Parameterized Complexity of Generalized Domination Problems

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Abstract. Given two sets σ, ρ of nonnegative integers, a set S of vertices of a graph G is (σ, ρ)-*dominating* if $|S \cap N(v)| \in \sigma$ for every vertex $v \in S$, and $|S \cap N(v)| \in \rho$ for every $v \notin S$. This concept, introduced by Telle in 1990's, generalizes and unifies several variants of graph domination studied separately before. We study the parameterized complexity of (σ, ρ)-domination in this general setting. Among other results we show that existence of a (σ, ρ)-dominating set of size k (and at most k) are W[1]-complete problems (when parameterized by k) for any pair of finite sets σ and ρ. We further present results on dual parametrization by $n-k$, and results on certain infinite sets (in particular for σ, ρ being the sets of even and odd integers).

1 Introduction

1.1 (σ, ρ)-Domination

Let σ, ρ be a pair of nonempty sets of nonnegative integers. A set S of vertices of a graph G is called (σ, ρ)-*dominating* if for every vertex $v \in S$, $|S \cap N(v)| \in \sigma$, and for every $v \notin S$, $|S \cap N(v)| \in \rho$. The concept of (σ, ρ)-domination was introduced by J.A. Telle [18,19] (and further elaborated on in [13,20]) as a unifying generalization of many previously studied variants of the notion of dominating sets. See Table 1 for some examples.

It is well known that the optimization problems such as Maximum Independent Set, Minimum Dominating Set, etc. are NP-hard. In many cases of the generalized domination already the existence of a (σ, ρ)-dominating set

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Table 1. Overview of the special cases of (σ, ρ)-domination and their parameterized complexity (when parameterized by the size of the set). (Here $\mathbb{N}$ and $\mathbb{N}_0$ denote the sets of positive and nonnegative integers, respectively.)

σ	ρ	Problem name	Parameterized Complexity
$\mathbb{N}_0$	$\mathbb{N}$	Dominating Set	W[2]-complete
$\mathbb{N}$	$\mathbb{N}$	Total Dominating Set	W[2]-hard
$\mathbb{N}_0$	$\{1\}$	Efficient Dominating Set	W[1]-hard
$\{0\}$	$\mathbb{N}$	Indepependent Dominating Set	W[2]-complete
$\{0\}$	$\mathbb{N}_0$	Independent set	W[1]-complete
$\{0\}$	$\{1\}$	(1-)Perfect Code(Indep. Eff. Dom. Set)	W[1]-complete
$\{r\}$	$\mathbb{N}_0$	Induced r-Regular subgraph	W[1]-hard
$\{0\}$	$\{0,1\}$	Strong Stable Set	Unknown
$\{1\}$	$\{1\}$	Total Perfect Dominating Set	Unknown

becomes NP-hard (e.g., when both σ and ρ are finite and nonempty, and $0 \notin \rho$ [18]). Hence attention was paid to special graph classes, e.g. interval graphs ([15] shows polynomial-time solvability for any pair of finite σ, ρ), chordal graphs ([11] shows a P/NP-c dichotomy classification) or degenerate graphs [12].

Since the establishment of the Parameterized Complexity Theory by Downey and Fellows [7], domination-type problems have been among the first ones intensively studied in the framework of this theory. (We assume the reader is familiar with the concept of FPT and W[t] classes, otherwise we refer to [7,10] and [17] as excellent textbooks.) It is well known that Independent Set is W[1]-complete [6] and Dominating Set is W[2]-complete [5,7] (when parameterized by the size of the set). A number of domination-type problems are considered in [2], where it is shown (among other results) that Total Dominating Set is W[2]-hard and that Efficient Dominating Set is W[1]-hard. Independent Dominating Set is W[2]-complete [5], while Efficient Independent Dominating Set (also called Perfect Code) is W[1]-complete ([6] shows W[1]-hardness and [3] shows W[1]-membership). More results on parameterized complexity of problems from coding theory can be found in [9]. The complexity of finding an r-regular induced subgraph in a graph is studied in [16].

Parity constraints have been considered in [9]. A subset of a color class of a bipartite graph is called *odd* (*even*) if every vertex from the other class has an odd (even, respectively) number of neighbors in the set. Downey et al. show that deciding the existence of an odd set of size k, an odd set of size at most k, and an even set of size k are W[1]-hard problems; somewhat surprisingly, the complexity of Even Set of Size at Most k remains open.

All these individual results concern special (σ, ρ)-dominating sets, and thus call for a unifying approach. Our paper attempts to be a starting one by giving general results for large classes of pairs σ, ρ. The second goal of our paper is to study (many of) the above problems from the dual parametrization point of view (looking for a set of size at least $n - k$, where k is the parameter), both for the domination-type and parity-type problems.

1.2 Notation and Overview of Our Results

We consider the following (σ, ρ)-domination problem

(σ, ρ)-Dominating Set of Size at most k
Input: A graph G.
Parameter: k.
Question: Is there a (σ, ρ)-dominating set in G of size at most k?

and its variants (σ, ρ)-Dominating Set of Size k, (σ, ρ)-Dominating Set of Size at least $n-k$, and (σ, ρ)-Dominating Set of Size $n-k$, whose meaning should be clear. All these problems ar parameterized by k, and in the latter two, n denotes the number of vertices of the input graph. The first of our main results determines the parameterized complexity for finite sets σ and ρ.

Theorem 1. *Let σ and ρ be nonempty finite sets of nonnegative integers, $0 \notin \rho$. Then both (σ, ρ)-Dominating Set of Size k and (σ, ρ)-Dominating Set of Size at most k are* W[1]*-complete problems.*

The hardness part is proved in Subsection 2.1, and the W[1]-membership is proved in Subsection 2.2 in a stronger form when σ is only required to be recursive but not necessarily finite.

We further study the dually parameterized problems and show in an even more general way that these problems become tractable. In Section 3 we prove the following theorem (here and throughout the paper, $\overline{X} = \mathbb{N}_0 \setminus X$ for a set X of integers).

Theorem 2. *Let σ and ρ be sets of nonnegative integers such that either σ or $\overline{\sigma}$ is finite, and similarly either ρ or $\overline{\rho}$ is finite. Then the (σ, ρ)-Dominating Set of Size at least $n-k$ problem is in* FPT.

We show that a similar result cannot be expected for arbitrary recursive sets σ and ρ. Even for the parity case (when we denote **EVEN** $= \{0, 2, 4, 6, \ldots\}$ and **ODD** $= \{1, 3, 5, \ldots\}$) we can prove W[1]-hardness.

Theorem 3. *Let $\sigma, \rho \in \{\mathbf{EVEN}, \mathbf{ODD}\}$. Then both (σ, ρ)-Dominating Set of Size $n-k$ and (σ, ρ)-Dominating Set of Size at least $n-k$ are* W[1]*-hard problems.*

As a tool for the previous result we consider the following parity problems on bipartite graphs. Suppose that G is a bipartite graph and R, B is a bipartition of its set of vertices (vertices of R are called *red* and vertices of B are *blue*). A nonempty set $S \subseteq R$ is called *even* if for every vertex $v \in B$, $|N(v) \cap S| \in \mathbf{EVEN}$, and it is called *odd* if for every vertex $v \in B$, $|N(v) \cap S| \in \mathbf{ODD}$. The following problem

Even Set of Size at least $r-k$
Input: A bipartite graph $G = (R, B, E)$ and $r = |R|$.
Parameter: k.
Question: Is there an even set in R of size at least $r-k$?

and its variants Even Set of Size $r-k$, Odd Set of Size at least $r-k$, and Odd Set of Size $r-k$ are the dually parameterized versions of bipartite parity problems studied in [9]. We prove in Section 4 that all four of them are W[1]-hard.

In the last section we present observations on FPT results for sparse graphs.

2 Complexity of the (σ, ρ)-Dominating Set of Size at most k Problems - Proof of Theorem 1

2.1 W[1]-Hardness

We are going to reduce a special variant of the Satisfiability problem (the proof of W[1]-hardness of this problem is omitted here).

At most α-Satisfiability
Instance: A Boolean formula ϕ in conjunctive normal form, without negated variables.
Parameter: k.
Question: Does ϕ allow a satisfying truth assignment of weight at most k (i.e., at most k variables have value *true*) such that each clause of ϕ contains at most α variables which evaluate to *true*?

Suppose that σ and ρ are nonempty finite sets of nonnegative integers, $0 \notin \rho$. Let us denote $p_{min} = \min \sigma$, $p_{max} = \max \sigma$, $q_{min} = \min \rho$ and $q_{max} = \max \rho$. Further we set $t = \max\{i \in \mathbb{N}_0 \colon i \notin \rho, i+1 \in \rho\}$ (since $0 \notin \rho$, t is correctly defined), and $\alpha = q_{max} - t \geq 1$. We are going to reduce At most α-Satisfiability. Due the space restrictions we give here only a sketch of the reduction. Complete description will appear in the journal version of the paper.

We first construct several auxiliary gadgets. These gadgets "enforce" on a given vertex the property of "not belonging to any (σ, ρ)-dominating set", and at the same time guarantee that this vertex has a given number of neighbors in any (σ, ρ)-dominating set in the gadget. To describe the properties formally, we will consider rooted graphs and introduce the following notion. Let G be a rooted graph with a set of root vertices X. We call a set $S \subseteq V(G)$ a (σ, ρ)-*dominating set for* G if $|N(v) \cap S| \in \sigma$ for every $v \in S \setminus X$, and $|N(v) \cap S| \in \rho$ for every $v \notin S$, $v \notin X$ (i.e., the conditions from the definition of (σ, ρ)-domination are required for all vertices except the roots).

The first gadget is a graph $F(s)$ (s is a positive integer) with s independent roots $x_1, \ldots, x_s$ of degree one, all adjacent to the same vertex, say a_1, which has the following property: Every (σ, ρ)-dominating set S for $F(s)$ contains a_1, contains none of the roots, and all such sets have the same size $f = f(\sigma, \rho)$.

The second gadget is a graph $F'(s)$ (s is a positive integer) with s independent roots $y_1, \ldots, y_s$ of degree one, all adjacent to the same vertex, say x. It has the following property: Every (σ, ρ)-dominating set S for $F'(s)$ contains none of the roots, neither it contains their common neighbor x, and all such sets have the same size $f' = f'(\sigma, \rho)$.

A selection gadget $R(l)$ (l is a positive integer) is a graph rooted in a clique X containing l vertices, and it satisfies the following property: Every (σ, ρ)-dominating set S for $R(l)$ contains exactly one root vertex, and all such sets have the same size $r = r(\sigma, \rho)$. Moreover, for every root vertex $x \in X$, there exists a (σ, ρ)-dominating set S in $R(l)$ which contains x (note that here we require that even the root vertices are dominated in a proper way).

Now we describe the reduction. Let ϕ be a formula as an input of the At most α-Satisfiability problem. Let $x_1, \ldots, x_n$ be its variables, and let $C_1, \ldots, C_m$ be the clauses.

We take k copies of the graph $R(n+1)$ denoted by $R_1, \ldots, R_k$, with the roots of R_i being denoted by $x_{i,j}$. For each clause C_s, a vertex C_s is added and joined by edges to all vertices $x_{i,j}$, $i = 1, \ldots, k$ such that the variable x_j occurs in the clause G_s. Now we distinguish two cases:

$t = 0$. In this case a copy of $F'(m)$ is introduced, and the m roots of this gadget are identified with vertices $C_1, \ldots, C_m$. In this case we set $k' = kr + f'$.

$t > 0$. We construct t copies of $F(m)$, and the roots of each copy are identified with $C_1, \ldots, C_m$. In this case we set $k' = kr + tf$.

The resulting graph is called G. The proof of W[1]-hardness is then concluded by the following lemma (whose proof is omitted).

Lemma 1. *The formula ϕ allows a satisfying truth assignment of weight at most k such that each clause of ϕ contains at most α variables with value* true *if and only if G has a (σ, ρ)-dominating set of size at most k'. Moreover, in such a case the size of any (σ, ρ)-dominating set is exactly k'.*

2.2 W[1]-Membership

Here we prove a slightly stronger claim.

Theorem 4. *Let σ be recursive, and suppose that ρ is finite. Then the (σ, ρ)-*Dominating Set of Size at most *k and (σ, ρ)-*Dominating Set of Size *k problems are in* W[1]*.*

To show the membership of the problems in W[1], we use the characterization of W[1] by Nondeterministic Random Access Machines as proposed in [10].

A nondeterministic random access machine (NRAM) model is based on the standard deterministic random access machine (RAM) model. A single nondeterministic instruction "GUESS" is added, whose semantics is: *Guess a natural number less than or equal to the number stored in the accumulator and store it in the accumulator.* Acceptance of an input by an NRAM is defined as usually for nondeterministic machines. The steps of computation of an NRAM that execute a GUESS instruction are called *nondeterministic steps.*

Definition 1. *An NRAM program $\mathbb{P}$ is* tail-nondeterministic k-restricted *if there are computable functions f and g and a polynomial p such that on every run with input $(x, k) \in \Sigma^* \times \mathbb{N}$ the program $\mathbb{P}$*

- *performs at most* $f(k) \cdot p(n)$ *steps;*
- *uses at most the first* $f(k) \cdot p(n)$ *registers;*
- *contains numbers* $\leq f(k) \cdot p(n)$ *in any register at any time;*

and all nondeterministic steps are among the last $g(k)$ *steps of the computation. Here* $n = |x|$.

The following characterization is crucial for our proof:

Theorem 5 ([10]). *A parameterized problem* P *is in* W[1] *if and only if there is a tail-nondeterministic* k*-restricted NRAM program deciding* P.

Now we introduce our program `SigmaRho` that takes a graph G and a positive integer k as an input and there is an accepting computation of `SigmaRho` on G and k if and only if there is a (σ, ρ)-dominating set of size exactly k in G. We present it in a higher level language that can be easily translated to the NRAM instructions. It is straightforward to show that this program is tail-nondeterministic k-restricted, the formal proof will appear in journal version of the paper and we omit it here. Recall that $q_{max} = \max \rho$. Here $\binom{V}{r}$ denotes the set $\{R \subseteq V \mid |R| = r\}$.

Program `SigmaRho`$(G = (V, E), k)$

for $r := 1$ **to** $q_{max} + 1$ **do forall** $R \in \binom{V}{r}$ **do**

$$B(R) := |\bigcap_{u \in R} N_G(u)| = |\{v \mid v \in V, \forall u \in R : uv \in E\}|;$$

Guess k **distinct vertices** $v_1, \ldots, v_k$**, denote** $S = \{v_1, \ldots, v_k\}$**;**

for $i := 1$ **to** k **do if** $|\{v_j \mid v_i v_j \in E\}| \notin \sigma$ **then REJECT;**

for $r := q_{max} + 1$ ***downto*** 1 **do**

$$D(r) := \sum_{R \in \binom{S}{r}} (B(R) - |\bigcap_{u \in R} N_G(u) \cap S|) = \sum_{R \in \binom{S}{r}} |\{v \mid v \in V \setminus S, \forall u \in R : uv \in E\}|;$$

$$C(r) := D(r) - \sum_{t=r+1}^{q_{max}} \left(\binom{t}{r} \cdot C(t) \right);$$

if $r \notin \rho$ *and* $C(r) \neq 0$ **then REJECT;**

if $0 \notin \rho$ *and* $\sum_{r \in \rho} C(r) \neq n - k$ **then REJECT; else ACCEPT;**

Lemma 2. *Let* G *be a graph and* $k \in \mathbb{N}$*. There is an accepting computation of* `SigmaRho` *on* G *and* k *if and only if there is a* (σ, ρ)*-dominating set of size (exactly)* k *in* G.

Proof. We will show that the program `SigmaRho` accepts the input if and only if the set S guessed in step 2 is a (σ, ρ)-dominating set of size k for the input graph G. It is easy to see that the members of the set S must satisfy the σ-condition due to step 3. Now observe that the number $D(r)$ computed in step 4 denotes the number of pairs (R, v) such that R is a subset of S of size r and v is a vertex not in S that has all vertices from R as neighbors (the first term counts all such vertices v in V and the second term subtracts such vertices v that are in S). Hence this $D(r)$ represents the number of vertices outside S which have at least r neighbors in S with multiplicities, in particular a vertex with t neighbors in S is counted $\binom{t}{r}$ times. Since in the first run of the cycle 4 with $r = q_{max} + 1$ we check that there is no vertex outside S with more than q_{max} neighbors in S, $C(r)$ represents the number of vertices outside S which have exactly r neighbors in S. It is now clear that if $r \notin \rho$ and there is a vertex outside S with r neighbors in S (i.e., $C(r) > 0$), then S cannot form a (σ, ρ)-dominating set. In the last step 5 we sum up the number of vertices outside S that satisfy the ρ-condition and thus S (which satisfies all the conditions checked by the previous steps) is (σ, ρ)-dominating if and only if this sum is equal to the total number of vertices outside S, i.e., $n - k$, or $0 \in \rho$.

Proof (Proof of Theorem 4). First observe that (σ, ρ)-DOMINATING SET OF SIZE AT MOST k can be easily reduced to (k calls of) (σ, ρ)-DOMINATING SET OF SIZE k. Hence it is enough to prove the membership for the second problem. But that is a direct consequence of Theorem 5 together with Lemma 2 and Program `SigmaRho` being tail-nondeterministic k-restricted.

3 Complexity of the (σ, ρ)-DOMINATING SET OF SIZE AT LEAST $n - k$ Problems

Theorem 2. *Let σ and ρ be sets of nonnegative integers such that either σ or $\overline{\sigma}$ is finite, and similarly either ρ or $\overline{\rho}$ is finite. Then the* (σ, ρ)-DOMINATING SET OF SIZE AT LEAST $n - k$ *problem is in* FPT.

Proof. We present an algorithm that is based on the bounded search tree technique. At the beginning the algorithm includes all vertices into the set S and then tries recursively excluding some of the vertices to make S (σ, ρ)-dominating. Once a vertex is excluded, it is never included in the set again (in the same branch of the algorithm). Obviously at most k vertices can be excluded from S to fulfill the size constraint.

We call a vertex v *satisfied* (with respect to the current set S) if it has the right number of neighbors in S (i.e., $v \in S$ and $|N(v) \cap S| \in \sigma$ or $v \notin S$ and $|N(v) \cap S| \in \rho$), otherwise we call it *unsatisfied*. Let $\widetilde{p}_{max}$ denote $\max \sigma$ if σ is finite and $\max \overline{\sigma}$ if $\overline{\sigma}$ is finite. Similarly let $\widetilde{q}_{max}$ denote $\max \rho$ or $\max \overline{\rho}$. (It is assumed here that $\max \emptyset = 0$.) Finally let b denote $\max\{\widetilde{p}_{max}, \widetilde{q}_{max}\}$. We call a vertex v *big* if $deg(v) > b + k$ and *small* otherwise.

The main idea of the algorithm is that there is at most one way to make an unsatisfied big vertex satisfied (to exclude it from S) and if this does not work, there is no (σ, ρ)-dominating set at all. On the other hand to satisfy a small vertex, we must either exclude it or one of its first b neighbors that were in S.

```
Procedure Exclude(S)
  if there is no unsatisfied vertex then Return(S);Exit;
  if |S| = n − k then Halt;
  let v be an unsatisfied vertex;
  if v is big then
    if v ∈ S and ρ is infinite then Exclude(S \ v);
    else Halt;
  else
    if v ∈ S then Exclude(S \ v);
    let {u_1, ..., u_r} = S ∩ N(v) be the set of included neighbors of v;
    if r = 0 then Halt;
    for i := 1 to min{b + 1, r} do Exclude(S \ {u_i}).
```

The algorithm consists of a single call `Exclude`(V) and returns the set S returned by the procedure or NO if no set was returned.

4 Complexity for the Case $\sigma, \rho \in \{\mathbf{EVEN}, \mathbf{ODD}\}$

As a counterpart to the results of [9] we first show that all four parity problems for Red/Blue bipartite graphs are hard under the dual parametrization.

Theorem 6. *The* Even Set of Size $r - k$, Even Set of Size at least $r - k$, *and* Odd Set of Size $r - k$, *and* Odd Set of Size at least $r - k$ *problems are all* W[1]*-hard.*

Proof. It was proved in [9] that

Odd Set of Size at most k
Input: A bipartite graph $G = (R, B, E)$.
Parameter: k.
Question: Is there an odd set in R of size at most k?

is W[1]-hard. It should be noted that W[1]-hardness was stated for the exact variant of the problem (i.e. for the question: Is there an odd set in R of size k?), but for our variant of the question, the proof of [9] works the same. We show that the problem remains W[1]-hard if all blue vertices have odd degrees (and also if all of them have even degrees). Then we deduce the claims by considering the set $R \setminus S$ for a would-be odd set $S \subset R$.

The main result of this section is the hardness of the (**EVEN—ODD**)-domination problems under the dual parametrization.

Theorem 3. *Let* $\sigma, \rho \in \{\mathbf{EVEN}, \mathbf{ODD}\}$. *Then the* (σ, ρ)-Dominating Set of Size $n - k$ *and* (σ, ρ)-Dominating Set of Size at least $n - k$ *problems are* W[1]*-hard.*

Proof. We prove this theorem for the (σ, ρ)-Dominating Set of Size at least $n-k$ problem. The proof for the (σ, ρ)-Dominating Set of Size $n-k$ is done by similar arguments. Also we give here only the proof for the case $\sigma = \rho = \mathbf{EVEN}$. The proofs for the other three cases use the similar ideas and are omitted here. We use the following lemma:

Lemma 3. *The* Even Set of Size at least $r-k$ *problem remains* W[1]*-hard if all red vertices have even degrees.*

Proof. We reduce the Even Set of Size at least $r-k$ problem by replacing each blue vertex by two vertices with the same neighborhoods. Trivially $S \subseteq R$ is an even set in the obtained graph if and only if it is an even set in the original graph.

If all red vertices have even degrees then $S \subseteq R$ is an even set if and only if $S \cup B$ is an $(\mathbf{EVEN}, \mathbf{EVEN})$-dominating set. It follows immediately that G has an even set of size at least $r-k$ if and only if G has a (σ, ρ)-dominating set of size at least $n-k$ for $\sigma = \rho = \mathbf{EVEN}$.

5 Complexity of the (σ, ρ)-Dominating Set of Size (at most) k Problem for Sparse Graphs

It is well known that many problems which are difficult for general graphs can be solved efficiently for sparse graphs. Very general results of such kind were established in [4]. Let v be a vertex of a graph G. For a positive integer r, denote by $N_r[v]$ the *closed r-neighborhood* of v i.e. the set of vertices of G at distance at most r from v. Let $\mathcal{G}$ be a class of graphs. Suppose that there is a family of graphs $\{H_r\}$ such that for each graph $G \in \mathcal{G}$ and for any $v \in V(G)$,

$G[N_r(v)]$ excludes H_r as a minor for $r \geq 1$. It is said that the graph class $\mathcal{G}$ is *locally minor excluding.* It can be noted that e.g. planar graphs, graphs of bounded genus, H-minor-free graphs are locally minor excluding graph classes. It was proved in [4] that if $\mathcal{G}$ is a locally minor excluding class of graphs, then deciding first-order properties (i.e. properties which can be expressed in the first-order logic) is FPT on $\mathcal{G}$. The next claim follows immediately from this result.

Theorem 7. *Let σ and ρ be sets of nonnegative integers such that either σ or $\overline{\sigma}$ is finite, and similarly either ρ or $\overline{\rho}$ is finite. Then the* (σ, ρ)-Dominating Set of Size (at most) k *problem is* FPT *on locally minor excluding graph classes.*

It is known that some domination problems are FPT for a more general class of *degenerate* graphs (see e.g. [1,14]). These results can be easily generalized for (σ, ρ)-domination problems for some special sets σ and ρ. It is an interesting open problem whether the results of Theorem 7 can be extended to degenerate graphs.

References

1. Alon, N., Gutner, S.: Linear time algorithms for finding a dominating set of fixed size in degenerated graphs. In: Lin, G. (ed.) COCOON 2007. LNCS, vol. 4598, pp. 394–405. Springer, Heidelberg (2007)
2. Bodlaender, H.L., Kratsch, D.: A note on fixed parameter intractability of some domination-related problems. Private communication (1994)
3. Cesati, M.: Perfect code is $W[1]$-complete. Inf. Process. Lett. 81, 163–168 (2002)
4. Dawar, A., Grohe, M., Kreutzer, S.: Locally excluding a minor. In: LICS 2007, pp. 270–279. IEEE Computer Society Press, Los Alamitos (2007)
5. Downey, R.G., Fellows, M.R.: Fixed-parameter tractability and completeness. Congressus Numerantium, 161–178 (1992)
6. Downey, R.G., Fellows, M.R.: Fixed-parameter tractability and completeness. II. On completeness for W[1]. Theoret. Comput. Sci. 141, 109–131 (1995)
7. Downey, R.G., Fellows, M.R.: Parameterized Complexity. Springer, Heidelberg (1998)
8. Downey, R.G., Fellows, M.R.: Threshold dominating sets and an improved characterization of $W[2]$. Theoret. Comput. Sci. 209, 123–140 (1998)
9. Downey, R.G., Fellows, M.R., Vardy, A., Whittle, G.: The parametrized complexity of some fundamental problems in coding theory. SIAM J. Comput. 29 (electronic), 545–570 (1999)
10. Flum, J., Grohe, M.: Parameterized Complexity Theory. Springer, Heidelberg (2006)
11. Golovach, P.A., Kratochvíl, J.: Computational complexity of generalized domination: A complete dichotomy for chordal graphs. In: Brandstädt, A., Kratsch, D., Müller, H. (eds.) WG 2007. LNCS, vol. 4769, pp. 1–11. Springer, Heidelberg (2007)
12. Golovach, P.A., Kratochvíl, J.: Generalized domination in degenerate graphs: a complete dichotomy of computational complexity. In: Agrawal, M., Du, D.-Z., Duan, Z., Li, A. (eds.) TAMC 2008. LNCS, vol. 4978, pp. 182–191. Springer, Heidelberg (2008)
13. Heggernes, P., Telle, J.A.: Partitioning graphs into generalized dominating sets. Nordic J. Comput. 5, 128–142 (1998)
14. Kloks, T., Cai, L.: Parameterized tractability of some (efficient) Y - domination variants for planar graphs and t-degenerate graphs. In: Proceedings of the International Computer Symposium (ICS 2000), Taiwan (2000)
15. Kratochvíl, J., Manuel, P.D., Miller, M.: Generalized domination in chordal graphs. Nordic J. Comput. 2, 41–50 (1995)
16. Moser, H., Thilikos, D.M.: Parameterized complexity of finding regular induced subgraphs. In: Broersma, H., Dantchev, S.S., Johnson, M., Szeider, S. (eds.) ACiD 2006. Texts in Algorithmics, vol. 7, pp. 107–118. King's College, London (2006)
17. Niedermeier, R.: Invitation to Fixed Parameter Algorithms. Oxford University Press, USA (2006)
18. Telle, J.A.: Complexity of domination-type problems in graphs. Nordic J. Comput. 1, 157–171 (1994)
19. Telle, J.A.: Vertex partitioning problems: characterization, complexity and algorithms on partial k-trees. PhD thesis. Department of Computer Science, University of Oregon, Eugene (1994)
20. Telle, J.A., Proskurowski, A.: Algorithms for vertex partitioning problems on partial k-trees. SIAM J. Discrete Math. 10, 529–550 (1997)