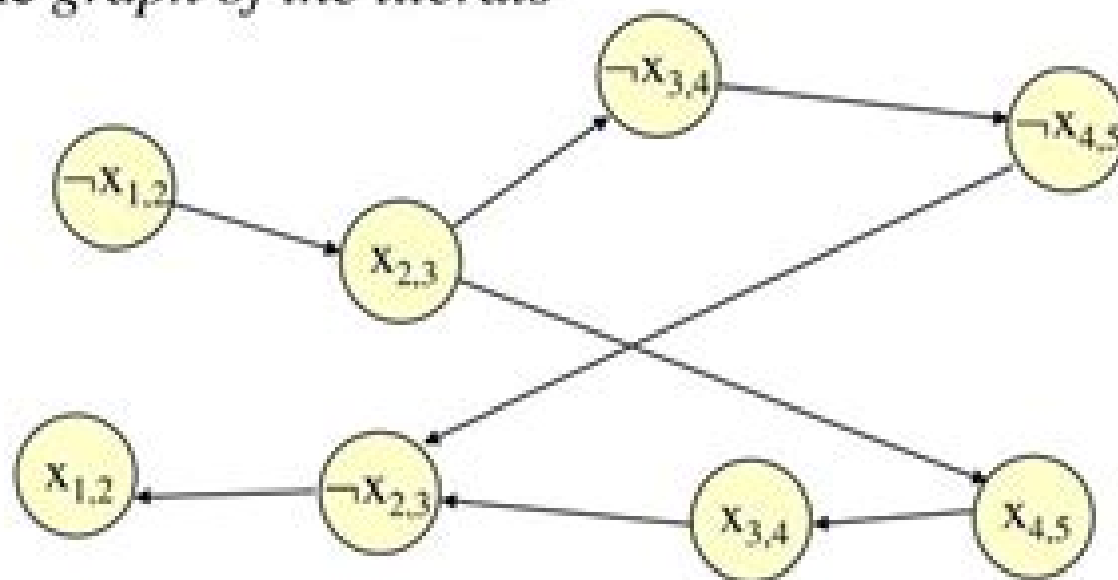


# solving a huge 2SAT

given a 2SAT formula

$$(x_{1,2} \vee x_{2,3}) \wedge (\neg x_{2,3} \vee \neg x_{3,4}) \wedge (x_{3,4} \vee \neg x_{4,5}) \wedge (x_{4,5} \vee \neg x_{2,3})$$

compute the *graph of the literals*



there is a direct path between a literal and its opposite and vice versa iff a solution without invalid paths does not exist (Aspvall, Plass, Tarjan, IPL '79)

# 2sat Study Guide

**Robert B. Kaplan**



## 2sat Study Guide:

*Elements of dynamic and 2-SAT programming: paths, trees, and cuts* Bentert, Matthias, 2021-11-18 In dieser Arbeit entwickeln wir schnellere exakte Algorithmen schneller bezogen auf die Worst Case Laufzeit für Spezialfälle von Graphproblemen. Diese Algorithmen beruhen gr teils auf dynamischem Programmieren und auf 2 SAT Programmierung. Dynamisches Programmieren beschreibt den Vorgang ein Problem rekursiv in Unterprobleme zu zerteilen sodass diese Unterprobleme gemeinsame Unterprobleme haben. Wenn diese Unterprobleme optimal gelöst wurden dann kombiniert das dynamische Programm diese Lösungen zu einer optimalen Lösung des Ursprungsproblems. 2 SAT Programmierung bezeichnet den Prozess ein Problem durch eine Menge von 2 SAT Formeln aussagenlogische Formeln in konjunktiver Normalform wobei jede Klausel aus maximal zwei Literalen besteht auszudrücken. Dabei müssen erfüllende Wahrheitswertbelegungen für eine Teilmenge der 2 SAT Formeln zu einer Lösung des Ursprungsproblems korrespondieren. Wenn eine 2 SAT Formel erfüllbar ist dann kann eine erfüllende Wahrheitswertbelegung in Linearzeit in der Länge der Formel berechnet werden. Wenn entsprechende 2 SAT Formeln also in polynomieller Zeit in der EingabegröÙe des Ursprungsproblems erstellt werden können dann kann das Ursprungsproblem in polynomieller Zeit gelöst werden. Im folgenden beschreiben wir die Hauptresultate der Arbeit. Bei dem Diameter Problem wird die gröÙte Distanz zwischen zwei beliebigen Knoten in einem gegebenen ungerichteten Graphen gesucht. Das Ergebnis der Durchmesser des Eingabegraphen gehört zu den wichtigsten Parametern der Graphanalyse. In dieser Arbeit erzielen wir sowohl positive als auch negative Ergebnisse für Diameter. Wir konzentrieren uns dabei auf parametrisierte Algorithmen für Parameterkombinationen die in vielen praktischen Anwendungen klein sind und auf Parameter die eine Distanz zur Trivialität messen. Bei dem Problem Length Bounded Cut geht es darum ob es eine Kantenmenge begrenzter Größe in einem Eingabegraphen gibt sodass das Entfernen dieser Kanten die Distanz zwischen zwei gegebenen Knoten auf ein gegebenes Minimum erhöht. Wir bestätigen in dieser Arbeit eine Vermutung aus der wissenschaftlichen Literatur dass Length Bounded Cut in polynomieller Zeit in der EingabegröÙe auf Einheitsintervallgraphen Intervallgraphen in denen jedes Intervall die gleiche Länge hat gelöst werden kann. Der Algorithmus basiert auf dynamischem Programmieren. k Disjoint Shortest Paths beschreibt das Problem knotendisjunkte Pfade zwischen k gegebenen Knotenpaaren zu suchen sodass jeder der k Pfade ein kürzester Pfad zwischen den jeweiligen Endknoten ist. Wir beschreiben ein dynamisches Programm mit einer Laufzeit  $n \cdot O(k^2)$  für dieses Problem wobei  $n$  die Anzahl der Knoten im Eingabegraphen ist. Dies zeigt dass k Disjoint Shortest Paths in polynomieller Zeit für jedes konstante  $k$  gelöst werden kann was für über 20 Jahre ein ungelöstes Problem der algorithmischen Graphentheorie war. Das Problem Tree Containment fragt ob ein gegebener phylogenetischer Baum  $T$  in einem gegebenen phylogenetischen Netzwerk  $N$  enthalten ist. Ein phylogenetisches Netzwerk bzw ein phylogenetischer Baum ist ein gerichteter azyklischer Graph bzw ein gerichteter Baum mit genau einer Quelle in dem jeder Knoten höchstens eine ausgehende oder höchstens eine eingehende Kante hat und jedes

Blatt eine Beschriftung trägt. Das Problem stammt aus der Bioinformatik aus dem Bereich der Suche nach dem Baums des Lebens der Geschichte der Artenbildung. Wir führen eine neue Variante des Problems ein, die wir Soft Tree Containment nennen, und die bestimmte Unsicherheitsfaktoren berücksichtigt. Wir zeigen mit Hilfe von 2 SAT Programmierung, dass Soft Tree Containment in polynomieller Zeit gelöst werden kann, wenn  $N$  ein phylogenetischer Baum ist, in dem jeweils maximal zwei Blätter die gleiche Beschriftung tragen. Wir ergänzen dieses Ergebnis mit dem Beweis, dass Soft Tree Containment NP schwer ist, selbst wenn  $N$  auf phylogenetische Bäume beschränkt ist, in denen jeweils maximal drei Blätter die gleiche Beschriftung tragen. Abschließend betrachten wir das Problem Reachable Object. Hierbei wird nach einer Sequenz von rationalen Tauschoperationen zwischen Agentinnen gesucht, sodass eine bestimmte Agentin ein bestimmtes Objekt erhält. Eine Tauschoperation ist rational, wenn beide an dem Tausch beteiligten Agentinnen ihr neues Objekt gegenüber dem jeweiligen alten Objekt bevorzugen. Reachable Object ist eine Verallgemeinerung des bekannten und viel untersuchten Problems Housing Market. Hierbei sind die Agentinnen in einem Graphen angeordnet, und nur benachbarte Agentinnen können Objekte miteinander tauschen. Wir zeigen, dass Reachable Object NP schwer ist, selbst wenn jede Agentin maximal drei Objekte gegenüber ihrem Startobjekt bevorzugt, und dass Reachable Object polynomiell lösbar ist, wenn jede Agentin maximal zwei Objekte gegenüber ihrem Startobjekt bevorzugt. Wir geben außerdem einen Polynomzeitalgorithmus für den Spezialfall an, in dem der Graph der Agentinnen ein Kreis ist. Dieser Polynomzeitalgorithmus basiert auf 2 SAT Programmierung. This thesis presents faster in terms of worst case running times exact algorithms for special cases of graph problems through dynamic programming and 2 SAT programming. Dynamic programming describes the procedure of breaking down a problem recursively into overlapping subproblems, that is, subproblems with common subsubproblems. Given optimal solutions to these subproblems, the dynamic program then combines them into an optimal solution for the original problem. 2 SAT programming refers to the procedure of reducing a problem to a set of 2 SAT formulas, that is, boolean formulas in conjunctive normal form in which each clause contains at most two literals. Computing whether such a formula is satisfiable and computing a satisfying truth assignment, if one exists, takes linear time in the formula length. Hence, when satisfying truth assignments to some 2 SAT formulas correspond to a solution of the original problem and all formulas can be computed efficiently, that is, in polynomial time in the input size of the original problem, then the original problem can be solved in polynomial time. We next describe our main results. Diameter asks for the maximal distance between any two vertices in a given undirected graph. It is arguably among the most fundamental graph parameters. We provide both positive and negative parameterized results for distance from triviality type parameters and parameter combinations that were observed to be small in real world applications. In Length Bounded Cut, we search for a bounded size set of edges that intersects all paths between two given vertices of at most some given length. We confirm a conjecture from the literature by providing a polynomial time algorithm for proper interval graphs, which is based on dynamic programming.  $k$  Disjoint Shortest Paths is the problem of finding vertex

disjoint paths between given vertex terminals such that each of these paths is a shortest path between the respective terminals Its complexity for constant  $k \geq 2$  has been an open problem for over 20 years Using dynamic programming we show that  $k$  Disjoint Shortest Paths can be solved in polynomial time for each constant  $k$  The problem Tree Containment asks whether a phylogenetic tree  $T$  is contained in a phylogenetic network  $N$  A phylogenetic network or tree is a leaf labeled single source directed acyclic graph or tree in which each vertex has in degree at most one or out degree at most one The problem stems from computational biology in the context of the tree of life the history of speciation We introduce a particular variant that resembles certain types of uncertainty in the input We show that if each leaf label occurs at most twice in a phylogenetic tree  $N$  then the problem can be solved in polynomial time and if labels can occur up to three times then the problem becomes NP hard Lastly Reachable Object is the problem of deciding whether there is a sequence of rational trades of objects among agents such that a given agent can obtain a certain object A rational trade is a swap of objects between two agents where both agents profit from the swap that is they receive objects they prefer over the objects they trade away This problem can be seen as a natural generalization of the well known and well studied Housing Market problem where the agents are arranged in a graph and only neighboring agents can trade objects We prove a dichotomy result that states that the problem is polynomial time solvable if each agent prefers at most two objects over its initially held object and it is NP hard if each agent prefers at most three objects over its initially held object We also provide a polynomial time SAT program for the case where the graph of agents is a cycle

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